Developing A Circumstance-Based Innovation Strategy for a Midsized Aerospace Manufacturer: Fostering Intrapreneurship, Opening Boundaries, and Seeding Disruption

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Abstract

This thesis derives a seven-stage methodology and presents a case study for developing an actionable innovation strategy for manufacturing firms. The methodology is based around a careful examination of their firm's circumstances, or external context and internal praxis. How a firm should innovate is dependent on industry environment, firm activities, technology competencies, internal culture, and its networks—and this thesis aims to develop a "theory of practice" in how to do such circumstance-based strategy. Thus, unlike much of the innovation literature, which push universalistic theories on innovation (*e.g.*, form a Skunkworks to create a new radical product) this work aims to help firms become more innovative by developing strategies unique to their conditions.

The methodology has seven modules: 1) stake intent, 2) survey the industry and firm, 3) create an innovation strategy, 4) audit the firm, 5) develop the plan to reinforce the capabilities through its existing culture, 6) execute and measure the plan, and 7) periodically reflect and adjust the plan as the firm's environment change. The case study focuses on modules 2–5.

The case company is a midsized aerospace manufacturing-focused firm competing in the thick of the highly competitive global aerostructures market, specializing in airframe control surfaces. It employs a variety of advanced manufacturing techniques, with an emerging focus in carbon-fiber reinforced polymer (CFRP) composite fabrication. Undertaking the methodology, the thesis finds that the highly competitive landscape combined with the firm's current market position and capabilities suggest an innovation strategy focused on differentiation (as opposed to low-cost), high levels of collaboration (as opposed to in-house R&D), and architectural innovation (as opposed to component innovation), with a balanced perspective on processes and products, core and new markets, and sustaining and disruptive approaches.

The thesis proposes "ideal" capabilities for the company to execute this strategy, audits their current state, and proposes solutions embedded in an actionable, three-phase plan to reinforce them compatible with the firm's existing culture and networks.

Thesis Advisor: Deborah Nightingale, Professor of Aeronautics & Astronautics
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I. Innovation and the Aircraft Industry

A. Introduction

As we enter the second century of flight, the timing for a thesis on innovation in the aviation industry could not be more appropriate. In December 1903, Orville and Wilber Wright flew a self-designed, flimsy-looking aircraft on the beach of Kitty Hawk, North Carolina. The first flight lasted just twelve seconds and traveled a distance of about 120 feet, less than the wingspan of a Boeing 747-100 (Bryson, 1994). Although this modest first flight is often recounted as the birth of an intense age of aviation innovation—in one lifetime flight would go from one man traveling less than half a football field to millions crossing the globe on jumbo jets—what is often lost is the process of how the Wrights accomplished their incredible feat.

In achieving powered flight, the brothers had to engineer fundamental breakthroughs in the design of multiple systems, such as wings, engines, and propellers, and integrate them into a functioning whole (Bryson, 1994). They methodically attacked problems as a team through feverish experimentation in their bicycle shop in Dayton, Ohio, constructing one of the first wind tunnels and inventing control mechanisms still used on aircraft today. The pair employed the use of technical modeling, devising a formal theory of propeller dynamics to assist in prototyping (*ibid.*). Additionally, the brothers borrowed heavily from concepts in other fields, particularly bicycles. In the vernacular of the innovation literature, the Wrights achieved multiple breakthroughs through setting up a dedicated workspace, scanning the environment for ideas, decomposing the problem into functional elements, applying mathematical models, experimenting heavily, and working as a heavyweight team. In retrospect, the Wright's inventive efforts were a showcase on how to achieve product innovation.

Fast-forward a hundred years, and the aviation industry has matured greatly. While maturity brings many benefits,[1] it also has brought a slowdown to innovation.[2] Modern aircraft design and production involves mind-boggling levels of complexity (the Boeing 777 large twin-jet has over 130,000 discrete parts and had almost 20,000 people involved in its development), risk (the 777 cost more than an estimated $10 billion to develop, about one and a half times of Boeing's book net worth), and regulation (FAA requirements for certifying just one variant of the 777, the -300ER, necessitated over 2,600 hours of flight and ground testing).

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[1] Planes have a mean time between failure of over 2 million operating hours, compared with less than 900 in the early 1920s (*ibid.*), and the forthcoming Airbus A380 will use about a quarter the fuel per passenger (about 80 miles per gallon) than the average new vehicle sold in the US.

[2] Roughly, innovation can be defined as a product or service that is creative and profitable (von Stamm 2003b); a more complete definition is in the next section.

The days of crack airplane engineers clustered in a hangar, designing and building radical new planes with exotic materials and technologies in just months—such as Kelly Johnson's legendary Skunkworks and its U2 and SR-71 planes of the 1950s and 60s—seem long gone. In its place are developers that are equal parts businesspeople as engineers, performing endless financial cases and risk analyses for planes that have had the same architecture ("swept wing and tube") and many of the same technologies (*e.g.*, alloy construction, jet propulsion) as the first successful commercial jet, the Boeing 707, which first flew in December 1957.

Ultimately, the maturing environment has whittled what once were dozens of viable airframe manufacturers[3] down to two major commercial (Boeing and Airbus) and four military (Boeing, Lockheed, Northrop, and EADS) manufacturers. These airframe manufacturers, facing the numerous cost, risk, and regulatory constraints and a dominant product design—while implementing numerous "sustaining" innovations such as fly-by-wire and polymer composite materials—have arguably lost the innovative spirit of their pioneering forbearers, the Wrights. As Robert Buderi (2003), editor of Technology Review, wrote in his editorial for the September magazine about Boeing:

> *"(Boeing)...once a symbol of innovation, seems to be sticking increasingly with non-innovative, behind-the-times aircraft and watching its previously commanding lead...be whittled away...unless, that is, Boeing innovates its way to reversing this trend"*

This quote easily applies to all of the major airframe manufacturers and their suppliers.[4] Simply, how can the aerospace industry innovate its way to reversing the trend of maturity and, its counterpart, commoditization (*i.e.*, undifferentiated, marginally profitable products)?[5] This thesis will attempt to answer this by outlining a methodology for creating an actionable innovation strategy and plan, and applying it to a mid-sized aviation manufacturer.

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[3] In this thesis, airframe manufacturers—alternatively called original equipment manufacturers or OEMs—are major designers, system integrators, and assemblers of aircraft such as Boeing, Lockheed, and Airbus. Tier-1 suppliers provide major systems and modules directly to the OEMs; Tier-2s supply components and materials to the Tier-1s, and so on.

[4] "The Airbus A380 is a stunning achievement," wrote New York Times aviation reporter Matthew Wald in 2003, "but with all the excitement of a train with a few extra cars," while Lockheed struggles to bring to market by the end of the decade the Joint Strike Fighter, which began design in the early 1990s.

[5] A recent quote in the New York Times (Maynard, 2003) by James Womack, president of the Lean Enterprise Institute, about Boeing's forthcoming 7E7 nicely summarizes the increasing commoditization in the aviation industry. "There could be no more important time for Boeing to make the 7E7 a reality but none when it matters less to the average traveler. The flier can't tell the difference from one airplane to another, no matter how pretty the painting is. People can tell you if they're riding in a BMW or a Lexus, but they can't tell you if they're riding in an Airbus or a Boeing."

B. What is Innovation?

Innovation is a word that is hardly controversial in the business world; the word is abundant in marketing literature, CEOs evoke it frequently in speeches and shareholder meetings, and it is the topic of countless business books and articles, including many of the titles referenced in this thesis.

But what exactly is innovation? Almost all the literature on innovation begins with this question—and almost all struggle in defining the term. In reviewing dozens of definitions, two descriptions from the literature stand out: the first for its breadth, the second for its simplicity. Neely and Hii (1999) state, "innovation consists of all those scientific, technical, commercial, and financial steps necessary for the successful development and marketing of new or improved manufactured products, the commercial use of new or improved processes or equipment, or the introduction of a new approach to a service." Von Stamm (2003b) more elegantly defines innovation as "creativity plus (successful) implementation...coming up with ideas and putting them into practice."[6]

Once generally defined, innovation can be decomposed in many ways. Innovation can refer to an outcome or a process; in other words, it can refer not just to tangible goods and services but also to the methods of how they are created (this thesis will use the term in both contexts). Innovation outcomes themselves have a typology, with dozens of sub-classifications and new ones emerging every year—Prahalad's and Ramaswamy's (2003) "experience innovation" centered on customer perceptions is a good example. A classification system, modified from Volery (2003) and borrowing from Christensen (1997), highlighting the major categorizations of innovation as an outcome, appears in Table 1. While it is easy to get caught up in proper classifications and understanding the subtleties among the various definitions,[7] with respect to business strategy and this thesis, understanding the four major types of innovation—product, process, incremental, and radical—is sufficient. In addition, the definitions in Table 1 are context-specific; what is a sustaining innovation in one market can be considered radical in another. For instance, microprocessors were arguably a sustaining innovation for the automobile (*e.g.*, enabling internal-combustion engines to

[6] Another perspective on innovation that is worth mentioning is the view that it is a socially constructed "story line" or narrative with several meanings (Jamison and Hard, 2003). From the social constructivist perspective, the underlying story line in this thesis follows what the authors call a "neoclassical-economic technology discourse," (*ibid.*) where "technological change is the core activity of business behavior, and it is by understanding the 'learning processes' and selection mechanisms involved in technological innovation...that companies will be able to survive in an increasingly globalized economy." The thesis will take other perspectives, such as innovation as a social (non mechanistic) process as well, but focus on the highly mechanistic economic/strategy viewpoint as it offers a more tangible, easier-to-implement framework for analysis.

[7] For example, Christensen argues that his term "disruptive" is often treated as synonymous with "radical", but in fact is a subset of that class.

run with more sophisticated control strategies), but a radical innovation for the business office (*i.e.*, replacing the typewriter and completely redefining how people work).

Table 1. A Typology of Innovation (modified from Volery (2003) and Christensen (1997))

Type of Innovation	Principle and Example
Product	The conventional definition, a new or improved product such as the Apple iPod or the Boeing 7E7.
Process	Development of a new manufacturing or management process such as the assembly line or business process re-engineering.
Incremental or Sustaining	Improvements to existing products, services, or processes, such adding airbags for automobiles or jakoda pulls to assembly lines.
Radical or Inventive	Totally new product, service, or process, such as the Wright's airplane or Edison's light bulb.
Sustaining: Extension	Improvement or new use of an existing product, service, or process, such as the development of desktop computers based on the mainframe.
Sustaining: Duplication	Creative replication or adaptation of an existing product, service, or concept, usually across different markets or industries, *e.g.*, the adaptation of the Southwest Airlines model in Australia with VirginBlue.
Radical: Synthesis, Integration, or Architectural	Combination of existing products, services, or processes into a new formulation or use: the fax (telephone + photocopier).
Radical: Disruptive	Radical technologies that at first underperform established products in mainstream markets but offer a strong value proposition to new types of consumers. Examples include transistors in the 1950s (enabling the hearing aid and portable radio) and minimill steel (dramatically undercutting the cost of low-end steel in the 1980s).

One question that naturally follows "what is innovation?" is "why is it necessary?" The literature often assumes that innovation is a good unto itself, but is innovation always a virtue? Many businesses have pursued an innovation strategy to ill success—several prominent "dot com" businesses of the late 1990s come to mind. While innovation provides no guarantee for business success, Porter, in his seminal article "What is Strategy" (1996) makes the strongest case of why pursuing innovation is necessary to most modern businesses. As innovation is by definition about uniqueness of some sort—*e.g.*, providing lower-cost products through differentiated operating strategies or selling higher value goods with proprietary design or technologies—most businesses cannot survive in a competitive marketplace without being innovative. Operational effectiveness—performing similar activities better than rivals, the heart of manufacturing practices such as the Toyota Production System and TQM—as Porter argues, is insufficient:

> *"Constant improvement in operational effectiveness is necessary to achieve superior profitability. However, it is not usually sufficient. Few companies have competed successfully on the basis of operational effectiveness over an extended period, and staying ahead of rivals gets harder every day. The most obvious reason is the diffusion of best practices. Competitors can quickly imitate management techniques, new technologies, input improvements, and superior ways of meeting customers' needs...Continuous im-*

> *provement has been etched on manager's brains. But its tools unwittingly draw companies toward imitation and homogeneity. Gradually, managers have let operational effectiveness supplant strategy. The result is zero-sum competition, static or declining process, and pressures on costs that compromise companies' ability to invest in the business for the long term."*

In fact, Porter argues that strategy is the discipline of aligning activities in unique (hence innovative) ways to create competitive advantage. Businesses, including the case company of this thesis, thus should care about innovation—and develop a coherent strategy for achieving it—because it is the main (but not only)[8] tool for achieving competitive advantage and profits.

The final question after "what" and "why," and thrust of this thesis, is "how": how can a company become innovative? Despite its importance, and regardless of how it is measured,[9] innovation is incredibly difficult to master. Christensen (2003) points out that only one out of ten companies achieve innovation-fueled growth for more than a few years. And the aforementioned "new economy" of the late 1990s showcases the limited long-term success of most innovation-based businesses. Thus, while innovation is certainly necessary for long-term business success, it certainly is not easy to achieve.

For managers hoping to find answers in the latest *New York Times* bestseller, the literature on innovation offers a dearth of consistent advice on how companies going forward can improve their innovation practices. Thousands of articles, books, and many consultancies propound how firms can become more innovative, often with conflicting recommendations. For instance, experts offer no consensus on whether innovation is better suited to bigger or smaller organizational structures (*e.g.*, von Stamm (2003b) says smaller, Sorescu et al. (2003) says bigger), whether having an internal R&D capability is critical (*e.g.*, Burgelman, et. al. (1996) says yes, Chesbrough, (2003) says no) or even whether "entrepreneurial" versus "process-driven" cultures provide better results (*e.g.*, Neely and Jasper (1999) argue for entrepreneurial, Patterson (1999) argues for process). Abetti (2000) even explicitly lists "luck" as a success factor for innovation in a five case study. Christensen (2002) summed it up best when he wrote, "the management of

[8] It is easy to project the definition of innovation onto every means of competitive advantage; however, it is clearly possible for a company to achieve competitive advantage in a competitive market without developing something "new and improved" or "creative." For instance, a firm can build economies of scope or scale through making prohibitively large capital investments to lower the cost of their offerings (essentially "gaming" competitors out of the market); similarly, a firm can enjoy network effects that provide positive externalities for users of its products, "locking in" a consumer base. It is worth noting that the case company, due to its market and size does not enjoy any of these factors.

[9] Common measures include the present value of growth opportunities built into a company's equity, the firm's percentage of revenue from new products and services, and even "attitudinal" surveys of how innovative employees and customers perceive the company to be.

innovation today is where the Quality Movement was 20 years ago, in that many believe the outcomes of innovation efforts are unpredictable."

To drive better practice in industry, Christensen calls for "circumstance-based" theory to drive a better understanding of the causation of innovation. This thesis will build on this insight to provide a methodology for practitioners based around a careful examination of their firm's circumstances, or external context and internal praxis. Unlike much of the innovation literature, which push universalistic theories on innovation (*e.g.*, form a Skunkworks to create a new radical product) this work aims to help firms become more innovative by developing strategies unique to their conditions. Thus "how" a firm should innovate is dependent on industry context, firm activities, technology competencies, internal culture, and its networks—and this thesis aims to develop a "theory of practice" in how to do such circumstance-based strategy.

C. The Context: Innovation in Aviation from the Wright Brothers to The Present

The main contextual factor for the case company of the thesis is its industry: aviation. As alluded to in the first section, for the first three quarters of the 20th century, aviation was arguably among the most innovative industries in products, technologies, processes, and service. In particular for fixed-wing aircraft,[10] the aviation industry had six revolutionary product innovations: the biplane w/flaps, the monoplane, the closed aluminum body plane (epitomized by the Ford TriJet and DC-3), the subsonic jet (early models included the DeHavilland Comet, Boeing 707, and DC-8), supersonic jet (starting with the North American F-100), and finally stealth/flying wing (Birkler et al., 2003). Technology innovations included the shift from wood and fabric to aluminum, titanium, and most recently polymer composites; from propeller-drive to jet propulsion; and from mechanical to hydraulic to electronics/by-wire control.

While some may find the claim of process innovation arguable, the industry pioneered modern design and engineering techniques including the aforementioned "Skunkworks," "design for manufacturing," and computer-aided design. In manufacturing, the industry created fabrication and assembly techniques for a host of advanced materials and technologies, and even employed innovative mass-production techniques World War II when some factories were producing an aircraft model an hour (Boeing, for comparison, produced less than one aircraft a day of all their models combined in 2003). Even the primary service of aircraft, passenger travel, has experienced several radical innovations: in the 1920s early airlines such as Lindburgh's Transcontinental Air Transport flying Ford Tri-Motors cut cross-country travel time in half

[10] Aside from fixed wing, the other major aviation architecture is "rotorcraft", or more commonly known as helicopter.

(Bryson, 1994); in the 1950s airlines such as Pan-Am introduced jets to international travel to largely replace ocean liners;[11] jumbo jets in the early 1970s cut seat-mile costs dramatically, making international travel affordable for the mass market; and finally low-cost airlines like Southwest emerged in the mid 1970s to replace bus and even car travel for relatively short distances.

However, over the last quarter century, innovation in aviation has slowed as the triple threat of cost, risk, and regulation began to overwhelm the progress in design, engineering, and manufacturing that fueled the early abundance of advances. Moreover, the innovation that has occurred over the last twenty-five years has been largely sustaining in nature, such as shifting from batch production to moving assembly lines for large jets to substituting polymer composites for aluminum in secondary (*i.e.*, non safety-critical) structures such as ailerons or flaps. And even these sustaining innovations have been difficult to implement given the risk, cost, and complexity of modern aircraft development. Innovative technologies often face a "catch 22" scenario where they considered too risky because they have not been previously employed; yet, without an airframe maker taking a chance to put a new technology on a plane, the technology will never have the in-use experience to be considered of acceptable risk for new programs.[12]

Compounding the slowdown of innovation in aviation is the consolidation of firms within the industry. After Boeing's acquisition of McDonnell Douglas in 1997, only two major airframe manufacturers, Boeing and Airbus, remain in commercial aviation. The military sector as experienced a similar shrinkage of primary manufacturers. After World War II, the plethora of development programs and active production lines provided work for over a dozen airframe manufacturers in the US alone (Birkler, et al, 2003). In contrast, since 1990, just two major new manned military aircraft programs have started full engineering development—the Advanced Tactical Fighter (F-22) in 1991 and the Joint Strike Fighter (F-35) in 2001—and there are only five lines (F/A-18, F-22, C-17,C-130, and E-2C) in active production. As a result, military OEMs,[13] have shrunk fourfold in the US from twelve to three (Northrop Grumman, Lockheed, and Boeing), with arguably only two other major OEMs outside the US (EADS and BAE in Europe).

[11] In fact, a Boeing 707 could carry as many transatlantic passengers a year as the sixfold more expensive Queen Mary using a tenth the fuel (Boeing, 1998).

[12] Polymer composite materials, which will be discussed extensively throughout this thesis, fell largely into this "Catch 22" trap for decades until Boeing recently decided, in a bid to differentiate their plane from rival Airbus, to employ them extensively in the fuselage and wings of its forthcoming 7E7.

[13] In this thesis, aircraft producer, aircraft manufacturer, aircraft assembler, and OEM (original equipment manufacturer) are used interchangeably to describe major firms that sell aircraft directly to customers, like Airbus, Boeing, and Lockheed.

Consolidation may have negative effects on future levels of fundamental innovation within the industry. RAND found that historically, "major innovations did not come from dominant firms in the aerospace industry" (*ibid.*). In other words, with twelve vigorously competing firms, the incentive to innovate to gain competitive advantage was large—hence companies like DeHavilland creating the first passenger jet (and launching Boeing and Douglas into action). With oligopolies in both the commercial and military markets, what will spur innovation going forward? With decreasing rates of fundamental innovation and increasing consolidation, the industry clearly is in line for a strategic renewal for innovation as it enters its second century of aviation.

D. The Challenge: Develop an Innovation Strategy for a Midsized Aircraft Supplier

How did the opportunity to create an innovation strategy for a firm in the aviation industry arise? Leaders of a midsized (about $200M US sales per year) aviation supplier specializing in aerostructures, recognized the slowdown in innovation within aviation and their sector, and saw a potential for developing competitive advantage through selling unique products and services. The firm (which will remain nameless in this thesis due to the competitive and sensitive nature of the subject matter) is an independently run business unit of a global airframe manufacturer, with sales to several major OEMs including Airbus, Boeing, Lockheed, and BAE.

The firm originally created a MIT Leaders for Manufacturing internship to create a new company product that was differentiated in the market place and contained proprietary, defensible intellectual property (IP). At the beginning of the internship, the goals expanded to focus on a proposed innovation strategy and plan in order for the company to look at a longer-term approach to creating a pipeline of new innovations into the future. The new company product would be a test case of the innovation plan.

Once the goal of an innovation plan was established, a host of questions emerged. In general, how should the firm innovate? Who would its target customers be? Specifically, what types of innovations were appropriate for the company within its market, and within its general positioning in its market, as well with its existing relationships? Should it offer new products? Develop and license a new manufacturing process? Could it even define a new business model within the industry?

Moreover, even if an ideal innovation approach was identified, did the company have the capacity to commercialize the innovations successfully? Could the company innovate with its existing technical and organizational resources and processes? Did this company need to "insource" new innovation, develop it from scratch, or was there IP trapped within the firm that could be commercialized? Did the company have capability gaps that it needed to reinforce? Did its history and culture affect the way the innovation could be commercialized?

Following the initial goal of creating a new company product, the internship's early approach took a new business development strategy—identifying promising, underserved markets within the aerostructures industry where the company could develop new products leveraging its technologies and engineering talent. The internship explored market opportunities such as airplane interiors, rotorcraft, unmanned aerial vehicles (UAVs), aerodynamic modifications to wings, and aftermarket replacement parts. But as the internship went beyond identifying new products to building an innovation strategy, the research changed dramatically.[14] The internship had to propose how the firm was going to create, capture, and deliver value from an innovation, assess the company's abilities to execute this strategy (essentially auditing its resources and capabilities), and then develop a plan to build capabilities and resources with which to execute the strategy.

In the process of the internship, the author created a novel methodology on developing an innovation strategy and plan, specific to this case but generalizable in its tactics. As discussed more fully in the next chapter, the methodology involves a rigorous industry and firm analysis using industry standard tools to define a space within which the leadership can define a strategic position for innovation. Next, the analyst defines from this position which "ideal" capabilities are relevant to successful execution and assesses the company's current capabilities to this ideal. Concurrently, the analyst seeks out lead innovators that have tried to innovate or lead change within the firm. These innovators, both in their successes and failures, have created implementation pathways within the culture and politics of the company; analyzing and looking for patterns within these pathways help shape the innovation plan by customizing it to the firm's practices, norms, and values. Moreover, if a dominant, successful innovation pathway emerges (which may not always be the case), then the plan should also reinforce (*i.e.*, "pave") this pathway to facilitate more widespread innovation. Finally, the innovation plan is implemented, measured, and adjusted over time. The generalized framework is detailed in Chapter II and employed in Chapter III for the case company.[15]

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[14] Of note, the internship identified and launched a proprietary product due to preliminary implementation of part of the plan (through implementation of a corporate venturing program), but IP issues prevent a detailed discussion.
[15] Another related Leaders for Manufacturing thesis on innovation worth examining is Fyke's (2002) "Organizational Policies Which Promote Innovation in the Product Development Process," which takes a survey-based approach for recommending management policies for implementing product-based innovation.

II. A Methodology for Innovation Plan Development: A Theory of Practice

A. Overview

How should a company go about building an innovation strategy and plan? The first order of business is deciding who will lead the planning process. The literature typically propounds that the first step in "becoming innovative" is for the company's leadership to front the development of the innovation program.[16] Thus the practitioners of strategy development ideally will be a team of senior leaders within the company comprising executives such as directors of the Board, the CEO, COO, and VPs. Senior management not only needs to lead the development of the innovation plan but also must communicate its message and gain buy-in from its employees and other key stakeholders, allocate resources (primarily financial and human capital) toward developing and sustaining innovation-related activities, and provide political support to help overcome internal implementation barriers.

Of course, the day-to-day activities of running the business may constrain the leadership from actively leading an innovation planning process, particularly for small to midsized companies. Accordingly, this methodology assumes support from leadership (*i.e.*, the leadership formally acknowledges the innovation program, provides some level of resources, and does not actively oppose innovation activities within the company), but allows for practitioners to be mid-to-front-level managers, consultants, or even interns.

Once the company assigns development responsibility and resources for the project, the strategy-development practitioners need to establish a methodology. The practitioners can tackle this challenge in numerous ways. They could craft a plan around a conventional deliberate (or intentional) strategy-forming process, *e.g.*, establishing a mission, setting objectives, crafting a strategy to achieve the objectives, and then implementing and adjusting the strategy. They could emphasize an emergent (or opportunistic) strategy-forming process such as discovery-driven planning that emphasizes real-world testing of critical assumptions before defining a formal plan (Christenson, 2003). Alternatively, they could take a more technology-focused approach, employing competitive assessments, technology roadmaps, and IP portfolios to guide innovation development (Burgleman, et al., 1996).

Better yet, the practitioners could use a methodology that combines elements of each approach. Such a methodology would follow a structure that is logical, accessible, and able to be measured and adjusted over time; it would be flexible enough to allow for real-time adjustments due to fortuitous and unpredictable events; and it would have a strong technological grounding.

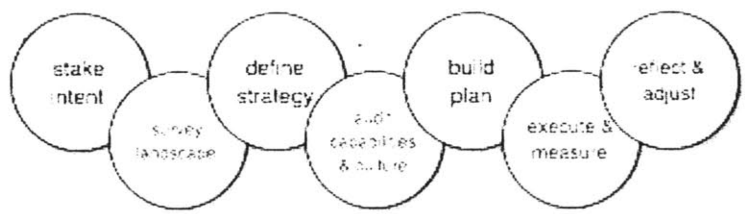
[16] A very few such as Gary Hamel (2000) hold a dissenting view, that innovation may best be initiated and led from the "bottom up" by front-level employees and managers.

B. The Core Activities

This chapter proposes such a methodology for developing a sustainable innovation plan, essentially a "theory of practice" for the leaders of the process. The methodology is very straightforward and has seven elements:

1. stake the intent to pursue an innovation strategy,
2. survey the industry and internal firm environment,
3. define a contextual innovation strategy,
4. audit the firm's capabilities and existing innovation culture,
5. build a plan to fill in capability gaps,
6. execute the plan and measure its progress, and
7. reflect on the plan periodically, adjusting it as necessary.

Figure 1. Innovation Development Methodology

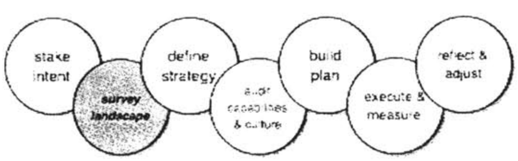


In summary, once top-level intent is secured, the practitioners survey the industry to map the competitive environment, as well as internally assess the company's innovation-related strengths and weaknesses. Next, the practitioners create an innovation strategy for the firm and define the "ideal" resources and capabilities required to execute it. Afterwards, they audit the company's relevant capabilities and culture of innovation through a second round of more focused data collection. Then, the practitioners develop a plan to implement the strategy, focusing on developing and sustaining an aligned set of activities that fit within the culture and networks of the firm. Finally, the company executes and measures their plan, adjusting it periodically as external and internal factors change.

Going forward, the thesis will focus on the four core elements of surveying, strategizing, auditing, and plan building. Three elements are de-emphasized in this thesis: the "front end" of staking intent and the "back end" of executing and adjusting. These elements define the boundary conditions of the case analysis and are well established in the literature.[17] Thus what follows is a more detailed discussion of the four middle core tasks emphasized in the case study.

The sections below describe a toolkit for carrying out the core elements of the methodology. However, practitioners need not be limited to the tools outlined below; the methodology defines an architecture in which the elements are essentially modules that offer a "plug and play" functionality. In other words, if the tools described below are not relevant to a firm's circumstances, or if new tools emerge that are more effective, the practitioner can plug different tools into the framework. As such, the methodology *itself* is the innovation—not its components—fitting within Henderson and Clark's (1990) "architectural innovation" classification (section III.B.3.c).

1. Survey the Landscape



The goal of surveying the landscape is to provide a general understanding the industry and firm (particularly its position within the industry with respect to products, customers, competitive advantages, etc.) and to define constraints for developing and executing the innovation strategy. This map will provide boundaries for choosing a strategic position. Surveying the landscape is critical in this regard as many generic innovation strategies will not apply to a firm—and the map should help the practitioners filter out inapplicable strategies.

For instance, "Company X" competes in a crowded marketplace dominated by commodity products (*i.e.*, artifacts that are "good enough" for the consumer, hence sold primarily based on price, convenience, and quality), devotes few resources to R&D, and has an operations-focused culture. Such a company may not want to focus on new product innovation; the boundaries on the map would define a space for process innovation, within which the company could choose strategies such as fostering sustaining innovations to its existing operations or seeking out disruptive processes that could lower the costs or increase the quality of its core products.

It should be noted that innovative companies (like innovative people) often find their way around constraints to create innovation by changing the rules of the game (von Stamm 2003b). Thus an alternate way to use the surveying exercise is to "invert the map" and purposely define a strategy *outside* the boundaries. In the example above, Company X may want to go after product innovation in a commodity market

[17] Establishing a vision on the senior managerial level falls under the discipline of "leadership," how to create a plan and execute falls under subject of "project management," and adjusting is treated in the "quality" literature.

to redefine the basis of competition in that market. Vendors offering designer bottled water or oil companies selling premium versions of gasoline are examples of this strategy. In fact, "game changing" strategies can be viable, exciting, and highly profitable—but they can also be of high risk. Again, the modularity of this framework allows for either approach; for the case company example described in this thesis, I take the former "within the boundaries" approach due to management's risk-averse tendencies.

To survey the landscape, the practitioner analyzes through an "innovation lens" the industry[18] and firm. At the industry level, the practitioners should look at markets, products, customer requirements, technologies, industry structure, and issues such as regulation, geopolitics, and intellectual property. At the firm level, practicioners can look at company-specific markets, technologies, products, and customers, as well as firm history, financials, operational structure, general capabilities and resources, R&D, and culture.

Arguably, surveying the landscape has the most established tools and frameworks available, from Porter's (1980) Five Forces analysis of industry profitability, to Peters and Waterman's 7S breakdown of a company (1982). Both authors' tools, particularly Porter's, are useful enough to almost be integrated into the methodology—*i.e.*, tools that all practitioners using this framework should use.[19] Technology frameworks that are useful include Utterback and Abernathy's (1975) technology lifecycle, and Henderson and Clark's (1990) integrated/modular innovation typology. An alternative "quick and dirty" tool that surveys the industry and firm environment together is the SWOT Analysis pioneered by Andrews (The Concept of Corporate Strategy, 1987); this Swiss army knife examines strengths and weaknesses at the company level along with threats and opportunities within the external industry environment.

One downside of the aforementioned tools is that most (except for the technology lifecycle) are static; they provide a series of snapshots of the industry and firm, which leaves the user with limited insight into their changing interrelationships. Complementary tools are those that involve dynamics—such as system dynamics modeling pioneered by Jay Forrester—which can help the practitioners understand how the industry and firm have evolved over time, and where both may be headed in the future. As well, futuring tools such as scenario planning (Schwartz, 1991) can offer robust insights into possible long-term directions of the industry.

[18] Defining in which industry a firm competes in could be a thesis unto itself; as long as the practitioner is consistent throughout the framework, industry definition can be conventional (*e.g.*, product/market, based on SIC codes) or less conventional (*e.g.*, based on customer needs).
[19] To provide an appropriate scope for the thesis, the text will not go into detail on most of the tools themselves, assuming the reader as a strategy practitioner is versed in them. If not, the reader should reference the source texts (*e.g.*, Porter's *Competitive Strategy* for Five Forces and Value Chain analysis) or consult a strategy textbook for a briefing on their use.

Industry data is generally accessible from a wide variety of secondary sources. In gathering firm data, practitioners will need to use primary sources such as financial and operations data, employee interviews and surveys, and direct observations from their experiences (*i.e.*, ethnographic data). Observations are particularly important: as Intel CEO Andy Grove remarked, "to best understand companies' actual strategies, pay attention to what they do, rather than what they say" (quoted in Christensen, 2003).

Figure 2 outlines the toolkit assembled by the author (borrowing from Afuha 1998, von Stamm 2003b, Dodgson 2000, among others) to survey the landscape, employed for the case company in Chapter III.

Figure 2. Surveying Tookit

A. Survey the Industry Landscape

1. **Overview**
    a. Background
    b. Market size
    c. Major products and services
    d. Major customers and requirements
    e. Competitive landscape

2. **Industry Structure**
    a. Porter's value chain analysis: a map of the industry from raw material to finished product
    b. Porter's five forces analysis
        i. rivalry
        ii. threat of entry
        iii. buyer power
        iv. supplier power
        v. substitutes

3. **Technology Assessment**
    a. Materials, manufacturing processes, and embedded technologies employed
    b. Utterback-Abernathy (1975) assessment: fluid, transitional, or specific (dominant) technological regime?
    c. Speed of change in the industry and product architecture

4. **Other Industry-Specific Issues**

B. Survey the company

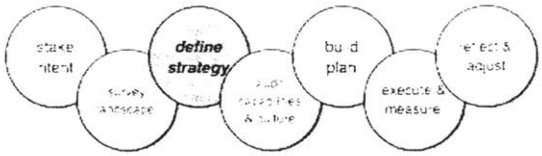
1. **Overview**
    a. Background
    b. Market size and share
    c. Major products and services
    d. Major customers
    e. Competitive positioning

2. **Company Analysis**
    a. General strategy: How does the firm create, capture, and deliver value?
    b. Firm-level value chain
    c. General resources and capabilities
    d. Structure
    e. Politics and culture

3. **Technology Assessment**
    a. Materials, manufacturing processes, and embedded technologies employed in the firm
    b. Systems

4. **Other Firm-Specific Issues**

2. Define Innovation Strategy



In defining the innovation strategy, the practitioners first use the industry and firm assessments to map a strategic "space"; stake a position within that space; and finally outline ideal capabilities to execute the chosen strategy.

a. Map the Strategic Space

As described, the survey of the industry and firm defines a map with boundaries, within which firms can stake an innovation strategy. While it may be easy to visualize this map as a two-dimensional plane (*e.g.*, with two axes, such as levels of cost and differentiation as defined in Porter's (1980) "generic strategies" map), in reality, the map is *n*-dimensional, with many axes defining the potential innovation space. Of course, the space is non-quantifiable, and should be treated conceptually by the practitioners as they choose a position within it.

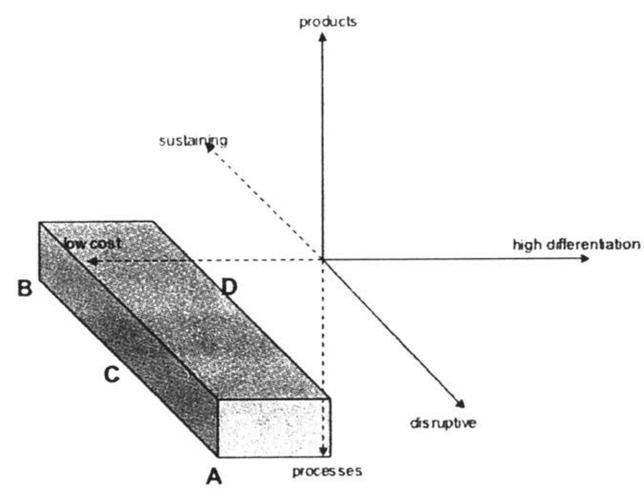
What exactly defines the space? The immense complexity and high number of combinations of the key factors from the industry and firm analysis defy an algorithmic approach to determining the innovation space. In other words, no formulas can be created that determine which innovation options are available to a firm, say, with high R&D spend and a risk-prone culture in a structurally attractive industry (although the options would be quite large). Instead, the practitioners must use heuristics—*e.g.*, judgment, experience, trial-and-error—to define the space given the firm and industry context. Thus, choice of the axes that define the space is flexible and at the discretion of the practitioner. That said, the methodology's employment of a TQM-inspired framework (see section II.C.3) enables practitioners to adjust and modify the space over time; ideally, heuristics and other tools such as peer review can help guide the construction of the strategic spaces, and, more importantly, the company position within it.

Below are several suggested axes—not necessarily mutually exclusive (*i.e.*, orthogonal)—that can bound strategic choices:

- "Generic strategy" orientation of innovation (low cost, high differentiation)
- Type of innovation (process, product)
- "Disruptedness" of innovations (sustaining, disruptive)
- Target markets for innovation (established, emerging)
- Scope of innovations (focused, diverse)
- R&D focus (closed, open)
- Level of innovation (component, architectural)
- Time to market relative to competitors (lead, follow or offensive, defensive)

Figure 3 shows a hypothetical three-dimensional strategic space for "Company X", with low cost/differentiation, product/process, and sustaining/disruptive axes. The space would bound the innovation strategy to focus on low-cost processes, allowing for sustaining or disruptive innovations, or possibly a combination of the two.

Figure 3. Representative Strategic Space for "Company X"



b. Stake Company Strategy within the Space

After defining the space, the practitioners then stake a strategy with respect to its boundaries (again, most likely within it). Regardless of the authority of the practitioners, senior leadership should ultimately determine this strategy—*e.g.*, if consultants survey the landscape and define the space, leadership at this stage should carefully review the work and ultimately make the strategic call. The stake will embody explicit positions on the axes—*e.g.*, leaders of Company X could stake a strategy focusing on first-to-market, low-cost processes employing new, disruptive architectures that leverages outside intellectual property (corresponding to point A in Figure 3). What is important about this step is that it emphasizes *choice*, acknowledging that no one ideal strategy exists. For instance, Company X could also choose point B, a sustaining strategy for processes, C, a combination, or even D, which allows for some exploration of new, differentiated products (although many experts such as Porter recommend being on the outer "frontier" of a space, with a clearly focused strategy). Thus, while the space may eliminate certain innovation strategies, it leaves a lot of options for senior leadership decision-making.

One other constraint for the innovation strategy is that it must be consistent with the firm's overall strategy, both explicit and implicit. If, in the event that the methodology converges on a strategy that is inconsistent with the firm's general strategy (*e.g.*, choosing to innovate in non-core markets when the company is focused on core business), the practitioners can explore three avenues:

1. revisit the innovation strategy: did problems arise in the defining the strategic space, or are there other strategic options within the space that fit better within the overall strategy?
2. revisit the overall strategy: given that the innovation strategy development process may be more up-to-date, does the overall firm strategy need to be refreshed?
3. re-examine firm boundaries: if the innovation strategy seems appropriate and the overall strategy is sound, could the innovation strategy be applied as a "spin-out" of the parent firm? (Chesbrough, 2003)

c. Outline Ideal Capabilities to Execute Strategy

Once the company takes a strategic position, how can it best execute this strategy? As the practitioners have already bounded strategic options by assessing the landscape of the industry and firm, the firm should have many of the elements in place necessary for successful execution, such as an R&D activity or strong expertise in a particular technology. However, unless the firm *already* has been executing the strategy (which would obviate the need for this methodology), it is very likely that critical elements for executing the strategy are missing, need reinforcement, or are poorly aligned with the new strategic direction.

The strategic concepts of resources and capabilities offer a helpful framework with which to assess a firm's ability to execute its innovation strategy and prioritize resources to address shortcomings. The perspective of firms competing on interrelated set of resources and capabilities is commonly known as the "Resource Based View" (RBV) pioneered by Edith Penrose in her *The Theory of the Growth of the Firm* in the late 1950s (Prencipe, 2001). Penrose's work was brought to prominence by Prahalad and Hamel

(1990) and has evolved into a dominant paradigm in the discipline of strategy. Taking a Resource Based View, resources are stocks of tangible objects such as factories and tooling, intangibles such as brand and intellectual property, and technological knowledge embedded in the workforce (Sorenson, 2002). Capabilities are the flows of the resources, how the company leverages its stocks through organizational routines, incentive systems, and dynamic processes (*ibid.*).

As an "evolutionary" rather than "neoclassical" perspective, the RBV of the firm focuses on "learning, path dependencies, technological trajectories and opportunities, complementary assets...performance as a function of intangible assets, skills, and (as) the ability to develop new capabilities over time" (Arnold and Thuriaux, 1997).[20] In other words, the RBV is more robust than traditional, mechanistic views of the firm, emphasizing continuous, collective learning and the integration of diverse skills and technologies as the key to innovating and gaining competitive advantage (*ibid.*, Burgelman and Rosenbloom, 1989).

Thus, employing RBV, this methodology has the practitioners outline a set of "ideal" resources and capabilities[21] to execute the defined innovation strategy. However, similar to defining the strategic space based on the industry and firm assessment, defining the ideal capabilities based on the chosen innovation strategy belies an objective, quantitative approach. Organizations can build resources and organize activities in an infinite number of ways; "ideal" in this methodology is not the Platonic ideal, as there is no one perfect strategy. Instead, the ideal resources and capabilities will be dependent on the judgment of the practitioners, which again involves a level of heuristics combined with the careful application of research from the literature and best practices from firms in similar circumstances.

Innovation studies a breadth of idealized innovation capabilities from which practitioners can draw. Writings are split among articles that define the capabilities based on rigorous studies, others that build theory, and a third set that synthesize other works. What follows is a summary of ideal capabilities and resources in seven works of the innovation literature: Neely and Hii (1998), Cooper, et. al., (2003), Quinn

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[20] Another helpful definition of the RBV is "firms conceptualized as bundles of resources, which are heterogeneously distributed across the firm, and where resource differences persist over time...when resources are valuable, rare, difficult to imitate, and non-substitutable they can create a competitive advantage. Capabilities are based on antecedent organizational and strategic routines by which mangers alter their resource base to generate new value-creating strategies." (Wilson, et. al., 2002)

[21] The literature is inconsistent whether "culture" is a resource, capability, or neither. As a critical element in the methodology is to work within the norms and values of the firm in the short term, this thesis treats culture as a separate concept to resources and capabilities—more along the lines of Christensen's (2003) "RPV" or resources, processes, and values framework, where capabilities substitute for processes and culture for values. That said, the reader should not get caught up with definitions (which are generally inconsistent across the strategy literature). The key point of this module is to define ideal capabilities that the practitioners deem actionable and changeable. Thus, if the reader considers culture a subset of the RBV, they could categorize them as "fixed" capabilities outside the bounds of this module.

(1985), Burgelman, et. al (1996), Lawson and Samson (2001), Arnold and Thuriaux (1997), Dodgson (2000), and Prencipe (2001).

Neely and Hii (1998) define ideal innovation resources and capabilities for small to midsized manufacturing firms based in the UK. The authors performed an extensive literature review on innovation capabilities, and then undertook a detailed, cross-sectional survey with follow-up interviews of twenty-one manufacturing firms. Their assessment of ideal resources includes "managers with broad experience; a multi-skilled workforce; well-blend of skills in development; resources directed to projects with high success rate; up to date systems and tools; pragmatic project screening approach; patents ownership." Ideal capabilities include "idea generation; in-house product development capability; co-development with customers; strength in the application of existing technologies; good knowledge of market and technologies; fast-paced decision-making; tuned to customer's developments; strong customer interface; strong customer feedback mechanism; synergistic integration of development, production and field engineers; detection of opportunities from field." In addition, the authors emphasized the important role of "networking" as a capability—innovating firms must link to "trade shows; engineering and professional societies, personal networks; global networks; suppliers and customers and competitors; local businesses; universities; and consultants." Further, the authors find that innovating firms are "strongly opportunistic and entrepreneurial; adept at judging risks and opportunities; strongly committed to innovation; continuously challenging assumptions; having a small firm mentality; pragmatic; actively seeking external ideas; and communicating openly."

Cooper, et. al., (2003) surveyed 105 business units to define an ideal mixture of resources, capabilities, and cultural elements. About half of the companies surveyed were in manufacturing, their median sales were $400 million, and they spent on average 5.2% on R&D. The authors matched the survey results with the percentage of revenues from new products (top 20% has 38% of new revenues from new products) to determine best practices. These practices included: "climate supports entrepreneurship; product champions developed/recognized/rewarded; open communication across functions; management not risk averse, invests in high risk products and doesn't punish for product failure; resources available for new product and process work; Skunkworks encouraged; employees given time off for creative work (3M rule); idea suggestion scheme in place; senior management strongly committed."

Quinn (1985) in a seminal *Harvard Business Review* article posits several innovative capabilities based on a worldwide survey and interview-based study of small and large US companies in the mid-1980s. These capabilities include: long-term, clear vision from top management; market orientation; small project teams; experimentation, multiple approaches to solutions; developmental shootouts; Skunkworks; and project management as incremental, goal-oriented, interactive learning processes."

Burgelman, et. al (1996) based on extensive studies and literature review developed a generic "innovative capabilities audit framework" that tests five core areas: resource availability, understanding competitor's strategies, understanding the technological environment, business unit cultural context, and the capacity to deal with entrepreneurial behavior. In this framework, ideal capabilities to test against include strong R&D funding; a strong depth and breadth of R&D and engineering skills; distinctive competence in the core technology; high levels of competitive intelligence and understanding of the technological environment; strong management mechanisms for transferring technology, integrating functional groups, funding unplanned initiatives, eliciting new ideas, reward systems for entrepreneurial behavior; and a strong capacity of the business to assess the importance of entrepreneurial initiatives.

Lawson and Samson (2001) describe a generalized "innovation capability" from "underlying patterns that can be identified" from the literature and case studies. These include: creating a strong vision and strategy around "being the best"; strong resource management, with a variety of funding channels; strong fostering innovation champions; high levels of customer and competitive knowledge; high levels of creativity and idea generation; strong reward systems for innovation; and tolerance for ambiguity, creative time, communication

Arnold and Thuriaux (1997) also list generic innovation capabilities using an extensive literature review, including the management of a tangible technology base (product, R&D, plant and equipment), development of intangible resources (intellectual capital, skills, tacit knowledge), organizational development (technology management, change management, coordination), as well as external capabilities (access to external knowledge and complementary assets). In the same vein, Dodgson (2000)'s synthesized list includes resources such as "strong resident knowledge and skill; strong technology base" and capabilities including "forecasting and assessing; idea searching and selecting; implementing new technologies and strategies; integrating and coordinating different functions and divisions."

Finally, Prencipe (2001) lists innovation-related technological capabilities from an aerospace industry context, which offer particular insight for the case company described in detail in Chapter III. The author categorizes technology capabilities showcased by successful aerospace suppliers into four areas: absorptive, integrative, coordinative, and generative. Absorptive capabilities refer to a firm's ability to monitor new opportunities emerging from science and technology. Integrative capabilities center on a company's "capability to set the requirements, specify source equipment, materials, and components which can be designed or manufactured either internally or externally, and integrate them into the architectures of products" (*ibid.*). Coordinative capabilities focus on organization's cross-functional abilities to organize development of new and emerging bodies of technical knowledge across firm boundaries. And finally, generative capabilities are a firm's ability to internally innovate at the component level.

Commonalities clearly emerge in this set of the literature: strong bases of know-how and technology combined with idea generation, the ability to resource and execute new product and process development (*e.g.*, through Skunkworks) and strong levels of initiative and entrepreneurship are just a few that appear consistently. Still, given the ample list of resources and capabilities from the literature (the set is just a sample), as well as the approach of employing best practices from firms in similar circumstances, how does the practitioner ultimately chose the list of ideal resources and capabilities? Again, as a modular methodology, practitioners have a lot of leeway in choosing the ideal capabilities appropriate to its circumstances and strategy; as a starting point, practitioners can take the above (or other) lists and ask a very simple "litmus test" question: does this capability reinforce the selected strategy? With this approach, the practitioners should be able to create a set of ideal resources and capabilities with which to base its innovation plan.

3. Audit the Firm and Build Plan

After the practitioners define the set of ideal resources and capabilities, they need to perform a reality check and measure the stock of these resources and functioning of the capabilities. During this audit, the practitioners also seek out and interview the lead innovators within the firm to discover any patterns in their successes and failures. With the measurement and interview data sets, the practitioners then build a plan to reinforce the firm's capabilities and any emergent patterns of innovation.

a. Audit Ideal Capabilities

In auditing the firm, the practitioners must define how they will measure the firm's resources and capabilities (*i.e.*, set units of measurement); set targets for the desired states; and then dive into the firm to measure the health of the ideal resources against the benchmarks. First, given that innovation management—not to speak of the RBV—is a nascent field of study and that resources and capabilities can often times be abstract, practitioners will find a dearth of units and standards with which to measure. Some measurements (*e.g.*, measuring the resource of intellectual property by number of patents and trade secrets) will be straightforward; others will push the boundaries of tractability (*e.g.*, measuring the level of entrepreneurship within the staff). Overall, the practitioners have a lot of freedom in defining exactly how they will measure and test; the literature offers some help, but many of the practitioners' assessments will likely be qualitative. Performing longitudinal studies using carefully documented measuring criteria with a diverse panel of experts (and averaging their assessments as in a Delphi study) can help offset the inherent subjectivity.

Once the practitioners establish measurement criteria, they set targets for the levels of resources and functioning of the capabilities. These targets are preferably determined through the external benchmarking of firms of similar circumstances; however, competitive information may not always be easily accessible, particularly for smaller firms. In this case, the literature may offer helpful information.[22] Absent information from competitors and the literature, the practitioners need to use their judgment to set targets that balance, stretch, or "blue sky" goals with those that are reasonably achievable given the constraints of the firm.

[22] *e.g.*, if an ideal resource for Company X is Cooper's (2001) "resources available for new product and process work," then the literature would offer the widely cited example of 3M's "15% rule"—all researchers at 3M get 15% of their time to explore non-core business related ideas.

Finally, the practitioners dive into the firm to collect information with which to test the firm against the targets. They must scour the sources used in the firm assessment including interviews, internal documentation, surveys, etc., to find relevant information.

b. Interview Lead Innovators to Discover Innovation Patterns

During the second round of data collection, the practitioners have an opportunity to "dig deeper" than in the initial firm assessment to understand more of the inner workings of the company. At this point, the practitioner gathers data on the firm's existing entanglement of politics and culture through seeking out and exploring examples of innovation and change within the company. The author propounds (but cannot prove) that every firm, even those not renown for innovating within their industry, has a set of "change agent" employees[23] that have attempted to implement some sort of transformation to the core business—whether it involved championing a new technology or merely changing the way a component is manufactured on the factory floor.

The practitioners interview these "lead innovators" to document case studies of how they brought (or failed to bring) their changes to life. Ideally, the practitioners will find numerous examples of attempted change within the company and should aim for documenting a half dozen or more cases—obviously the more the better. Ultimately, the aim is to search for patterns among these cases to find an innovation-friendly pathway through the dense thick of the firm's networks and culture. While the process of searching for patterns could reach high levels of complexity, the practitioner should aim for a broad overview of similarities among the cases: what are common themes that emerge from the stories? For instance, the practitioners may find that in the majority of the cases, the ideas for the innovations came from specific external sources like a web site; or that most had strong support from a certain manager; or that a particular funding mechanism worked well.

Discovering local innovation patterns is important to this methodology, as it aims to build a plan around the firm's existing culture (particularly its deep-seated values) and long-established networks. In the long term a firm's culture can (and usually does) change, but in the short term effecting culture change is incredibly difficult, particularly for practitioners with limited authority (such as the author with respect to the case company). The analysis of the firm's context and circumstances along with the case analysis of local innovation patterns should create a "cultural map" within which the practitioners can build an ac-

[23] This theory is built around the well-established principle that peoples' drive to implement change and try new experiences distribute roughly according to a bell curve, at one end a few pushing change, the other a few resisting change at all costs, and the majority in the middle not actively pushing or resisting change. Assuming the firm is of sufficient size (*e.g.*, at least 50 people) its employees should fall roughly into this distribution, with some employees relatively more proactive than others.

tionable innovation plan—*i.e.*, one that the firm can realistically implement and achieve given its habits, practices, and values. Specifically, practitioners should build the innovation plan around local innovation patterns in two ways:

1. The plan should strengthen resources and capabilities using similar mechanisms employed by successful lead innovators; *e.g.*, if a pattern emerges that successful innovations at a firm tend to have leadership support from, say, the COO, the innovation plan also needs to deeply engage that stakeholder.
2. The plan should actively reinforce the successful innovation path; in other words, the plan should not just strengthen "ideal" resources and capabilities, but help align them in ways that mimic the innovation path. Thus, if an "ideal" capability is idea generation, and an emergent pattern in the cases is the use of a particular external source for ideas (*e.g.*, an industry trade conference), the innovation plan could strengthen idea generation by formalizing a link to that external source (*e.g.*, establishing a regular practice of sending staff out to conferences with templates to record ideas, providing an internal database to record them, and setting up meetings at the company for the staff to present their findings and brainstorm possible offshoots).

c. Build the Innovation Plan

After gathering data on the state of the firm's ideal resources and local innovation culture, the practitioners build a plan to fill the resource and capability gaps. Again, the methodology allows the practitioner to tackle plan building in numerous ways; for instance, they could approach it as creating an internal business plan, outlining internal customers (*i.e.*, stakeholders), needs (*i.e.*, resource gaps), products (*i.e.*, solutions to filling the gaps), competitors (*i.e.*, the status quo or alternative solutions), operations (*i.e.*, the resources and timing needed to implement the products using planning tools like GANTT, critical path, or theory of constraints), and the team (*i.e.*, those responsible for executing the plan). Another method is the "process-based management" approach employed by the case company's parent, which brings together the stakeholders to build a plan with a mechanistic bent, carefully determining desired inputs, transformation processes, and outputs and outlining responsibilities for each item.

For the case company, faced with resource constraints the author used a simple approach to build a plan: 1) identify the resource and capability gaps; 2) identify solutions to fill the gaps through scanning the literature and case studies, interviewing select experts, and personally brainstorming; 3) group the solutions to find commonalities; 4) rank the groups according to cost, timing, cultural fit, and economic impact; and 5) target the highest ranking groups of solutions for implementation, identifying the resources required for execution. This approach is outlined in detail in the next chapter.

C. How is the Methodology Unique?

To review, this thesis proposes an innovation strategy development methodology to build on established strategic practices in the innovation literature while addressing the weaknesses. The methodology has seven elements: 1) stake intent, 2) survey the industry and firm, 3) create an innovation strategy, 4) audit the firm, 5) develop the plan to reinforce the capabilities through its existing culture, 6) execute and measure the plan, and 7) periodically reflect and adjust the plan as the firm's environment changes.

The core of this innovation strategy framework is not novel; for instance, much of the literature advocates some sort of industry study, careful positioning of the company within the industry, and measurement and feedback over time. However, the methodology innovates in addressing four identified weaknesses of the innovation strategy literature (see Christensen 2003, von Stamm 2003, Burgelman et al., 1996, Cooper 2001, Chesbrough 2003, Dodgson 2000, Drucker 1985, Lawson and Samson, 2001, Patterson 1999, Volery 2003, Peeters and von Pottelsberghe, 2003, among others).

1. It Emphasizes the Local Context of the Firm

A lot of the innovation strategy literature promotes "one-size-fits-all" solutions, de-emphasizing the importance of context and circumstances in formulating a localized innovation strategy for a company. Instead, many popular texts tend to look at desired outcomes (*e.g.*, making a new, radical product), examine the strategies that companies used to achieve them (*e.g.*, form a Skunkworks), and then promote the strategies to all companies wishing to achieve similar outcomes. Such best-practices literature tend to dominate the business bestseller list in the short term, to be forgotten just years later. Alternatively, another type of generalizing literature examines company attributes (*e.g.*, their size, industry, nationality), looks for trends (usually through statistical studies), and bases recommendations on those trends—even to firms outside the industry or country of study (see Neely and Hii, 1999, for instance, among many others).

Christensen (1997, 2002, 2003) best articulates the problem of overly generic approaches in writing "a major reason why the outcomes of innovation efforts have seemed quite random (is that) shoddy categorization has led to one-size-fits-all recommendations that in term have led to the wrong results in many circumstances." While both best-practices and attribute-based literature can provide useful insights, these insights need to be carefully applied, when relevant, within the context of the firm—and local context is the main thrust of the proposed methodology.

2. It Takes a Modular Approach

In addition to being too "generic", the literature tends to suffer from the syndrome of "not invented here"—different authors can describe and analyze very similar concepts but do not always build effectively on each other's work. In this sense, the innovation literature itself may be too innovative in authors' attempts to differentiate themselves from their colleagues' efforts. In the literature one can find a dizzying array of innovation strategies and frameworks, many of similar concept but different jargon.[24] Christensen and Utterback's treatment of disruptive technologies (the pair have even co-authored papers together, but both hardly mention the others' work in their main texts) is a prominent example of the "NIH" syndrome.

The proposed methodology in this thesis addresses the NIH issue by taking the modular approach in building off existing frameworks and tools. In fact, the methodology depends *entirely* on existing and relevant innovation research, which is "plugged" as modules into the overall architecture of the methodology.

3. It Balances Theory and Observation

It is rare to find in the literature strategy development approaches that balance both ideas and concepts with observation and practice. As described in the first identified weakness, one tends to find a lot of generalized theory about how companies can become more innovative based on a limited or inapplicable data set (*e.g.*, many of the "how to" articles, such as Hamel's (2000) "rules for revolutionaries" based on a single case study). One finds other literature taking the opposite approach—providing extremely detailed studies, usually based on surveys (fraught with issues themselves), with few extractable concepts (*e.g.*, Peeters and von Pottelsberghe (2003)'s administering of a ~50 question OECD survey to 1300 firms in Belgium).

Borrowing on a TQM-based model developed by Shiba (2000) called "WV problem solving", the methodology proposed in the thesis explicitly alternates from concept-building (theory) to observation and fact-finding (data) modules. Figure 4 shows the alignment of the framework modules from the "WV" perspective (as well as the "WV" shape from whence the model derives its name). Theory-building modules (top) shape the data collection scope. The fact-finding modules in turn better focus the successive theory building. By explicitly ordering the modules in a "WV" structure, the framework aims to inherently balance theory and observation in formulating an innovation strategy.

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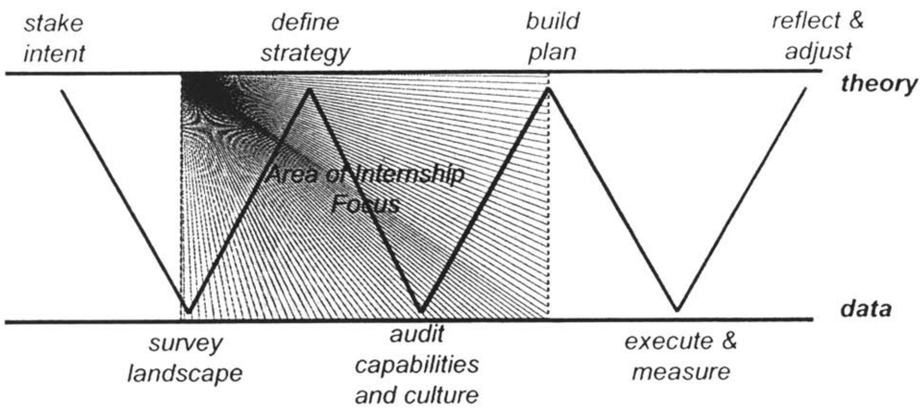
[24] Another perspective is borrowed from the technology "S-curve": the diverse array of similar theories may be explained by innovation being in a "pre-paradigmatic" phase, with no "dominant framework" such as Porter's Five Forces for industry analysis.

Figure 4. Schematic of Innovation Plan Development Framework



4. It Works within the Firm's Existing Culture

A final thread in the innovation literature is its tendency to propound radical changes to a company's culture and political networks to effectively implement new innovations (von Stamm, 2003a,b is indicative of this approach). Von Stamm (2003b) for instance states outright "many managers aim to make their organizations more innovative, and this tends to require a change in culture." Nicholas Negroponte (2003), founder and director of MIT's highly innovative Media Lab, lists culture as the key determinant for generating innovation, and advocates changing the culture to encourage risk, openness, and idea sharing.

For established companies in an innovation rut, culture change is certainly desirable, but accomplishing such change, particularly in the short term, often is not feasible. Culture change, in fact, may be the most difficult task facing senior leadership. Culture embodies the values and assumptions of the organization and tends to be deeply embedded and highly inertial, particularly if it involves changing firmly established practices or violates long-held tacit views. Even for very strong leaders at the hand of established companies—Lou Gerstner of IBM comes to mind—culture change can take years. Compounding the difficulty of culture change is when the innovation practitioners (such as the author for the case company) do not have a lot of authority or resources at their disposal.

Thus, for an innovation strategy to have short-term impact, it must fit *within* the existing cultural framework of the company, with an eye towards creating longer-term culture change. As discussed, the major tool for cultural mapping proposed is to seek out lead innovators within the firm and search for patterns in their successes and failures. The innovation methodology thus differs from those in the literature by extensively mapping the culture of the firm and building a plan focused on reinforcing its existing positive innovation patterns and building capabilities consistent with its existing praxis and values.

III. Case Study: Developing an Innovation Plan for An Aerospace Manufacturer

A. Overview

As described in section I.D, the author developed an innovation strategy and plan for the case company, a midsized aerospace supplier, employing steps 2–5 in the methodology outlined in chapter II. This chapter details the results of this work as a case study for executing the methodology.[25] To allow for richness in the discussion and to protect the firm's intellectual property, the case analysis will not disclose the names of the firm and its people, technologies, and related sensitive information.

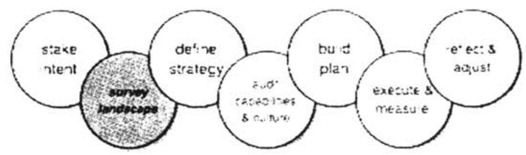
In executing the methodology, the author used a variety of primary and secondary sources. Industry data was gathered from trade and government publications, academic journals, and periodicals. Firm-specific data came from over fifty documented, open-ended employee interviews, direct observations from the author's experience working at the company for over six months (*i.e.*, ethnographic data), internal and published documentation, and company-issued employee surveys. In the two major rounds of data gathering (survey landscape and audit firm capabilities), the author talked with a broad cross-section of employees across all three business units (fabrication, assembly, repair), several functional areas (from engineering to HR), and positions of authority from shop floor technicians to members of the senior leadership team.

However, the data set is not perfect; it has several limitations due primarily to the location and non-thesis related responsibilities of the internship. The case company—as a recently merged firm—has two geographically separate sites, roughly equal in size, and the author spent all but one day of his six months at only one of them, limiting his direct experience with half of the company's operations. In the parlance of social science research, this site can be considered the methodology's "convenience sample." In addition, due to his work responsibilities and location, the author spent most of his time within the research and development group, although some time was spent in other areas, including product development and shop-floor operations. The stakeholder map in Figure 10 (section III.C.2.e) shows the author's relation to the various people within the company. Furthermore, due to security issues the author had limited access to company financial, strategic, and technical data. Finally, the author executed the case study independently—ideally, a team would perform the data gathering and analysis to provide a higher level of robust-

[25] According to Pare (2002), "case study research figures among those qualitative methods that have been recognized as having gained increasing acceptance over the past decades," even for "theory building" or inducing generalized causal mechanisms from the intensive analysis of even a single case. However, the intensive case-study research, also called "critical case" sampling, employed by the author does not attempt to theory build, but test a hypothesis—that the framework developed by the author can create a viable innovation strategy and plan.

ness. Regardless, while the data set underlying the case study may not be complete, the author feels it is sufficient for testing the methodology and providing a tenable innovation plan for the case company.

B. Survey the Landscape: the Aerostructures Industry



1. Overview

a. Background

The formal term "aerostructure" has come into common use only recently. A US International Trade Commission (USITC) report in 2001 provides a succinct definition of the term: "Aerostructures are structural assemblies that primarily house passengers, crew, cargo (and payload) of...(fixed wing)[26] aircraft, dictate the aircraft attitude, and support the aircraft on the ground."

For most of the 20th century, aerostructures were an integrated part of aircraft design and manufacture, a core, internal activity by the OEMs in producing airplanes. As the propulsion systems for aircraft have long been outsourced to companies such as General Electric and Rolls Royce, for many years OEMs were defined largely by their aerostructure-related capabilities of aerodynamics, mechanical control, structural engineering, product design, metal forming, and assembly—hence the historical, yet still common,[27] idiom of "airframe manufacturer" used to describe companies like Boeing and Airbus. While the manufacture of a few aerostructure systems were outsourced to external Tier-One suppliers[28], this manufacturing work was largely "build to print"; in other words, the OEM would design the parts (and often the tooling and assembly sequence) and the supplier would fabricate them according to the engineering drawings.

Over the last few decades, however, OEMs have more and more outsourced major aerostructure systems to external Tier Ones—not just for manufacturing but design and testing as well—creating a viable, independent aerostructures industry of competing, autonomous firms. Internal OEM divisions and subsidiaries are also acting with increasing self-determination: OEMs are giving their aerostructure subsidiaries full profit and loss responsibility, requiring them to competitively bid for internal contracts, and allowing them to bid for external contracts.

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[26] The aerostructures market in this thesis is for medium to large fixed-wing aircraft, and excludes rotorcraft. Rotorcraft structures are typically produced by specialist manufacturers, such as Sikorsky, that do not participate in the fixed-wing aerostructures market. Small business jets are also not included in the main analysis but are treated in section III.B.4.b.

[27] *e.g.*, Michael Crichton's 1996 novel *Airframe*, about a fictional aircraft producer's launching of a new jet.

[28] The Tier-One (also written as T1) aerospace supplier model was largely pioneered in the automotive industry. As opposed to manufacturing parts to exact customer OEM specifications (*i.e.*, "build to print"), Tier Ones design, engineer, manufacture, service, and even finance large, complex systems, sometimes with integrated electronics and mechanicals, directly to the OEMs.

The forthcoming Boeing 7E7 widebody twin showcases the emergence of aerostructure manufacturing as an independent industry. Almost two-thirds of its aerostructures (by mass) will be financed, designed, tested, and manufactured by Tier-One partners outside of the company (Mecham, 2003). Notably, thirty-five percent of the 7E7's aerostructures—primarily the wing box and fore fuselage sections—will be made by the Japanese "Heavies" (Mitsubishi, Kawasaki, and Fuji Heavy Industries), and twenty six percent—the horizontal stabilizer and center and aft fuselage—by a joint venture of the Italian firm Alenia and US-based Vought. The internal Boeing divisions (Fredrickson, Tulsa, Wichita, Winnipeg, and Australia) responsible for the other third had to compete aggressively for their sections of the plane, with some having to find external financing for product development and tooling costs (*ibid.*). With two-thirds of the aerostructures in Boeing's latest plane being outsourced—and with the "insourced" third treated essentially as outsourced systems—use of the term "airframe manufacturer" to describe a modern OEM may be in need of an update.

b. Market Size

As the aircraft industry is extremely cyclical, revenues year-to-year can fluctuate dramatically; in the long term, over the next 20 years Boeing (2003) projects that airlines will take roughly 24,000 large and regional aircraft deliveries valued at round $1.9 trillion. The USITC (2001) estimates the global aerostructures market to constitute around ten percent of all aircraft and parts sales. Thus, the market for new commercial aerostructures is forecasted to be around $190 billion over the next two decades, or around $10 billion a year. Boeing's (*ibid.*) estimate of commercial aviation support services is about $3.3 trillion, implying an additional $17 billion per annum in aerostructure services, consistent with Frost and Sullivan's estimate for this market (1999). Military aircraft, which tend to be less cyclical (due to consistent government demand)[29] is roughly a $7 billion market (Bureau of Census, 2002).[30] As most governments perform maintenance in-house, the services market for military is much smaller; Frost and Sullivan (1999) estimate the addressable market to be only a tenth the total expenditures, roughly $2 billion a year. Thus the market for newly manufactured aerostructures for commercial and military aircraft is approximately $17 billion per year, with services adding another $19 billion. Other markets, such as UAVs and small aircraft, are treated in section III.B.4.b.

[29] To wit, military aircraft expenditures in the US were $31 billion nominal in 1995, $34 billion in 2000, and $36 billion in 2002 (all around $25 billion in 1987 dollars), while commercial aircraft were $24 billion, $48 billion, and $29 billion respectively.

[30] Military aircraft spending was approximately $36 billion in 2002 (Bureau of Census, 2002); assuming the US spends half of the global turnover on military aircraft, this implies a $70 billion global aircraft market, $7 billion of which is for aerostructures per the USITC (2001)'s estimate.

c. Major Products and Services

Aerostructures include the primarily mechanical systems that make up an aircraft's fuselage, wings, empennage, engine nacelles, and the landing gear/undercarriage. Decomposing these systems one level further, the fuselage includes barrel sections, body panels, frames and stringers, and keel beams; the empennage includes tailplanes, tail panels, fins, rudders, and elevators; and wings comprise of skins, boxes, wing-to-body fairings, ailerons, flaps, flap fairings, leading and trailing edges, wing tips, winglets, and spoilers (USITC, 2001).

Other structures on planes requiring similar design and manufacturing capabilities, but which are not formally considered part of the aerostructure market are aircraft interiors (*e.g.*, walls, bulkheads, bins, seats), certain engine components such as fan blades, and rotorcraft structures (see footnote 26).

The predominant aerostructure "services" market is for the maintenance, repair, and overhaul (called MRO for short) of aircraft structures. Since deregulation in the 1970s, airlines have begun to outsource most of their maintenance requirements to independent firms (Frost and Sullivan, 1999). Outsourced MRO is primarily for what are known as "C" and "D" planned maintenance checks, which involve a detailed examination and test of aerostructure integrity (*ibid.*). In the "D" check, done approximately every eight years, all major structures are disassembled, removed, inspected, and repaired or replaced, a process that can take upwards of 40,000–70,000 person-hours for widebody aircraft (*ibid.*). Other types of outsourced MRO include unplanned repairs (*e.g.*, for hail damage of leading edge wing surfaces) and conversions (*e.g.*, converting a passenger 747-200 into one optimized for carrying cargo).

d. Major Customers and Requirements

The major customers for aerostructures are the manufacturers of fixed-wing commercial and military aircraft. As discussed in Chapter 1, decades of consolidation has reduced the number of global large commercial aircraft producers to two roughly equally sized (by aircraft deliveries) competitors, Airbus[31] and Boeing. Regional commercial aircraft (planes seating between 50–90 passengers) have four dominant producers: market leader Bombardier (Canada), Fairchild Dornier (Germany), Embraer (Brazil), and BAE (England). While the regional aircraft market is projected to be roughly a fifth the size by revenue of the large aircraft market over the next twenty years[32], some regional manufacturers, such as Bombardier, are looking to go "upmarket" into larger aircraft (Business Aviation, 2003). Finally, military aircraft are dominated by the two owners of Airbus (EADS and BAE) and three firms in the US: Boeing (which ac-

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[31] Airbus was recently restructured from a consortium to a single entity. Airbus formed in the early 1970s as a consortium of BAE Systems, Aerospatiale Matra, DaimlerChrysler Aerospace, and CASA. Airbus is now under one legal and management structure and is 80% owned by EADS and 20% by BAE.

[32] Assuming 8000 regional jets sold (Boeing, 2003) at an average real price of $40 million.

quired McDonnell Douglas and North American-Rockwell, Lockheed-Martin (which acquired General Dynamics), and Northrop-Grumman (which acquired Vought).

As fixed wing aircraft have evolved into a maturing, dominant design (see section III.B.3.b), major customer requirements for both commercial and military platforms center on cost and on-time delivery; mass reduction, particularly for military platforms, ranks closely behind. Cost differentiators include production efficiency, factor input (labor, materials, capital) costs, economies of scale and learning effects (USITA, 2001); and as Tier Ones take more front-end responsibilities, design and engineering capabilities that lower costs (*e.g.*, design for manufacturing) are becoming increasingly important. Due to the high safety requirements and regulations for aircraft, quality and durability are "must haves" to enter the market and are not differentiators.

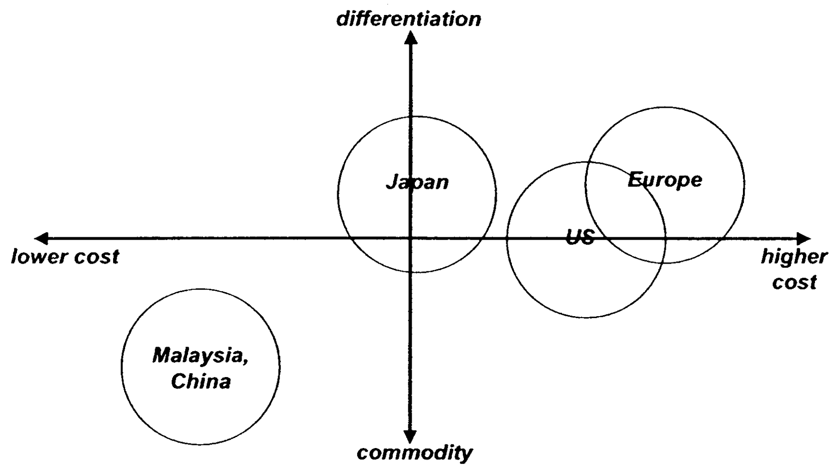
e. Competitive Landscape

The industry landscape is crowded: at least fifty global major firms supply aerostructures directly to major OEMs (*ibid.*), with thousands of smaller firms such as specialty machining shops supplying the majors. The industry is dominated by US and Europe, but with a growing Asian presence from Japan, Korea, China, Malaysia, and Taiwan. Other countries with major aerostructure suppliers include Argentina, Brazil, India, Israel, and Turkey. Dominant firms include Boeing's internal divisions (Wichita, Puget Sound, operations in Canada and Australia), Airbus' divisions (former assets of BAE, DC Aero, CASA, Aerospatiale Matra), Vought, BAE (England), GKN (England), Alenia (Italy), and Fokker (Netherlands) (*ibid.*). The industry has experienced some mergers—*e.g.,* Vought, the former aerostructures unit of Northrop-Grumman, merged with Aerostructures, Inc. to create the largest fully independent aerostructures firm—but has lagged the OEMs in consolidating.

Firms tend to cluster in capabilities according to geographic region. European firms lead with respect to experience with advanced technologies, particularly in metal forming and advanced composite manufacturing, but tend to have the highest costs—although with aggressive price cuts stimulated by OEMs over the past decade, these firms' costs are decreasing fast. Japan also has significant capabilities in composites, and leads in lean manufacturing. Non-Japanese Asian firms typically have less technology experience but the lowest costs (primarily due to low wages), and are increasingly winning build-to-print type contracts—particularly Chinese firms such as Chengdu, Shanghai, Shenyank, and Xi'an. Korean firms (Samsung, Hyundai, and Korean air) and CTRM in Malaysia, however, are rapidly climbing the learning curve and are becoming capable in design and engineering. US firms tend to fall in the middle—slightly lower in cost and technological advancement than Europe, higher in those areas than Asia. Outside of

Europe, Asia, and the US, firms tend to specialize in niche areas or technologies. Figure 5 maps this landscape over Porter's generic strategy axes of cost versus differentiation.

Figure 5. Competitive Industry Landscape



A significant competitive issue in the industry is government involvement, which tends to be heavy; governments widely view aerospace is as a strategic industry for economic development and national security. Almost every major aerostructure firm receives government support (*e.g.,* tax credits for R&D), and some are partly or wholly government-owned—*e.g.*, Hellenic Aerospace (100% owned by Greece), SNECMA (97% owned by France), Alenia (35% owned by Italy). A consequence of the heavy government involvement is that firms at times can engage in unprofitable activities—*e.g.*, firms often receive government subsidies for materials or manufacturing technologies with below cost-of-capital internal rates of return. In addition, many governments have historically required OEMs to "offset" a portion of a plane's manufacturing and assembly in return for their purchasing military and commercial aircraft. While most countries have formally abandoned this practice, it clearly remains a tacit factor in OEM's bidding for work. Government influence thus can distort market dynamics, and must be considered in innovation strategy-making as both an opportunity and threat: aerostructure firms may be able to enlist home government support for innovation initiatives, while at the same time must factor in competitors' ability to gain similar advantages from their governments.

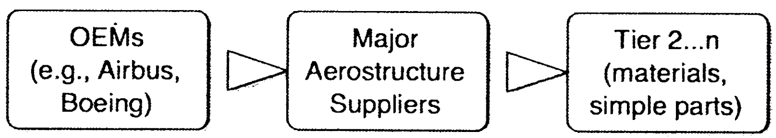
2. Industry Structure

a. Industry Value-Chain

Clearly, the aerostructures industry is a complex network of thousands of firms, but a simplified value chain diagram of the aerostructures business (Figure 6) highlights the three major groups within the industry that add value in converting raw materials (primarily light metals and polymers) into products such as fuselage sections and control surfaces on fixed-wing aircraft:

- OEMs/assemblers such as Boeing and Airbus that buy and modify aerostructure systems for their aircraft, which are ultimately delivered to government and commercial airline customers;
- Major aerostructure firms—such as the case company of this thesis—that assemble and increasingly design and engineer aerostructure systems; and
- "Downstream" or lower tiered suppliers that provide simple components and raw materials to the aerostructure Tier Ones.

Figure 6. Simplified Value Chain of Aerostructures Industry



b. Porter's Five-Forces Analysis

A Porter's Five Forces analysis of the aerostructures industry, summarized in Table 2, shows that it is a tough industry to compete in: a threat of new entrants is present (yet not particularly high), rivalry among firms is very high, buyers and suppliers have very high bargaining power, and a threat of substitute products (from the perspective of structures made from polymer composites) is medium to high.

Table 2. Summary of Five Forces Analysis of Aerostructures Industry

Market Force	Level	Key Factors
Threat of Entry	Medium	- sophisticated technology capability requirement - strong economies of scale and learning effects - customers offer long-term contracts - high levels of government regulation + government subsidization of new players + increasing modularization and commoditization of products + emergence of lower-cost manufacturing technologies
Rivalry	Very High	+ large number of firms + contracts are competitively bid + modularization and commoditization of products shifting competition from differentiation to cost
Buyer Power	High	+ few number of very large buyers in commercial and military markets + modularization of products lowering switching costs + end aircraft market faces strong price competition + credible threat of backwards integration
Supplier Power (polymer composites)	High	+ few number of qualified material suppliers + suppliers dominate the materials value chain + suppliers forward integrated into the aerostructure market + high switching costs as materials are expensive to qualify - emergence of low-cost Asian suppliers - increase in "standardized" composite material systems
Threat of Substitutes (polymer composites)	Medium-High	+ OEMs have flexibility in choosing material-systems for their aerostructure components + advances in aluminum and light metals make them a "moving target"

i. Threat of Entry

The threat of new entrants into the aerostructure industry is credible, ranked as medium. The traditional factors of technology requirements, learning effects, economies of scale, long-term contracts, and high regulation help keep new entrants at bay. However, factors that are increasing the threat include government involvement, increasing modularization, cost-based competition, and new lower capital cost technologies.

Traditionally, the aerostructures industry has afforded a fairly high barrier to entry. First, it is a high-technology industry that requires strong levels of advanced resources and program experience to succeed in the market. A company (or nation) cannot simply decide to start making structural airplane parts; it must have a strong engineering base, experience with high-precision manufacturing, and access to advanced technologies from computer-aided design tools to non-destructive testing apparatus. Second, the industry has historically been highly dependent on the "learning curve"; much of the knowledge of designing, manufacturing, and assembling aerostructures is tacit, and learning-by-doing is often the most important factor in lowering costs. Furthermore, necessary large investments in equipment and tooling[33] create economies of scale. Fourth, the long production cycles of most aircraft afford long-term contracts to established firms; contracts are not re-bid year to year as in other industries. Finally, regulations in the industry require firms to adhere to strict, often difficult to master practices; it can take years to achieve regulatory certification from the US's FAA and Europe's JAR.

However, several factors have eroded the barriers to entry and have been increasing the threat—as evidenced by the large number of firms in the industry. First, the heavy government involvement mentioned in the last section has helped subsidize new entrants, particularly in Asia. Second, increasing modularization of aerostructure components (see section III.B.3.c) can lower OEM switching costs (*e.g.*, well defined interfaces between the wing and its control surfaces such as ailerons can enable new competitors to offer compatible parts). Third, as the industry is in a dominant design phase (III.B.3.b), aerostructures are increasingly exceeding core customer performance needs and becoming commoditized, changing the nature of competition to cost, providing incentives for firms with access to low-wage labor to enter the market. Finally, new lean-manufacturing focused technologies such as determinant assembly—which obviates the needs for jigs and fixtures—are reducing the tooling costs for new parts, lowering economies of scale.

Thus, the industry has traditionally had relatively high "market" barriers to entry, but government involvement and recent technology trends have mitigated these barriers and have created a credible threat of entry. Of note, however, one recent trend, risk sharing, is creating a new barrier to entry. In risk-sharing arrangements, the Tier Ones pay for much of the non-recurring costs of a new program, which have traditionally been born by the OEM; Airbus has practiced risk-sharing for over a decade, and Boeing is establishing this practice with its 7E7 program. In return, the suppliers can further lock-in long term contracts, increase their margins, and in some cases own or control the IP (although the latter is not the norm). Of course, risk-sharing combined with government involvement can create a double-edged sword, as it creates a "pay to play" marketplace, creating an advantage for subsidized new firms.

ii. Rivalry

Rivalry is a more clear-cut force than threat of entry; simply, with over fifty major firms—with no clear dominant player—in a mature, highly cyclical market, rivalry is intense. Most contracts are competitively bid to dozens of suppliers, and given the importance of learning effects and, traditionally, economies of scale, firms can "underbid" individual contracts in order to gain overall learning and scale advantages.

[33] Such investments are called, along with product development expenses and overhead, "non-recurring" costs in aerospace, compared with labor and materials which are called "recurring."

Moreover, increasing modularization and commoditization for most aerostructure systems and the general absence of defensible intellectual-property (section III.B.4.b) mitigate attempts at differentiation at the design and engineering level (while differentiation through low-cost manufacturing remains strong, although this can be obtained through either low-cost labor or advanced, highly-automated technology). Overall, rivalry in the aerostructures industry can only be classified as intense, with very few potential developments within the industry other than consolidation attenuating this force.

iii. Buyer Power

The bargaining power of OEMs, like the rivalry among firms, is very high. Buyers are few and large; aerostructure firms are relatively small, with a limited customer base; buyers largely control the IP, have low switching costs, and can backwards integrate; and finally, buyers themselves face intensive price pressures from airlines and governments, which flow down to the aerostructure firms.

Specifically, with consolidation at the OEM level, Airbus and Boeing form a "bilateral oligopoly" in commercial aviation (USITA, 2001), and the fixed-wing military market has only three major aircraft (the F-22, F-35, and A400M) under development. Major OEMs also dwarf the size of the largest independent aerostructures firm (or even OEM aerostructure division); Boeing is fifty times larger by revenues, for instance, than Vought (Derby, 2003). Most aerostructures firms are undiversified and focused on aerostructure products; thus the OEMs typically constitute a large fraction of their revenues. Furthermore, as buyers still typically own the intellectual property of aerostructure components—even as suppliers increasingly share risk—OEMs can arguably switch among suppliers or backwards integrate as necessary to increase their leverage in negotiations.

Finally, despite enjoying an oligopoly, OEMs (particularly producers of commercial aircraft) face a highly cyclical market where demand can fluctuate wildly and price wars are frequent. For instance, still reeling from a depressed post-9/11 travel market and increased competition from Airbus, Boeing shipped around 280 jets in 2003—55% fewer than the 620 it delivered only four years previously. Airbus, for its part, is rumored to have sold its forthcoming A380 super-jumbo to its launch customers at $150 million a plane, a hefty 40% discount (*Aviation Daily*, 9/12/2003). The fluctuating demand and price discounting translates to strong cost pressures—and strong OEM bargaining power to lower prices—for aerostructure firms.

iv. Supplier Power

The bargaining power of suppliers depends on the nature of the input to the aerostructure firm: polymer composite material suppliers hold very strong bargaining power, component suppliers—typically small machine shops or low-cost Asian suppliers of simple commodity parts such as brackets—generally hold low power, and light metal material suppliers fall somewhere in between.[34] For the case study company's dominant purchased input, polymer composite materials, supplier power is generally high. Three aerospace composite material suppliers dominate the industry: Cytec, Hexcel, and Toray. Cytec is Boeing's largest supplier, while Hexcel mostly supplies Airbus (Hunter, 2003). These companies, through years of mergers and acquisitions, are bigger than most independent aerostructure firms (*e.g.*, Cytec has $1.5 billion in annual revenues) and control the production of the three key elements of composite material supply: resin, fiber, and consolidated resin/fiber systems such as preimpregnated tow (known in the industry as "prepreg"). The materials are generally difficult to manufacture to aerospace requirements, and switching costs can be high; each resin, fiber, and material system requires qualification by the FAA and JAA, costing several million dollars per material. As well, material suppliers are forward integrated into the aerostructures market; Hexcel, for instance, produces finished composite wing-to-body fairings, wing skins, leading edges, rudders, and elevators for jet aircraft. Mitigating the supplier power to an extent is the emergence of new, low costs entrants from Asia, and OEMs' (and aerostructure firms') push to "commoditize" composite material elements by standardizing on qualified, non-proprietary resin formulations and fiber forms.

v. Substitutes

From a design perspective, particular aerostructure parts can have substitutes for new aircraft programs, particularly for military and small aircraft applications such as UAVs. For instance, design approaches such as the blended-wing-body (BWB) fuses the wing and fuselage together, eliminating many of the traditional aerostructure components on a "wing and tube" design; as well, novel launch and recovery systems for UAVs can eliminate the traditional undercarriage and landing gear. However, for existing platforms and the commercial aircraft market, aerostructures have no substitutes—Boeing, for instance, can not decide to start producing 737s with a rudder "substitute" in mid-production cycle.

However, from the materials perspective employed in the section above, the threat of substitutes is medium-high. For most aerostructure applications, light alloys can substitute for composite components (and vice versa) when OEMs are designing new aircraft; even in mid-production cycle, an OEM can substitute materials (and design) for a particular component, although it is more rare. Advances in lighter weight alloy formulations, aluminum material forms (*e.g.*, Alcore aluminum honeycomb core) and aluminum manufacturing processes (*e.g.*, stir welding) make metals a "moving target" for composite components

[34] As the case company predominately uses polymer composite materials, the case study emphasizes this material type in its analysis and will give only cursory treatment to light metals such as aluminum and titanium. In the Porter framework, alloy suppliers (*e.g.*, ALCOA and ALCAN) hold bargaining power as they are concentrated and large and, for some materials, offer proprietary alloy blends; yet this bargaining power is tempered as most alloys of light metals are a commodity prone to intense price competition given the global supplies (*e.g.*, large aluminum supplies in Russia) of the material.

and raise the threat of substitution for aerostructure firms specializing in composite materials, such as the case company.

3. Technology Assessment

a. Materials and Manufacturing Processes

Aerostructures industry is a materials, manufacturing, and assembly dominated sector—as opposed to, say, an industry heavy in software or electronics. As mentioned in footnote 34, the dominant material in aerostructures is currently aluminum, hence the prevailing manufacturing technologies center on riveting or bonding formed sheet metal. However, the use of polymer composites—the main material of the case company—is becoming increasingly common in the aerostructures industry, and will be the centerpiece technology throughout this chapter.

Advanced polymer composites combine two distinct materials to create a new material system with superior properties to its parts. These materials combine a tough, light polymer matrix with strong and stiff reinforcing fibers. A multitude of resin and fibers can be employed in a variety of material forms. Aerospace applications typically use tapes or rolls of high-strength, continuous, directionally aligned polyacrylonitrile or "PAN"-based carbon fibers preimpregnated with elevated-cure (upwards of 180°C), high-performance epoxy thermosetting resins; such composites are often called carbon-fiber reinforced plastic (CFRP) "prepregs". Prepregs can be used in "monolithic" structures or as the face sheets in a cored "sandwich" structure. While this thesis does not explore the details of these materials,[35] CFRPs' main advantages over metals are improved specific strength and modulus (hence lower weight), reduced tooling and equipment costs (hence lower capital costs), and greater parts consolidation (hence reduced assembly). However, these materials cost several times more per kilogram than aluminum, are difficult to work with, typically have higher defect and reject rates, and can be hard to service.

Advances in manufacturing processes and reductions in material costs (driven largely by the learning curve and scale effects) however have helped overcome the materials' limitations and are increasing their market share within aerostructure applications, particularly for military aircraft. For instance, CFRPs make up ten percent of the structural weight and 50% of the surface area of the F-18; for the Eurofighter, CFRPs make up over 30% of the weight and 70% of the surface (Wilhelm, 2001). For commercial aircraft, CFRP's earliest production applications, for empennage control surfaces, were in Boeing's 757/767 and Airbus's A310. For Airbus's A320 and Boeing's 777, CFRP make up the whole empennage, and Airbus's forthcoming A380 superjumbo has over thirty tons of CFRP per plane. As mentioned, compos-

[35] For a full treatment of composite materials, the reader is encouraged to refer to Miracle, D.B. and Donaldson, S.L, *ASM Handbook Volume 21: Composites*, ASM International, 2001.

ites' commercial "tipping point" in market share may be Boeing's 7E7, planned for a 2008 launch, which will be primarily CFRP in the wing, fuselage, and empennage.

The primary manufacturing technology for composites is the hand or automated tape lay-up of prepreg. Essentially, prepregs in fabric or tape form are cut to shape and laid down directionally according to templates in open molds, in multiple layers, to take advantage of their anisotropic properties.[36] After the prepegs are laid down, they are cured at elevated temperatures, usually with a vacuum bag to assist with consolidation, in a high-pressure autoclave filled with nitrogen. Afterwards, the materials are trimmed, drilled, chemically finished, and assembled into larger structures through mechanical and chemical (adhesive) fastening techniques. While hand- or automated- prepreg lay up are well understood, and highly tailorable and precise processes, both are relatively slow (takt time for a large part can be measured in days), expensive, and in the case of hand-lay up, labor intensive and prone to errors. Faster, more automated liquid-molding based technologies common in automotive and sporting-goods markets, where resins are injected or infused into dry fibers, promise lower-cost fabrication for aerospace; going forward, liquid-based processes will likely become more dominant in aerospace as these technologies gain higher levels of precision.

b. Stage of Technology Lifecycle

Utterback and Abernathy (1975) in their classic paper "A Dynamic Model of Process and Product Innovation" first introduced the concept of the technology lifecycle "S-curve." Basically, the S-curve represents a technology's states of maturity as it moves from the R&D lab to mainstream customer adoption. A technology's lifecycle stage has tremendous implications for companies in that market. At the early, or fluid stage—akin to the early days of aviation, pre-WWII—a wide variety of technology designs and approaches exist, as companies (and customers) experiment and move up the learning curve. In the middle, or transitional stage, the approaches begin to coalesce, the number of companies producing the technologies thins out, and the performance and customer adoption of the technologies accelerate. In the aviation industry, the "jet age" of the 1950s and 1960s, which produced bold aircraft designs such as the titanium-dominated SR-71 yet saw increasing industry consolidation, was arguably its transitional stage. Finally, in the mature, or dominant phase, a clear standard (a "dominant design") emerges, market growth decelerates, and the key competitive criteria shift from performance to cost and quality.

[36] An anisotropic material has mechanical properties that change according to the direction of load. For CFRP, as carbon fiber has superior properties in the axial direction, laying down the tapes in the direction of the load can lead to more efficient structures, as material is placed only where it is "needed." In fact, composites' anisotropic properties account for much of the materials' specific strength and stiffness advantage over isotropic metals.

Arguably, for the last three decades, the aerospace—and aerostructures—industry has been in a dominant technology stage. For instance, the "wing and tube" design has dominated the commercial market for four decades, and composite materials have standardized on epoxy resins and carbon fibers. As a result, aerostructure companies in the key military and commercial aircraft markets as mentioned must focus on cost and schedule—even new manufacturing technologies such as those being introduced by the case company (section III.C.3.a) must focus on these criteria. Most innovations in the major markets have to focus on reducing cost over increasing performance, with a few exceptions; if a company desires to choose a performance-based innovation strategy, it must seek emerging markets still in their fluid or transitional phases such as UAVs and small jets (section III.B.4.b).

c. Speed of Technology Change and Product Architecture

The perspective that the aircraft industry has been in a dominant design stage for decades implies that its overall speed of technology change, or "clockspeed" in MIT Professor Charlie Fine's lexicon (2004), is relatively slow. While some systems in the aircraft industry have a relatively faster clockspeed—such as avionics, which has moved to an electronics-based architecture that enables more frequent updates, even in mid-production—aerostructures fall towards the slow end. The fundamental design of the wings, fuselage, and control surfaces has changed little since the 1950s, and airframe programs have very long product cycles and are launched relatively infrequently.

That said, even with aerostructures' overall slow clockspeed, Boeing's forthcoming composites-intensive 7E7 could arguably classify as a fundamental technology shift in the industry. While the materials in the 7E7 have been in service for decades, and the overall shape and geometry of the aerostructure systems are similar to a metal ones (*e.g.,* the fuselage will still be a tube with ribs and spars), the use of CFRPs extensively in the aircraft and the possible shift to novel manufacturing methods is clearly more than a small, incremental step from 1990s aircraft like Boeing's 777 or the Airbus A340. However, in the specific aerostructures niche of the case company (see section III.C.1.c), control surfaces, CFRPs are already extensively used and the design and materials for the 7E7 will likely not be a radical change. Thus, control surfaces not only have a slow clockspeed but also are not enjoying the imminent technological discontinuity of other aerostructure systems.

Compounding the dominant design and slow-clockspeed inherent in aerostructure control surfaces is its increasing modularity. Integral product architectures, like a microprocessor, have a very strong coupling and interdependence among its subsystems (*ibid.*). The elements of the system are generally in close proximity and are tightly synchronized, and the interfaces are not standardized. On the other hand, modular architectures, like a bicycle, have loosely coupled subsystems and standardized interfaces. Modules tend to have very specific functionality and can be interchanged relatively easily. While an aircraft overall is a highly integral architecture—it is difficult to design any part of a plane in isolation without thinking about the effects on the millions of others—several systems within the plane can be classified as modular. Jet engines, for instance, are highly modular, as most OEMs offer airlines the choice of engines with each airframe and thus design a highly standardized wing-to-engine interface.

Arguably, control surfaces such as flaps, ailerons, and elevators are becoming modular. The designs of these parts are increasingly mature and well understood. And while the capital expense and product volumes of these parts do not generally afford multiple suppliers, the interfaces between the wing, empennage, and control surfaces are becoming more standardized. The modularization even plays into the emerging Tier-One model in the industry: an OEM specifies the loads and general requirements and can let the Tier-One supplier design the surface as a "module."

Modularity has a significant impact on the ability for a company to innovate a product or technology. Henderson and Clark (1990) classify major innovations as incremental, modular, architectural, or radical depending on whether component and product architecture (*i.e.*, the overall product design) knowledge is enhanced or destroyed. For incremental innovation, both are enhanced. An example is a PC with a faster processor and memory. Modular innovation destroys the conventional knowledge of the module but leaves the architecture enhanced. An example is a shift in memory (SRAM to DRAM) or microprocessor technology (CISC to RISC) that revolutionizes those specific components but leaves the PC design intact. Architectural innovation does the opposite; for instance, the microprocessor itself had an architectural innovation when it went from CISC to RISC, as it used the same technologies (silicon, aluminum, copper) but in a completely different configuration. Radical innovation destroys both. The PC itself, when compared with a typewriter, was a radical innovation.

If one believes that control surfaces are dominant design, slow clockspeed, and increasingly modularized, then in Henderson and Clark's (1990) modular/integral innovation framework control surfaces (and aerostructures in general) have largely seen incremental innovation over the past few decades, and may allow for modular innovation (*i.e.*, innovation within the control surface itself[37])—but architectural and radical innovations (*e.g.*, moving to a wholly new control surface paradigm, such as wing warping) by private suppliers are out of the question.

[37] As this thesis will argue in section III.D.2, while the overall innovation for a control surface is modular, a firm could apply architectural innovation *within* this module.

4. Other Industry-Specific Issues

a. R&D and Intellectual Property

Given OEMs' major customer requirements (section III.B.1.d), research and development by firms in the aerostructures sector is focused on lowering cost by reducing the key economic drivers: the cost of materials, capital equipment, and labor. R&D's secondary priorities are reducing structural weight through design and manufacturing optimization, as mass savings lower the operating costs for airlines through greater fuel efficiency. R&D into more radical approaches, like wing-warping control surfaces (Ashley, 2003), is done by universities and the government.

As a percentage of sales, US, R&D including product development in the aerostructures industry over the past few decades has averaged around 10% of sales (USITC, 2001). Recently, until the launch of Boeing's 7E7, this number has been significantly lower in the US—for instance, Boeing (and its aerostructure business units) directly spent only 2.8% of sales on R&D in 1999. Europe and Japan typically spends at higher levels, about 15% of sales (*ibid.*), while low-end producers in Asia spend much lower amounts. Federal funds generally outmatch private funds two to one in both the US and Europe (*ibid.*).

Overall, R&D expenditures in the industry have slowed down over the past decade. One likely reason, is that aerospace suppliers rarely control their intellectual property. OEMs and governments tend to control ownership of IP, even when the firms come up with the innovation. Historically, when the OEMs largely developed the designs, dictated how they were manufactured, and licensed them to suppliers, IP control was not a major issue. However, with the emergence of the Tier-One model, IP ownership will likely be an increasing subject of interest in the coming decades. The case of blended winglets briefly described in the next section may be a hint of things to come within the aerostructures space.

b. Emerging Opportunities: Where the Industry Could Be Going

This section has focused on the dominant aerostructures market of commercial and military aircraft. However, in considering an innovation strategy, three emerging markets deserve consideration: unmanned aerial vehicles, micro jets, and aftermarket modifications. Currently, these markets represent a small fraction of the $36 billion aerostructure product and service market, but they are much earlier in their technology lifecycle and offer high growth—and innovation—potential.

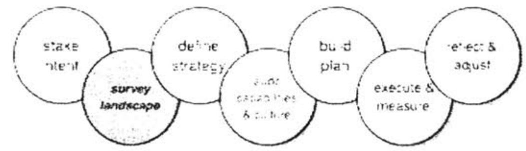
UAVs, or unmanned aerial vehicles, are used by military and commercial for missions that are "dull, dirty, or dangerous", such as surveillance—from monitoring ground troop movement to monitoring environmental conditions (Frost and Sullivan, 2002). The global UAV market currently is over $1 billion (US) with an 8% projected growth rate (implying, by the assumptions of section III.B.1.b, a $100 million aerostructures market). Over thirty countries are developing a total of more than 250 models of UAV (The Economist, 2003). Major UAV OEMs are Northrop Grumman (with its Global Hawk platform), General Atomics (with the Predator), Lockheed, Raytheon, IAI, and Boeing, with smaller companies in Israel, France, South Africa also producing UAVs.

Mechanically, UAVs tend to be lighter and simpler than human-piloted aircraft, yet they have more sophisticated avionics and control. Similar to large commercial aircraft, product development time is in the five-year range, yet unlike commercial aircraft programs stay on the market for a much shorter time, usually five to ten years. In addition, UAVs have less stringent regulatory certification requirements and require less testing. Moreover, they serve as a test bed for new technologies, particularly in sensors, propulsion, materials, and design—and no UAV dominant design currently exists. As a result of the increased number of OEMs, faster product cycles (and faster "clockspeed"), lack of a dominant design, reduced regulatory requirements, and increased use of advanced technologies, UAVs avoid the commodity-like market of commercial aircraft and could offer significant innovation opportunities to aerostructure companies. However, the same factors also make the UAV market more risky than mainstream commercial and military markets, and its small size limits the potential for a company to weight heavily its product portfolio in this market.

Micro jets represent another emerging aerostructure market. A new generation of higher-volume, lower cost small jet aircraft is rapidly coming to fruition, promising the emergence of the "air taxi"—lower cost, point-to-point air service utilizing jets that carry from a half dozen to twenty passengers (The Economist, 2003). Highly touted pre-9/11, the air-taxi has lost some momentum due to security issues, but a plethora of new designs that aggressively use composite materials, advanced low-cost jets, and sophisticated avionics are emerging. While representing a very small, sub $1 billion market today, "micro" jets such as the Dassault Falcon 7X, Gulfstream G150, Cessna Citation CJ3, Aerostar FJ-100, VisionAire Vantage, Century CA-100, Safire Personal Jet, Eclipse 500, Cessna Citation Mustang, Adam A700, Explorer 750T, and HondaJet will be coming to market over the next decade (Williams, 2003). All heavily utilize composites and should cost a small fraction of the typical price of a business jet—most notably the Eclipse 500, which is promising a sub-$1 million (US) price tag. The all-composite, highly efficient HondaJet, just beginning flight tests as of early 2004, represents a particularly intriguing opportunity (Brown, 2004); the engine maker designed the jet engines and airframe in-house, and promises to bring its experience with high volume automaking to this industry. Similar to UAVs, micro jets offer a more competitive OEM space, less mature designs, high growth opportunities, and faster clockspeeds—thus representing another promising market for future aerostructure innovations.

Finally, "value-added" retrofits to existing airframes are a promising opportunity in the aerostructure market. Such retrofits are akin to aftermarket parts for automobiles such as new wheel rims or body-kit spoilers: suppliers offer add-on structural modifications to OEM-designed aircraft that enhance their performance or appearance. Thousands of modifications are on the market, but from the perspective of aerostructure innovation, a notable retrofitting case is of Aviation Partners. That company offers an aftermarket "blended winglet" to the Gulfstream II and Boeing 737s. The blended winglet attaches to the end of the wing, curving upwards gradually to provide improved aerodynamic performance. Depending on the flight application, Boeing estimates the winglets provide a 2-8% improvement in fuel efficiency. Additionally, the blended winglet gives the jets a "modern" appearance; Boeing cites the availability of blended winglets on its next-generation 737s as a competitive advantage in sales against Airbus A320s. More importantly from the perspective of an innovation strategy, the blended winglet is patented—the broad patent covers the "blending" of the winglet and wing using a chorded (curved) interface of any degree lower than 90 degrees—and thus commands a strong price premium for the supplier. While financial information (and profitability) for the private company is not publicly available, winglets for a 737-800 can run over $1 million—quite notable for a jet that costs around $60 million. The Aviation Partners example showcases the possibilities of intellectual property protection in the aerostructures market; aftermarket products offer IP protection (as OEMs typically control the IP on their jets, even with Tier-One suppliers), enabling the innovating company to appropriate the innovation and enjoy competitive protection.

C. Survey the Landscape: The Case Company



1. Overview

a. Background and History

As introduced in section I.D, the case company is a midsized, manufacturing-focused firm competing in the thick of in the aerostructures market. The company is a fully owned subsidiary of a major OEM but operates with a high level of autonomy; the company has full profit-and-loss accountability and sells a significant fraction of its output to its owner's competitors. As will be detailed in this section, the company offers a wide range of products, but specializes in airframe control surfaces, and employs a variety of advanced manufacturing techniques, with an emerging focus in carbon-fiber reinforced polymer (CFRP) composite fabrication.

The company arose from a late 1990s merger of two aerospace firms located in two major cities that offered similar products and had similar engineering and manufacturing capabilities. To wit, both companies in the early 90s fabricated closely related, advanced-composite control surfaces for a major commercial jet, but engineered and developed the manufacturing processes independently. However, while the capabilities of the two pre-merger firms were similar, their backgrounds and cultures were quite different: one of the pre-merged companies was a longstanding, entrepreneurial private firm, while the other was a more process-oriented, state-run company. As with many post-merged entities, the company struggled initially with aligning the networks and cultures of the two former independent organizations. Yet as of early 2004 the case company was emerging as a unified entity, consolidating the management structure and standardizing processes across both company sites.

Despite their organizational and cultural differences, both pre-merged companies followed a similar historical pattern spanning over seven decades. From the 1930s to 1960s, the companies licensed military aircraft designs from major OEMs and assembled and built the aircraft to blueprint for their home market. As build-to-print aircraft manufacturers, the companies enabled their home country to establish a basis for a high-tech industry, and added global manufacturing capacity at a critical time during World War II. In fact, during the war, the pre-merged government-owned company had over ten thousand employees—over seven times the case company's current workforce.

Starting in the 1950s, as the companies climbed the aerospace learning curve and built up broader design and engineering capabilities, they began to design and produce their own small military aircraft. However, these aircraft for the most part were "import substitutes" and due to limited development resources were not globally competitive in cost or performance.[38] As a result, in the late 1960s the companies retrenched back into a "build to print" strategy in their core markets, but focused towards exporting OEM-designed metal components for commercial aircraft. As well, as was vogue at the time, both experimented with diversification to buffer the highly cyclical aircraft market. The companies produced a variety of manufactured goods, including boats, buses, and even mail boxes. However, these diversification efforts were unprofitable, and the non-aerospace products were discontinued or spun out by the 1980s.

With favorable exchange rates, relatively low labor costs, and a national policy of offsets, the export-focused, build-to-print component strategy enjoyed some success. Also of note, in the late 1980s both companies strategically started to shift their output from metals to advanced polymer composites, shed or spun-out much of the remaining non-aerostructure aerospace capabilities (such as avionics), and took on some structural design and engineering responsibility for its products. By the mid 1990s, the companies had evolved to low-cost, high-tech, focused aerostructure control-surfaces fabricators.

This strategy, for several years, provided a degree of competitive advantage and profitability. But the industry forces highlighted in section III.B.2.b, particularly entrants from Asia, and rising labor costs quickly eroded this advantage. As the companies merged in the late 1990s, management realized that the company needed another strategic shift. As a result, company leadership has started to position the company as a Tier-One supplier (see footnote 28), striving to move "up the value chain" by taking greater responsibility for system design, engineering, testing, and servicing from the OEMs. Tier-One responsibilities include financing the capital and development expenditures of their products, managing their supply chain, holding design authority (*i.e.*, the supplier is responsible for holding the design data and any modifications to it), and obtaining regulatory certification.

Tier-One responsibilities are formidable, and require significant expertise and resources. In return for these responsibilities, the Tier Ones enter a less crowded, and ideally more profitable, market. Of the fifty major global aerostructure firms identified in section III.A, possibly a dozen truly qualify as Tier Ones. Thus a key part of the case company's current strategy is moving into this more attractive (yet still highly competitive) market. At the time of the case, the company had many of the elements of a Tier One—particularly its design and engineering capabilities—but was still developing others. In particular, the company lacked design authority for some OEMs, autonomous regulatory certification, sophisticated

[38] One exception was an internally developed target aircraft system that had innovative design and very strong capabilities, including sophisticated control algorithms and a flight envelope of over 60,000 feet. In addition, this product served as a development platform for a variety of applications over the next four decades, providing a control system for a ground-to-ground tank weapon and homing torpedo, among other products.

supply chain management, and the ability to secure equity financing (due to its relationship with its parent OEM). As well, its organizational structure (section III.C.2.d) reflects more a build-to-print than Tier-One business focus. However, management feels the company is on course to achieve Tier-One status by 2005—hence the innovation strategy proposed can take advantage of this business model and its associated capabilities.

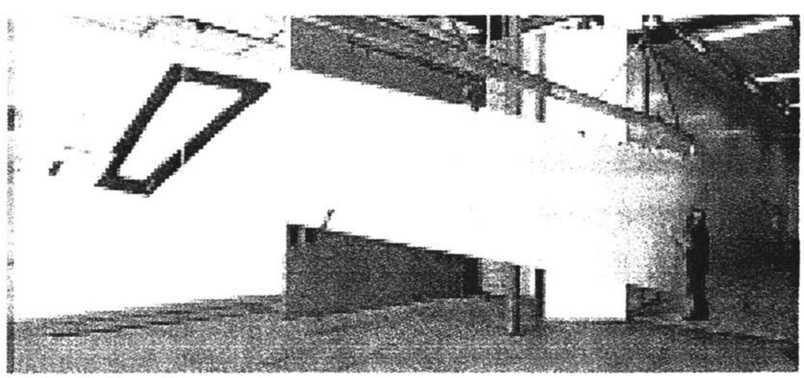
b. Size and Market Share

The case company's sales, net of aerostructure services, has averaged roughly $200 million US over the past two years. As the aerostructure market for new structures is roughly $17 billion (section III.B.1.b), this figure equates to a 1.1% market share. Potential work over the next five years from new Tier-One programs could double the company's sales, which would increase its global market share to 2%. Service and repair sales are roughly $10 million, implying a very small global market share in a highly fractionated market, but are rapidly growing; the company's repair and service sales has enjoyed a 100% CAGR (compound average growth rate) for the last three years.

c. Major Products and Services

As mentioned, the company's product mix is dominated by "control surfaces"—structural assemblies that control the direction of aircraft. Control surfaces the company produces include flaps, ailerons, spoilers, rudders, elevators, landing gear doors, wingtips, and winglets.[39] Figure 7 shows one of the larger control surfaces produced by the company. The company utilizes metals and composites in its products, but is shifting its mix primarily to the latter material system.

Figure 7. Large Control Surface Produced By Case Company



[39] One key strategic issue in the company's product portfolio is the degree of imitability—within the aerostructure market, purely structural, largely monolithic, and modular products such as ailerons and spoilers may be easier to imitate as the design, engineering, and manufacturing of such components are simpler than systems such as a landing gear or barrel section of the fuselage.

d. Major Customers

The company's five major customers for its aerostructures are Airbus, Boeing, BAE, EADS, and Lockheed, with the first two companies comprising the bulk of its sales. Key customer requirements of the case company reflect the requirements of the market overall (section III.B.1.d): cost and the ability to deliver on schedule. Design (*e.g.*, part performance) and materials are secondary requirements, and quality is a customer "must have."

e. Market Position

Without disclosing its geography, the case company's positioning within the aerostructures industry is in the "middle of the market": across its products and capabilities, the company is mid-range in both cost and technology differentiation when compared with its global competitors. As discussed, as opposed to taking a diversified approach, the company is focused on fabricating control surfaces—some of its competitors serve multiple markets or are more vertically integrated. As outlined in Table 4 in section III.C.2.c, the company has some unique resources and capabilities in composites fabrication, design, and engineering and design which further differentiates the company; yet, as the company does not have a formal IP protection scheme, its resources are potentially at risk from imitation or appropriation.

2. Company Analysis

a. General Strategy: How the Firm Creates, Captures, and Delivers Value

In crafting a firm's innovation strategy, it is important for the practitioner to understand the company's overall strategy to ensure both strategies are consistent with and, ideally, reinforcing each other. For the case company, understanding the general strategy is relatively straightforward, as management has clearly defined and regularly articulates its desired strategy for the firm. In both internal and external company documents, management describes the ideal strategic position of the company as "Tier-One supplier of choice for control surfaces." This statement implies the company's location in the value chain (Tier One) and its product focus (aerostructure control surfaces), while leaving open how the firm fulfills customer needs, whether through offering low cost or highly differentiated solutions (appropriate for its "middle of the market" positioning).

The "create, capture, and deliver" framework (Sorenson, 2002)—how the company creates value, captures it from competitors, and delivers it to its customers—provides further insight into the company's desired strategy and is summarized in Table 3.

Table 3. Summary of Case Company Strategy

How the Company...	Explanation
Creates Value	• Offers low cost or differentiated solutions (depending on customer requirement)
Captures Value	• Negotiates long term, risk-sharing contracts • Makes large investments in new manufacturing technologies • Works with local government to help win contracts
Delivers Value	• Uses lean production methods in fabrication and assembly • Builds strong design and engineering capabilities

The company creates value through offering solutions tailored to its customers' needs. For customers requiring low-cost parts, particularly for build-to-print orders, the company aims to provide minimized cost solutions, adding value to the customer by lowering their procurement costs. For customers requiring more value-added products—*e.g.*, systems where the supplier holds Tier-One responsibilities such as design work and in-service support—the company aims to provide a differentiated, high-value package. As described previously, the company is rapidly shifting towards the Tier-One model, thus shifting its overall value creation strategy towards differentiation.

The company captures value largely through engaging in large technology investments and long-term, risk-sharing contracts. The large technology investments, such as in assembly automation and new composite fabrication machinery, create a financial and capabilities-based barrier to entry. Competitors must be able to match both the capital expenditures and the requisite skills needed to effectively develop and operate the technologies. As well, the long-term contracts enable the supplier to act as a risk-sharing partner by investing capital in the aircraft program. In return, the supplier can lock itself into the program over the long term and enjoy higher returns commensurate with the increased risk. However, the lock-in is not guaranteed, as the supplier generally has to agree to aggressive cost reduction targets over the program's life—based on the principle of the learning curve—and consistently meet quality and schedule targets.

Finally, the company delivers value by building strong, integrative engineering capabilities and engaging in lean manufacturing processes. The former set of capabilities, discussed in more detail in section III.C.2.c, enables the company to optimize product development around their manufacturing skills—such "design for manufacturing" can lower costs and increase performance compared with built-to-print approaches—while the latter help the company continuously improve its operations to minimize the cost to the customer. However, as noted by Porter (1996) and discussed in section I.B., it is very difficult for a firm to use lean manufacturing as a competitive advantage. Lean techniques employed by the firm such as kanban and cellular production (both of which reduce work in process inventory) are valuable but widely imitated across the globe, and are thus essentially operational tools that enable the company to keep up with its competitors. Moreover, the company has had some difficulty in implementing lean methods and may lag its competitors in this area.[40] Thus, while in theory lean manufacturing helps the deliver value to its customers, in practice it is not a strong part of the company's value proposition in the aerostructures market.

Overall, the case company has a clearly articulated, consistent general strategy that emphasizes its emerging Tier-One status. However, referring back to Andy Grove's insight in section II.B.1., does the company strategically do what it says it wants to do? In other words, how is the company executing its general strategy? On two fronts—create and capture—the company's actions are consistent with its intent, while on the last front, delivering, the company is somewhat inconsistent. Based on its existing and fore-casted product mix that emphasizes in-house designed control surfaces, the company indeed seems to be creating value through being a focused Tier-One aerostructure supplier. Its forthcoming technology investments, as well, and pending risk-sharing participation in several large OEM projects shows that it is also capturing value consistent with its strategy. However, the company lags a bit in integrating its capabilities, *e.g.*, linking its product development, tooling, manufacturing, and repair operations. As will be discussed in III.C.2.d, the company has had some difficulties shifting from a functional to cross-functional firm, an essential element of not only their Tier-One plans but also their proposed innovation strategy.

b. Firm-level Value Chain

Digging a level deeper from the industry value chain in section III.2.a, a schematic of the case company's value chain—emphasizing its core activities—is presented in Figure 8 (adopted from company literature). At one end of the chain, the company procures raw materials (mostly aluminum and prepreg carbon-fiber and epoxy tapes and fabrics) and subcomponents from Tier Two suppliers. In its position as emerging Tier-One supplier, the company fabricates some subcomponents but primarily manufactures major composite and metal structures and assembles them into aerostructure systems. As shown in the schematic, management views the major fabrication and assembly steps as the company's core activities. At the other end of the value chain, the company supplies these systems to OEMs for use in their aircraft platforms.

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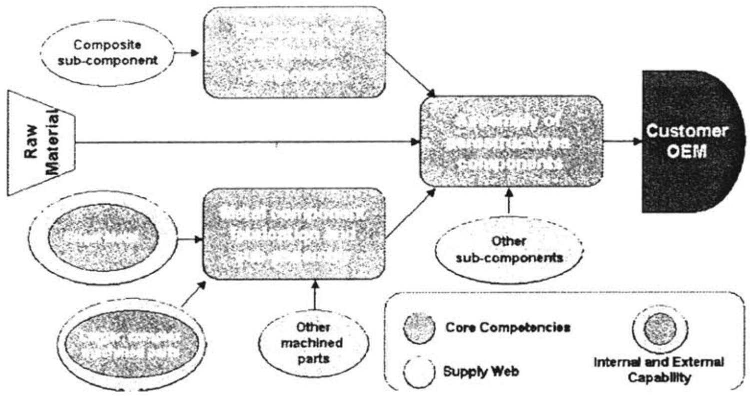
[40] While not the focus of this thesis, conversations with the company's lean-manufacturing experts, observations in the factory, and the author's benchmarking other aerostructure companies skilled in lean production indicate that the company may lag behind its competitors in key lean-related metrics such as inventory turns, return on invested capital (*e.g.*, capital efficiency), defect rates (and improvement in such rates).

Figure 8. Case Company Value Chain



c. General Resources and Capabilities

Just as the proposed innovation strategy must be consistent with and reinforcing of the firm's general strategy, the "ideal" resources and capabilities defined by the practitioner in the next phase of the methodology should be roughly consistent with and reinforcing of the firm's current set of resources. For the case company, the resources and capabilities center on its emerging Tier-One business model and composites fabrication skills.

Based on the author's observations at the firm, company literature, and interviews with company employees, Table 4 groups and provides details on the major resource and capability areas. Those resources and capabilities germane to the innovation strategy are further analyzed in section III.D.3. The major groups of company resource stocks are R&D, engineering, manufacturing, and repair capital. In addition, the company has stocks of human capital that embody the expertise in the aforementioned areas and coordinate them through functions such as human resources and program management. As shown in the table, the major company "flows" of capabilities cluster in manufacturing, engineering, and cross-functional integration. All company capabilities hinge on the company's budding Tier-One abilities to provide full lifecycle solutions for composite aerostructure systems. As mentioned in section III.C.1.a, a few of these Tier-One related resources and capabilities are immature and are classified as "emerging" in the table.

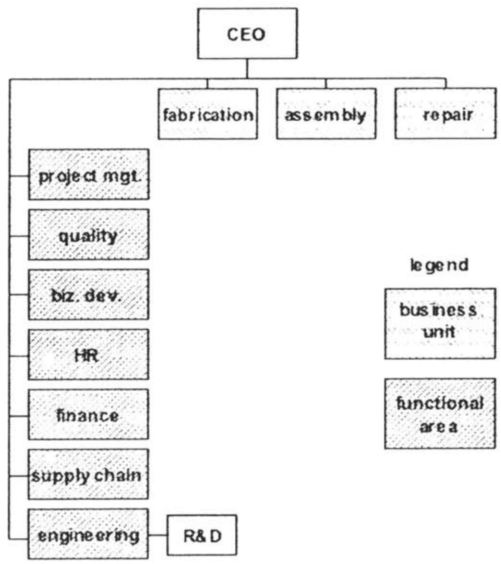
Table 4. Major Resources and Capabilities of the Case Company

Resources	**Detail**
Manufacturing Technologies	• metal forming and bonding • composites processing, mainly prepreg-layup but also liquid molding • chemical processing/finishing • non-destructive evaluation • assembly automation (emerging)
Engineering and R&D	• composites-optimized computer-aided design, engineering, manufacturing (CAx) capital • in-house mechanical, environmental, materials, structural, flight testing facilities • in-house prototyping and material testing facilities
Repair	• in-house composites-optimized repair facilities with regulatory certification
Human Capital	• stock of expertise in composites manufacturing and assembly • stock of expertise in computer-aided design and engineering • stock of expertise in composites repair
Capabilities	
Manufacturing	• ability to fabricate and assemble complex composite aerostructure systems to aerospace-grade quality and competitive cost • ability to introduce and integrate new state-of-the-art manufacturing and assembly technologies (emerging) • ability to design and lead a multi-tiered supply chain (emerging)
Engineering	• ability to collaborate closely with OEMs as part of integrated product teams • sophisticated structural/mechanical design of anisotropic (e.g., non-homogeneous) composite parts • aerodynamics/aeroelastics analysis • electrical/avionics design and analysis • fatigue/fracture mechanics analysis • prototyping and testing
Cross-Functional	• co-located ability to do preliminary design, design and build subcontract, single source manufacture, repair, and refurbishment of aerostructure system

d. Structure

The case company, given that it is the recent merger of two disparate firms that each had dynamic histories, has been through an inordinate amount of restructuring in its operations and organizational makeup. Currently, the operational and management structure (Figure 9) has an interdisciplinary senior leadership team overseeing three business units—assembly, fabrication, and repair—and seven functional areas—business development, quality, finance, engineering, human resources, procurement, and project management—spread out across two sites. Despite the appearance of a cross-disciplinary matrixed structure in the diagram, most employees report to either a business unit or functional group, generally (but not always) with clear lines of accountability. There are a few exceptions to the functional structure, such as the production support engineers that report to both a business unit and engineering. However, the preponderance of functional alliances—reinforced by a "culture of function" described in the next section—potentially constrain the opportunities for cross-functional integration, a key capability for Tier-One suppliers.

Figure 9. Organizational Structure of Case Company



Of the approximately 1300 employees in the firm, the majority are located in fabrication and assembly. The largest functional group is engineering, which encompasses design, product development, and R&D, with around 120 employees. The smallest is business development with three employees. The concentration of resources around manufacturing-centered business units—and the de-emphasis on business development and other functions—showcases more the company's historical market orientation of "build to print" manufacturing than its emerging Tier-One model. As the company moves towards the latter model, it is anticipated that the relative allocation of employees will shift from fabrication- and assembly-related activities to more service- and lifecycle-oriented roles such as engineering services, supply chain management, and repair.[41]

The general managers of each business unit and functional area, along with the CEO, collectively operate as an eleven person 'leadership team' that makes core decisions. On the positive side, the leadership structure facilitates cross-functional decision making at the top level; on the negative side, the structure also tends to lengthen decision response times, as approval is needed from all areas. Several layers of

[41] One consequence of the organizational structure is that it poses a potential "core rigidity" that will affect the choice of an innovation strategy. Such a small allocation towards business development, for example, constrains the ability to execute strategies heavy on market-development activities.

management exist between the leadership team and workers on the ground level, with the amount depending on the functional area or business unit, but the number of levels in the organization averages to around six. For example, in engineering there are upwards of three layers of management between an entry-level engineer and the general manager; a structures engineer working on the analysis of a new project reports to an analyst lead, who reports to an integrated project team leader, who reports to the product development manager, who reports finally to the general manager of engineering, who in turn reports to the CEO.

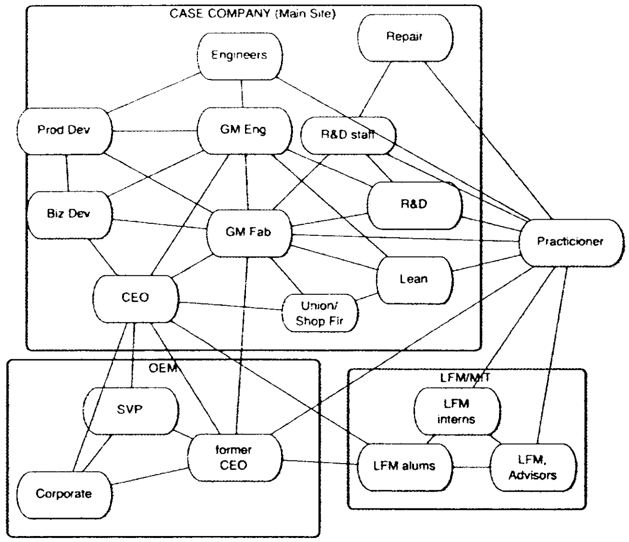
e. People and Values (i.e., Politics and Culture)

Understanding a firm's politics and culture is central to the innovation strategy development process—it helps give the practitioner a more robust view of the firm, and as hypothesized in Chapter II, helps create a more easily implemented strategy. What exactly, though, are a firm's "politics" and "culture"? A company's politics centers on an analysis of its stakeholders: their networks, goals, and struggle to control resources and get things done when their goals conflict. Culture, on the other hand, focuses on a firm's narratives, artifacts, norms, and symbols, and posits that organizations operate through these shared meanings.

From a political perspective, the case company is dominated by external stakeholders, particularly the parent OEM, and the fabrication and assembly business units. Moreover, as is common with most mergers, stakeholders from one former company have emerged with more power—in this case, the former government-run company. To wit, former government-company and parent-OEM managers comprise the bulk of the senior leadership team, with only one person from the former private company on the team as of early 2004. As well, a simplified stakeholder map[42] (Figure 10) from the perspective of the practitioner, a MIT Leaders for Manufacturing intern, shows the dominance of the fabrication business unit, as its GM has the most ties to the various stakeholders both internal and external to the company. Lastly, unions have a strong role within the company, as the majority of the workforce are members and collectively bargain for employment terms.

[42] The simplified map is taken from a more extensive mapping exercise for a LFM leadership class in which the author analyzed his connection with stakeholders in the case company. The nodes represent key stakeholders within the company, and the lines connecting them represent how they are connected—including structural, formal relationships (*e.g.*, one stakeholder reports directly to another) and the author's perception of informal ties (*e.g.*, people who eat lunch together).

Figure 10. Simplified Stakeholder Map of the Case Company



From observations, two cultural features of the case company stand out: the firm's emphasis on production, and its strong functional orientation.[43] As will be highlighted more in one of the case studies in section III.E.2.b, the case company has a strong "culture of production." The company site centers on the physical factory; fabrication and assembly dominate the locale, with disciplines such as design engineering literally off to the side in support areas. Key metrics emphasized to staff are safety incidents and percent on-time delivery of "ship sets." The key initiative by leadership is transitioning to "process-based" management, which posits managerial functions as transforming inputs into outputs using consistent, well-defined methods—literally taking a view that management can be mechanistic and predictable, akin to operating a stamping press. Overall, the case company' culture is manufacturing-dominated; the emphasis is on "making and shipping product" and reinforcing manufacturing norms.

The company also appears to have a strong "culture of function," where people align strongly to their work role—particularly with respect to working on "the floor" versus working in an area such as engineering. In interviews, employees almost universally framed their experiences by their group or business unit in their discussions about the company. In one case, an employee attempting to implement a process change within the factory described having to work in series with four disparate internal groups—engineering, production support, tooling, and the fabrication cell—to affect the change. Also, during lunchtime and breaks, it appeared that people rarely left their work areas or mingled with people

[43] The author wants to make it clear that these cultural observations are value-less; in other words, they are not "bad" or "unattractive" features of the company, but gestalts based on his analysis.

from other areas of the company. R&D staff, for instance, would eat lunch together in the labs, while engineering staff would do the same within their area. In fact, the author personally introduced about a dozen long-tenured people from one site that had never met each other. To its credit, management has tried many initiatives to cross-link people on site, from launching multi-disciplinary "transformation" and "tiger" teams to supporting a company-wide social club. However, the company appears to have a functional culture that is deeply ingrained in its operations.

3. Technology Assessment

a. Materials, Manufacturing Processes Employed in the Firm

The case company has an emerging focus on polymer composite materials. While its metals facilities are advanced—including state-of-the-art CNC machining, stretch forming, and metal bonding—these capabilities are increasingly being de-emphasized. Composite materials in use are aerospace-qualified epoxy resins, carbon fiber, and foam and honeycomb core (for "sandwich" structure composites); limited amounts of glass and aramid fibers are used as well. Overall, the company acknowledges that its "materials allowable" database—materials the company can use with regulatory approval—is quite limited. The dominant composite technology in production, by part volume, is "hand lay up" of preimpregnated (prepreg) fiber in tape and fabric form. More "advanced" composite technologies in limited use on the factory floor include diaphragm forming—essentially a lay-up based technique involving diaphragms that vacuum-form and cure the prepreg within the autoclave, minimizing hand labor—pulforming, resin-transfer molding (a highly automated, low-labor technology where liquid resin is pumped into a pre-shaped, non-crimp fabric "performs"), and co-curing (*i.e.*, curing subassemblies simultaneous to the main structure to minimize assembly steps). Of note, none of these technologies are unique to the company, although the firm does have experience and expertise in implementing them in a production environment. Thus the company has a knowledge base of solving the inevitable problems that arose transferring these technologies from the lab to the floor.

In addition, the company through its R&D group has investigated technologies such as thermoplastic forming (*i.e.*, fabricating parts with thermoplastic resins, which are costlier, heavier, and more expensive, but have a faster processing takt time), thermoplastic welding (*i.e.*, using thermoplastic resins to join thermoset parts), and resin-film infusion—a slow, yet low-labor intensive technology similar to resin transfer molding involving the infusion of film-based resin into preforms. R&D also has performed significant research in composite-based assembly automation; a case study on its automation work is presented in section III.E.2.b.ii.

Importantly, based on its experience with technologies such as resin transfer molding and resin film influsion, the company is developing a strong capability in liquid molding of composite structures. In fact, as of early 2004 the company was beginning a major program of investment in these technologies. The investments in liquid molding technologies, combined with its advances in low-cost automation, will involve the company shifting from the hand lay-up of prepreg tapes and sheets, with hand-based mechanical assembly, to the infusion of resin into large preformed fabrics, creating solid laminate structures with greatly reduced assembly costs. While the company will not own the IP imbedded in these core liquid-molding based manufacturing technologies—and while outside of aerospace, in industries such as automotive, liquid molding is a mature technology—such a liquid-molding manufacturing paradigm will provide the company advanced manufacturing capabilities that could lower its costs (hence increasing its competitiveness in mainstream markets) and possibly provide it with new market opportunities.

b. Systems

In the 1950s and 1960s, when the case company designed and built its own aircraft, it had very strong systems capabilities, including expertise in such fields as avionics and electronics. The company shed most of these systems-based assets in the late 1980s. But as described in the mini-case in section III.E.2.b.i, the company has since re-instituted some of its systems capabilities and now has roughly a dozen non-mechanical or structural engineers, including experts in aerodynamicists, control, and electronics. The systems capabilities are thus relatively small within the company, yet the systems engineers themselves are highly capable—a reflection of the generalist engineering capabilities typical in the case company's home country. In addition to the military retrofit application of its target aircraft platform as described in III.E.2.b.i, the company is dedicating its systems-based resources to its Tier-One business model. For instance, in the design of some proposed large composite structures, its experts are helping integrate non-structural sub-components into the modules and optimizing the modules with other aircraft systems. As the company grows as a Tier-One and develops an innovation strategy, such systems engineers and capabilities should be come increasingly important to the firm.

4. Other Firm Issues: R&D and Intellectual Property

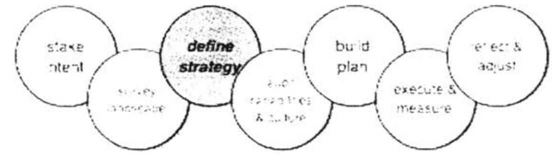
R&D at the case company is highly applied, focusing on developing composite products for OEM customers and implementing "sustaining" composite innovations on the factory floor (such as diaphragm forming and co-curing). In addition, the company's R&D staff collaborates heavily with outside parties, particularly universities, participating in several collaborative research consortia. Through these consortia the company has investigated a few "breakthrough" technologies such as the low-cost automation processes discussed in III.E.2.b.ii.

Overall, R&D expenditures including OEM product development are roughly 8% of sales, inclusive of all design and mechanical engineers. While this number appears to be in the middle of typical R&D expenditures, only 1.7% of the company's revenues, inclusive of external government funding,[44] are spent on "pure" research and development—that is, R&D not related to developing products for OEMs under contract. Both numbers fall towards the low end of the R&D spectrum in the aerostructures market—especially compared with European and Japanese competitors. Moreover, since the IP resulting from OEM product development is typically controlled and/or owned by the OEM itself, the 1.7% number is the proper indicator for the company's level of spending for research that could be the genesis for differentiated products and services.

Not surprisingly, the firm has a strong base of innovative capabilities (which the 8% product development funding would support) but a very small base of protected, unique IP, or a formal IP management plan (*e.g.*, the company lacks a Chief Technology Officer). In fact, the company holds no formal patents, although most of its accumulated knowledge in the area of systems engineering and composite design and fabrication are carefully held as trade secrets. In future, with increasing risk sharing as a Tier One and a stronger innovation focus, IP management should be more important, and it is anticipated that the company will develop a formal IP strategy in the years ahead.

[44] R&D at the company is funded through a combination of internal funding, government grants, external research facilities, a tax concession, and research councils.

D. Define Innovation Strategy

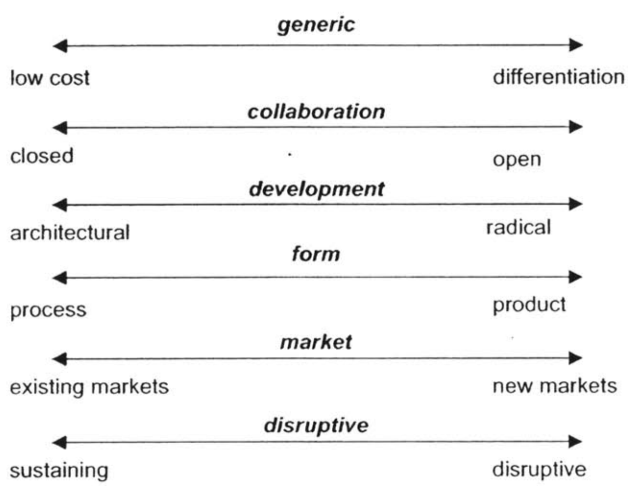


1. Map the Strategic Space

a. Choosing the Innovation Axes

Mapping the innovation space requires choosing decision axes that will provide a meaningful framework for bounding management's strategic choices. While numerous axes could be applicable, this thesis will use six (Figure 11): (Porter's) generic strategy axis of cost v. differentiation; a "collaboration axis" of closed v. open innovation; a "form axis" of product v. process; a "development axis" of applied (or architectural) v. fundamental (or radical); a "market" axis of focus v. diversification; and a "disruption" axis of sustaining v. disruptive.

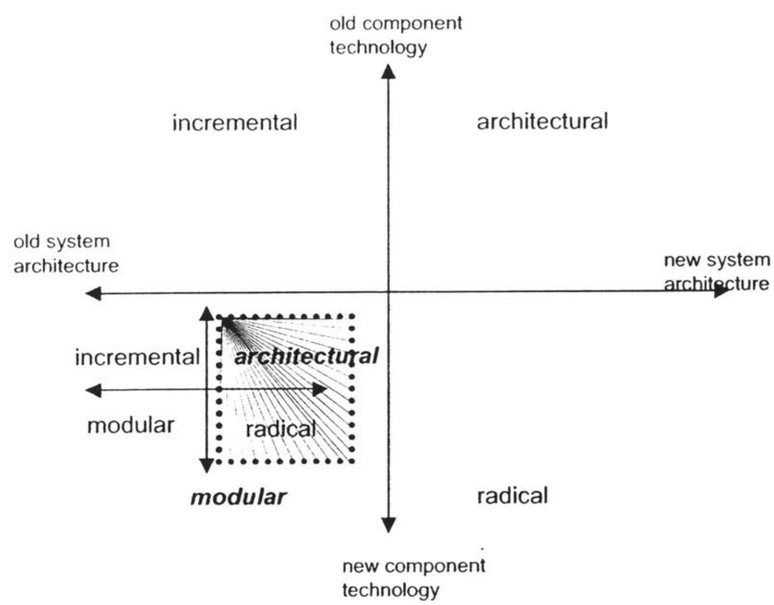
Figure 11. Innovation Axes for Case Company



The generic axis, first framed by Porter (1980) highlights a company's core decision of offering low-cost or differentiated leadership in goods and services. Both, of course, require significant innovation in order to be at the forefront of either strategy. The collaboration axis, discussed extensively by Chesbrough (2003), focuses on a firm's strategy of keeping R&D and innovation-related activities in-house, or opening it to emphasize partnerships. The development axis, borrowing from the Henderson-Clark (1990) framework, examines the R&D development approach from the perspective of inventing new technologies versus seeking established technologies in the market within a larger modular framework (see further explanation below). The form axis looks at the degree to which the company focuses its resources on process (*e.g.*, improving how it fabricates components through new manufacturing equipment or intellectual capital) versus product innovation. The market axis showcases the focus versus diversification dichotomy. Finally, the disruptive axis borrows from Christensen (1997, 2003) and frames the choice of concentrating on sustaining or disruptive innovation.

The framing of the development axis deserves a bit of clarification. Due to the modularity constraint within the industry—*i.e.*, an aerostructures firm has to supply systems within a dominant architecture—the axis assumes choice *within* an overall modular strategy. Taking a radical innovation strategy—*i.e.*, providing a fundamentally new technology and architecture—as a supplier within a mature aerostructures market may not be ideal. Given that the industry is in a dominant design phase, a radical approach such as offering warping wings would likely fail in the short-to-medium term.[45] In this context, the development axis asks: how should the case company develop the modules that it provides to the OEMs? Figure 12 shows the embedded nature of this axis within the Clark-Henderson innovation taxonomy; essentially, the company plays on its system strengths to define new systemic architectures within the modules (lower left quadrant of the big graph), choosing whether to fundamentally innovate (radical) with new componentry or architecturally innovate with existing components (right quadrants of the embedded graph).

Figure 12. Detail of Development Innovation Axis



[45] Even OEMs themselves have had difficulty breaking away from the dominant architecture, such as McDonnell Douglas's attempted introduction of a BWB (blended wing body) design in the mid-90s and Boeing's aborted Sonic Cruiser design of the late-90s.

For the most part, the six innovation axes are independent and orthogonal, forming a six-dimensional (and extremely difficult to represent two-dimensionally) space. Two axes are possibly interdependent, however. The choice of development strategy affects the disruptive axis; while the company could follow a sustaining or disruptive path for an architectural development strategy, clearly it could not choose a radical development approach with a sustaining (or incremental) mindset.

b. Using Industry and Company Constraints to Define the Space

In surveying the aerostructures industry and case company in the last section, clear boundaries emerge that constrain the decision-making space for the innovation strategy. From the industry landscape, several constraints stand out:

- the aerostructures industry is crowded, with over fifty large firms and over a dozen Tier Ones;
- with a dominant design, slow clock-speed technology platforms, and products that are "good enough" to the customer, aerostructures are becoming commoditized, as the basis of competition is shifting from performance to price;
- based on a Porter analysis, the overall profitability and attractiveness of the industry is low;
- companies in the industry, particularly those specializing in composite materials, are squeezed in the value chain by dominant customers and suppliers; and
- suppliers enjoy little intellectual-property protection—the overall appropriability of intellectual assets is strong.

The company's situation presents its own set of boundaries:

- the company is small, with a little over 1% market share, affording few economies of scale or scope;
- it wants to focus its business on composite aerostructures, specifically control surfaces;
- its resources are concentrated in fabrication and assembly, with few devoted to business development;
- it is moving to a new generation of more automated, liquid-molding based fabrication technologies;
- it does not enjoy a competitive advantage in lean manufacturing or labor costs;
- it has strong engineering capabilities, particularly in structures and systems;
- it possesses a fast growing business in repair and service;
- it spends relatively little on R&D that is not related to contracted product development;
- it collaborates heavily with outside organizations such as universities;
- and it has no formal IP protection strategies, *e.g.*, it owns no patents;

Thus, given the six innovation axes, a "space" is defined by precluding regions within them that do not fit the industry or company constraints listed above. For the generic axis, strategies emphasizing low-cost should be precluded. Given the company's cost structure, history with lean manufacturing initiatives, and the entrance of very low cost competitors from Asia, an emphasis on a "sustaining" innovation strategy focused on lowering costs may not fit within the strategic space. A "healthy core business" is clearly important to form a basis of revenues, customers, and capabilities. But given Porter's argument in section I.B and the firm's current mid-cost position, the case company's ultimate innovation strategy needs to reach beyond operational efficiency. Simply, the firm may never be able to "lean" its way to cost parity with very low-cost, heavily subsidized new entrants (a situation many firms outside of the aerostructures industry face as well).

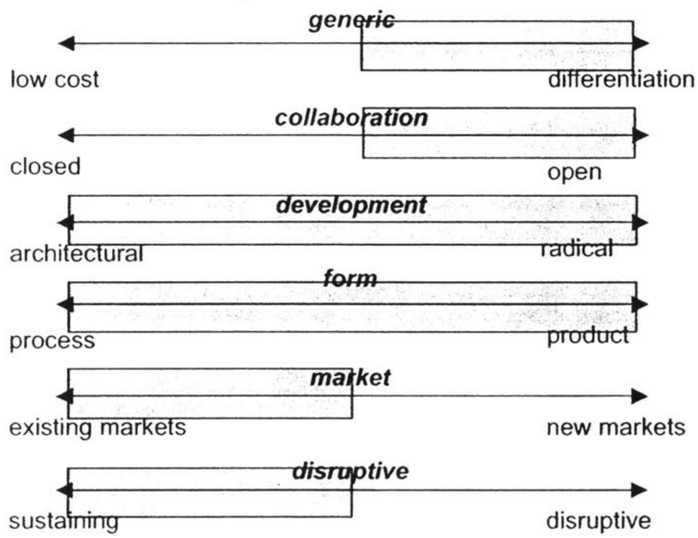
For the collaboration axis, the company does not have the resources to do all research and development in-house, and should emphasize collaboration. Arguably, the industry or company constraints should not affect the choice of development approach or form (process versus product), thus leaving those axes open. The market axes should emphasis focus: an innovation strategy mainly based on diversification into new markets may not fit within the company due to its low business development resources and historical failure in non-core markets. Finally, while the author may personally favor a disruptive approach to innovation, a short-term disruptive strategy may not mesh with the company's current culture of production or low emphasis on fundamental R&D. As well, given the industry's slow clockspeed and highly regulated core markets the opportunity for fast-growing disruptive technologies may be somewhat limited. However, disruptive opportunities clearly exist in emerging markets such as UAVs, as well as non-core markets. Thus, the space should emphasize sustaining innovation, but not preclude the longer-term emergence of disruptive approaches.

Based on the axes and the industry and company constraints, Figure 13 shows the resulting "innovation space" for the case company.

2. Stake Company Strategy

Once the innovation space has been mapped (Figure 13), the next task is to choose a strategic position within it. Ideally, as mentioned in section II.A, senior management leads this step and ultimately chooses the company's strategic position. However, due to the circumstances of the Leaders for Manufacturing internship, senior management was not heavily involved in this stage of the methodology. As a result, for this thesis the author will choose a "straw man" strategy based on his experience that could best position the company for long-term competitive advantage. Figure 14 shows the author's recommended innovation strategy for the case company: high differentiation, open innovation, architecturally focused development, and a mix of products and processes, core and new markets, and sustaining and disruptive approaches.

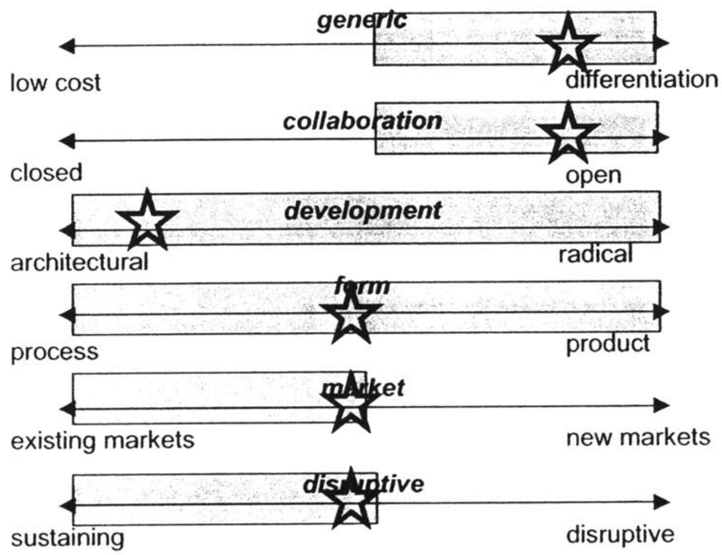
Figure 13. Innovation Space for Case Company



The choice of a highly differentiated position on the generic axis highlights Porter's (1996) claim that a company should push the "boundary" of a generic strategy. In other words, it should aim to be the lowest cost in its industry, or offer its customers the highest level of service or differentiation—points in between do not typically offer sustainable competitive advantage. For the case company, the implication for its innovation strategy is to shift the focus its efforts from lowering the costs of its products—a game the company basically can't win due to its rising labor costs and new entrants—and services to developing unique, customer-valued features. In emerging markets such as UAVs, where the basis of competition is performance, this strategy is self-evident. In the company's mature, core markets, however, where the basis of competition has shifted to price, a differentiation strategy is more difficult. In this light, the company's emerging Tier-One model offers promise. Tier-One end-to-end capabilities may enable the company to focus on providing a unique "one stop shop" of unique control surface solutions combined with novel products along the lines of blended winglets.

With the company's history of partnerships and low internal R&D spend, an "open" collaboration strategy (Chesbrough, 2003), where the company aggressively insources and outsources innovation-related IP is highly logical. Key in this strategy is implementing a stronger IP-management scheme within the company to facilitate the transfer of IP across company boundaries. The emphasis on an architectural development strategy complements the open innovation model as the company focuses on finding novel ways to use existing components in its systems. This "architectural-modular" strategy (as it aims to create new architectures in the modules it provides to OEMs) will require an "innovation factory" approach (Hargadon and Sutton, 2000) applied by firms such as DesignContinuum or IDEO of actively seeking external technologies to use internally—the crux of open innovation.

Figure 14. Innovation Strategy for Case Company



For the form and market axes, a "halfway" point was chosen due to broad opportunities in each area. As an integrated Tier One with an emerging advanced design and manufacturing capabilities, the company should look at innovating its products as well as its processes. Similarly, while the company has a strong base in its core markets and an overall strategy of focus, emerging markets offer strong potential that should not be ignored. These markets in most cases are faster clockspeed, have no dominant design, are high growth, and value performance over price. In essence, products and processes, and core and emerging markets all offer enough "real options" as of early 2004 for the company to continue exploration.

Similarly, the recommended point on the disruptive axis attempts to balance sustaining and disruptive processes. Tushman and O'Reilly (1996) call such balancing an "ambidextrous" approach. As opposed to taking a "middle ground," the organization develops resources for both sustaining and disruptive innovation and actively pursues both paths. Given the case company's history of sustaining innovation, the disruptive innovation-seeking capabilities need to be developed more-or-less from scratch; thus part of the implementation of this strategy, as will be described in section III.F, will involve developing resources for disruptive exploration.

Importantly, as will be addressed in section III.F, the choice of three "halfway" strategic positions will require a careful organizational design and managerial approach (Sorenson, personal communications). In particular, the axes of core vs. new markets and sustaining vs. disruptive approaches suggest a dichotomy where picking a position involves tradeoffs and conflicts.[46] Simply, choosing positions in the middle of the axes is, from an execution standpoint, less efficient than choosing points on the frontier. For instance, with a "midpoint" strategy, what priority should market development give to existing customers if a new, initially less profitable, but faster growing market opportunity presents itself? Or how should the R&D manager prioritize funds towards improving equipment in the factory versus developing completely new, potentially breakthrough technologies? The organizational design for such positions require, in Tushman and O'Reilly's (1996) lexicon, an "ambidextrous" approach. The company must set up structures, processes, and norms that enable—and not dilute—both positions. A simple and common way for companies to execute sometimes conflicting strategies is to create separate business units or structures; for instance, GM has its Chevrolet unit compete on cost, and its Cadillac unit on differentiation, even when both use common engineering and manufacturing resources. For the case company, the answer could be structurally separating the organizational units responsible for sustaining and disruptive innovation and core and new markets; in III.F, for instance, a new, external R&D center would focus on disruptive technologies while the in-house R&D would center on sustaining innovations.

As described in Chapter II, after choosing the innovation strategy the practitioners must check it with the firm's general strategy for fit. If the general strategy can be summarized as ""Tier-One supplier of choice for control surfaces," would the innovation strategy require a change of course for the company? Clearly, there are elements of the recommended innovation strategy that are not perfectly coordinated with the general strategy—particularly the recommendation to look at new markets, which is counter to the company's desire to focus on control-surfaces. But overall, the innovation strategy seems a solid fit that should reinforce the company's Tier-One aspirations and new manufacturing resources. The company already practices open collaboration in R&D (again, though, without a strong IP management scheme) and architectural innovation; as well, it has both innovated in products and processes. A differentiation strategy fits with the end-to-end capabilities of a Tier One, and a disruptive-shift could be a complemen-

[46] However, for aerostructures, focusing on product and process innovation arguably does not involve conflicts—in fact, the two are often so closely intertwined that both are necessary for either to be successful. For instance, innovations in control surface products, such as blended winglets (section III.B.4.b) require innovations in manufacturing processes; composite-manufacturing innovations enabled the geometry, weight, and strength necessary for blended winglets' commercial feasibility.

tary approach to its core incremental-improvement activities to provide a breakthrough in its core markets. Thus overall the innovation strategy appears to reinforce the firm's general strategy.

3. Outline Ideal Capabilities to Execute Strategy

Once the strategic position is chosen, the next step of the methodology is to define "ideal" capabilities required to successfully execute it. As described in Chapter II, this step may be the toughest for the practitioner, as it involves a high level of "art" and largely defies an objective, value-free method of selection. It certainly is likely that there are no one set of "ideal" capabilities for a given strategy, but this thesis's innovation-development framework hinges on a circumstance-based approach. As such, the author hypothesizes that the specific set of resources and capabilities described in this section should best fit the innovation strategy selected in the last section—itself chosen based on the firm's unique collection of industry and company circumstances.

The following list of two resources and six capabilities were selected by the author as a subset of the list in section II.B.2.c, and fit the proposed "litmus test" that each capability should reinforce the innovation strategy. The author does not propound that this is the only "ideal" set of resources and capabilities, but that it would provide a base that would enable the company to execute a highly differentiated, collaborative, architectural-development strategy emphasizing a mix of new and core markets, products and services, and traditional and disruptive innovations.

Resources (stocks)

- *differentiating manufacturing technology*: the company has a unique set of capital and know-how to manufacture composite aerostructures.
- *differentiating design/engineering*: the company has a unique set of capital and know-how to design and engineer aerostructure systems.

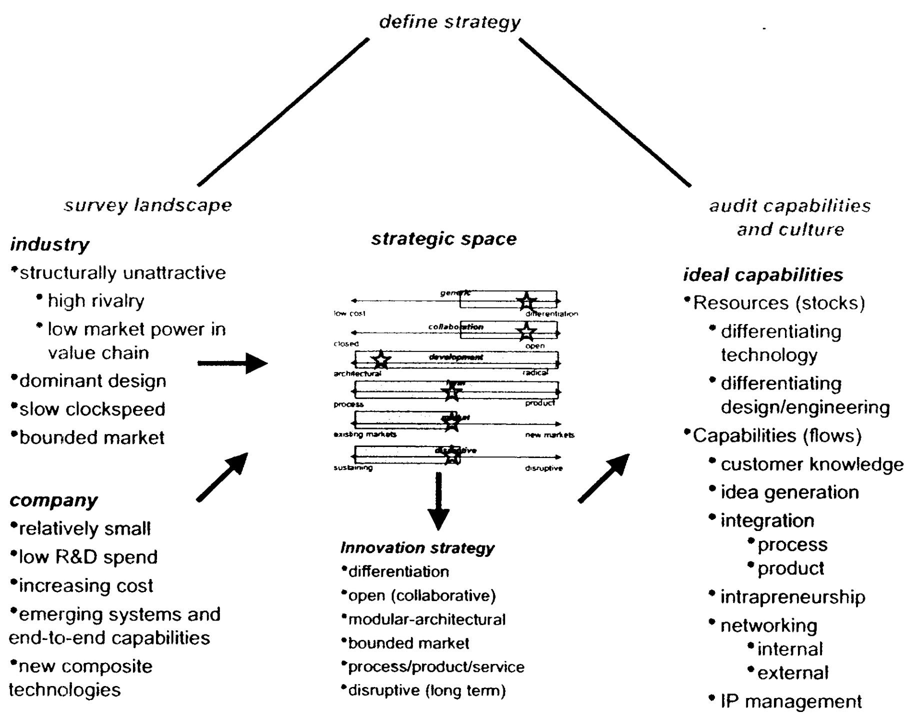
Capabilities (flows)

- *customer knowledge*: the company is deeply knowledgeable about current and future customer needs and can translate them into desirable products and services.
- *idea generation*: the company is able to internally generate ideas for improving operations and for new products and services.
- *integration*: the company is able to integrate disparate knowledge external and internal to the firm in its product development and manufacturing.

- *intrapreneurship*[47]: the company's employees are opportunity-seeking and empowered to create and implement changes that profit the company.
- *networking*: the company has well-connected internal and external stakeholders.
- *IP management*: the company has a strong intellectual property management program, actively seeking external IP for its own products and services and actively protecting and licensing internally developed IP that has more value in external applications.

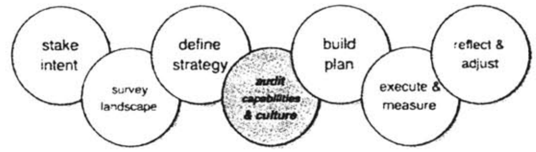
To this point in the methodology, the practitioner has surveyed landscape of the aerostructures industry and the company's history and context; defined strategic axes and an "innovation space" from which management can select a strategy; chosen an innovation strategy within this space that should provide sustainable competitive advantage; and listed a set of ideal resources and capabilities needed to execute the strategy. Figure 15 graphically summarizes the progress to this stage for the case company; the next step is to audit the firm and build the plan to reinforce the capabilities and implement the strategy.

Figure 15. Overview of Strategy Development Framework



[47] I classify intraprenurship as a capability, as a firm can be very 'intrapreneurial' or 'entrepreneurial' without many of the traditional cultural elements associated with it *e.g.*, lack of structure. Kelly Johnson's original Skunkworks in many ways was intrapreneurial in regards to capability but not culture, which was very disciplined and structured. An engineer from Lockheed who worked at Skunkworks summed up its philosophy: 'structure begets freedom'.

E. Audit the Firm



1. Audit Ideal Capabilities

After identifying ideal capabilities for the innovation strategy, the next step is to audit the case company. During the "survey the landscape" module, the practitioner performed an assessment of the company's general resources and capabilities. For the audit, the practitioner digs deeper into the firm and does a "purposeful sample"[48] using various data sources to better understand the firm's relevant capabilities to its strategy.

As described in section III.A., the purposeful sample of the firm's capabilities was biased towards the site location of the internship. The sampling included direct observations, internal company literature, employee surveys, and interviews with employees in R&D, engineering, production support, fabrication (composites), assembly, HR, business development, lean, 'transformation' (interdisciplinary teams focused on internal problem solving), and repair. The levels of employees included several members of senior leadership team, several first-level managers, base-level engineers and scientists, and "award" or hourly employees on shop floor. In addition, the author was able to perform only limited competitive benchmarking due to company budgetary constraints—although the author visited related business units of the parent OEM.

Table 5 summarizes the results of the audit, with a status of either strong, medium, or weak. As listed in the table, the author found both resources to be in medium condition, while two of the capabilities were considered medium and four considered weak. Again, it must be noted that the audit is based on the author's analysis of the data sources above in comparison with a limited benchmarking sample and best practices in the literature, including the studies described in Chapter II.B.2.c. Clearly, with more resources a more rigorous audit based on a multi-perspective, multi-practitioner sample with a more extensive and thorough benchmarking would provide a more meaningful analysis; however, for the purposes of this case study, the author's audit should give a first order analysis of the company's capabilities status.

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[48] Purposeful or purposive sampling is a non-probabilistic data gathering method that is optimal for qualitative research. The practitioner "purposefully" selects a data set to analyze based on his or her research objectives as opposed to taking a random sample, trading a more "objective" view for more rich and focused analysis. While this modular methodology allows for a random sample to be used by the practitioner to audit the firm (*e.g.*, using a survey or randomly selected focus groups), a purposeful sample for this stage of the methodology should give more valuable information—the practitioner can hone in on the relevant capability areas and use a flexible approach to investigating them.

Table 5. Resource and Capability Audit of Case Company

resource or capability	*status*	*description*
Differentiating Technology	medium	strong move to liquid molding, but low fundamental R&D (1.7% sales, all applied) for future research
Differentiating Engineering	medium	strong engineering base but increasing emphasis on disciplines
Customer Understanding	weak	limited customer involvement overall; repair cell deals daily with end customers but not much interaction with other functions or business units
Idea Generation	weak	no formal process or encouragement, few formal "front end" processes
Integration	medium	strength of company, but seemingly done ad hoc, no formal processes
Intrapreneurship	weak	historically strong at one site, poor at other
Networking	medium	strong via R&D, weak outside of market
IP Management	weak	no patents, IP strategy

In the purposeful sample, several observations stood out for each resource or capability that helps explain their status:

Resources

- *differentiating technology*: while the company is about to make large expenditures in a new liquid-molding-based manufacturing technology, it does not own or control this IP. The company has had trouble in the past implementing new technologies into the factory due to weak links among R&D, production support and operations. Fundamental R&D spend is less than its competitors.
- *differentiating design/engineering*: the company does have unique capabilities in systems and aeronautical engineering. However, due to management's reluctance to maintain engineering capacity on staff that is not highly utilized by existing contracts—which tend to require more traditional, less unique mechanical design or stress engineering—it is at risk of losing this strength in the long term.

Capabilities

- *customer knowledge:* staff within the company have good knowledge and exposure of OEM customer requirements, particularly for the units of the OEMs responsible for managing the control surface interfaces. However, employees other than in the repair center (which comprise about 5% of the overall staff) have limited exposure to end customers (airlines and governments) in their core markets, emerging markets, and have no formal processes such as voice of the customer to formalize product requirements.

- *idea generation:* employees overall are creative and showcase high problem solving capacity, but often ideas generated at the ground level are lost within the organizational structure.[49] The company has no formal idea generation and management processes—the company even lacks a "suggestion box" in the factory for minor operational improvements. Employees with high drive and initiative can get ideas resourced, but those who are not in top 5% of innovation find it very difficult to navigate the thicket.
- *integration*: the company integrates disparate elements across the organization and from outside firm boundaries (to the extent that it finds them, see the analysis of the networking capability below) decently well, but lacks formal integrative processes; most integration is seemingly done *ad hoc*. In other words, the company "architects" processes and products well, but does so largely on the initiative of a highly creative employee base, not due to a specific company culture or organizational process.
- *intrapreneurship*: overall, the majority of employees do not take nor are encouraged to take initiative in implementing change within the company, such as instigating and leading new business or engineering proposals. While there are exceptions that the author sought out and documented in the next section, most interviews highlighted the lack of an intrapreneurial culture. Reinforcing this observation were results from a recent employee survey. In response to the statement "I feel encouraged with new and better ways of doing things", 47% answered positively, 30% negatively, and 23% neutral, compared with company home country's average of 64% positive, 17% negative, and 19% neutral.[50]
- *networking*: As discussed in section III.C.2.e, the company has many internal barriers to cross-functional and business-unit communication, but management has deliberately started programs to break down the silos. Externally, the company is very good at networking with universities and government entities, as well as OEMs; however, it is not well connected to firms outside of its industry that could possibly help them innovate. For instance, the author in his work duties at the case company sought out and formed a connection with the head manager of innovation at a major company less than a mile away. The manager led a multi-million dollar innovation center—which case company management was not aware of—that

[49] One engineer, for instance, recounted how four years ago he found promising research into composites health monitoring at an affiliated organization, and recommended that the case company look into it. The idea was "lost in the shuffle" and never pursued; recently an OEM requested help from the case company in that area—and the company lost a promising opportunity in which it could have offered a unique capability.

[50] Intrapreneurship, however, did differ between sites. At the site affiliated with the pre-merger private company, the engineering community had a 50% higher positive response rate to the following two statements: "immediate supervisor encourages me to take appropriate action without waiting for approval," and "encourages to work across organizational and functional boundaries."

had many operational practices relevant to the case company; as well, the manager helped connect engineers at the case company with his own scientists to explore collaborations in manufacturing areas of potential mutual benefit, such as automation. Cross-industry collaboration is critical for the chosen innovation strategy. It is worth remembering that many of the technologies and principles the Wright Brothers' applied in their Flyer were from the bicycle industry.

- *IP management*: The company has no formal IP management or protection schemes outside of specific, standardized clauses it makes in contracts with OEMs. The company, for instance, holds no patents. However, on the positive side, the company is well practiced in protecting sensitive information due to its military contracts and relationships with multiple competing OEMs, so implementing a formal IP management scheme should not be difficult.

2. Interview Lead Innovators: Five Mini-Cases

a. Introduction

As described in Chapter II, in auditing the company the practitioner has an opportunity to seek out lead innovators to explore examples of innovation and change within the company. The idea is to document these cases, search for patterns, and find an "innovation pathway" within the company's networks and culture. This pathway will help build an actionable, achievable plan to implement the strategy and strengthen the ideal capabilities tailored to the firm's culture. If a successful company-specific pathway emerges, the plan should reinforce this path by formalizing it, instituting techniques employed by the innovators for wider use.

This thesis documents interviews with five lead innovators, each with stories of innovation-related change within the case company. The five "mini-cases" comprise a military-product retrofit, a new robotics technology, a repair center, a novel system for a small jet, and inventive "lean manufacturing" machines in the factory. No case is an unqualified success, but all technologies or products are beyond the concept stage and likely or already implemented. Finally, even though the case company remains anonymous in this thesis, most of the technologies in the cases are not formally protected, and thus the documentation below only broadly describes the technology and applications.

The mini-cases below will be presented in a consistent format: an "elevator pitch" highlighting the technical or business achievement, a description of what is innovative about it, its level of success based on

Abetti's (2000) criteria,[51] and a description of the innovation's genesis, evolution, and possible future direction.

b. Case Descriptions

i. Novel Aerostructure Retrofit for Military Application

Elevator Pitch: The innovation is an aerostructure modification to a military application that extends its tactical capability at low cost. The modification is simpler, more refined, and much cheaper than alternative approaches. *Success Criteria*: technical (yes), commercial (to be determined or TBD), financial (TBD).

Major Innovations:

- Uses company IP to develop novel solution for military program
- Employs company's systems engineering and integration capabilities
- Provides "breakthrough" solution as system/control engineering obviates need for complex mechanical system, saving upwards of 80% of cost compared with competitors

Description: The creator of the innovation is a gifted mechanical engineer, with strong complementary skills in electronics and aeronautics, who sought out in the mid-1990s to develop a novel product for the company. The innovator wanted to complement the company's focus on aerostructure components by developing a product that took advantage of the firm's re-emerging "non core" engineering skills such as avionics and aero-elastics and leveraged the company's experience with target aircraft.

The case company (specifically, the pre-merger government entity) in the early 1950s developed a target aircraft platform—ultimately producing 500 units—that had advanced range, control, and maneuverability. The mechanical, systems, and aerodynamics knowledge in this aircraft led to several derivative platforms over the coming decades, including an anti-tank weapon, anti-sub weapon, and advanced decoy rocket. As discussed in section III.C.1.a, in the early 1990s the government sold off this platform when it decided to focus the firm on building aircraft components. At that time, the innovator left the company. A few years later, in the mid-1990s private owners took over the firm and decided to reinstate part of the company's former systems-based assets. The innovator was re-hired, and given permission by management to "explore" new product concepts on his own time while working on in-service support contracts for the company's 1950s-designed aircraft fleet. He had a senior-management champion, moreover, that encouraged his extracurricular activities.

[51] Abetti (2000) lists three success measures for an innovation: a technical success meets the target specifications; a commercial success is accepted by customers; and a financial success has a return on investment that exceeds its cost of capital.

In his own time, the innovator scoured through the company's systems-based IP (which was not formally protected but kept largely as trade secrets) to find technology that could be applicable in the modern marketplace. At first, the innovator tried to re-launch a late 1980s-developed target aircraft platform, derived from the original 1950s platform, that he felt was not effectively sold or exploited by the former government managers. He found a beachhead customer but was politically blocked to sell the product, and the business case collapsed. Next, the innovator looked at optimizing this platform for different customers using advances in electronics to miniaturize the aircraft's systems, providing the original aircraft's functionality in a much smaller package. The key in this strategy was to use commercially available technology, using the original IP base as a modular architecture to apply state-of-the-art "parts bin" components. Facing a tough late 1990s military market, however, the innovator could not muster resources to develop his second proposed product.

Persistent in wanting to launch a systems-based product, the innovator pressed onwards. During a visit to a potential customer for the aircraft, he found a separate opportunity that he felt the company could exploit. The customer had a piece of military hardware that needed range-extension capabilities and was proposing a complicated mechanical retrofit as a solution. The innovator and his team felt the range extension could be accomplished with a much simpler mechanical system utilizing the IP embedded in the company's target aircraft platform. His proposed system would have no additional moving parts and emphasize sophisticated software-based control over more complex and expensive mechanical control.

Based on his insight and experience in his prior two proposed products, the innovator successfully lobbied for support with local government and arranged for a cost share agreement with the company to develop a hardware prototype. He formed a core "heavyweight" team of four interdisciplinary engineers to develop the system. Moreover, he structured the development with a Tier One, systems integrator approach; he had the company focus on aerostructure design and testing, while he subcontracted out the software-intensive autopilot implementation and testing. In the end, the company acted as the prime contractor, engineering the structure, interfaces, electrical design, and general system—all critical, differentiating Tier-One capabilities. The product now is in final testing and has a launch customer (the military of the company's home country). Given the reduction in mechanical complexity, the system is approximately 80% cheaper than competitive solutions and has strong promise in expanding its market share into other countries' military arsenals.

Lessons Learned

- The innovator relied on "emergent" strategy, coming in with a strong vision but showing strong flexibility and persistence in finding a market opportunity.
- The project was initiated and led by strong technical expert and had a senior management champion.
- The project was engineered by a core "heavyweight" team of cross-functional engineers.
- The project was heavily leveraged with outside funding.
- The innovator employed a Tier-One-reinforcing strategy of retaining aerostructure design, manufacturing, testing and systems integration, while outsourcing other areas.

ii. Assembly Robotics

Elevator Pitch: The company has developed inexpensive, automotive robotics for aerospace-tolerance assembly operations (trim, drill) for composites. *Success criteria*: technical (yes), commercial (yes), financial (TBD).

Major Innovations:

- Ties together existing hardware with novel positioning devices and control algorithms to enable "determinant" (*i.e.*, jigless) assembly at low cost.
- Enables aerospace-tolerance assembly operations using 80% cheaper automotive-assembly technology.

Description: In 1999, the R&D group launched an initiative to explore enabling technologies for determinant assembly. The process of determinant assembly relies on CAD-data to digitally align fastener holes in the pre-assembled parts, thus eliminating the need for jigs and fixtures. This assembly strategy enables more flexible, lower cost production and eliminates capital intensive "monuments" that require long production runs to make a profit. However, determinant assembly requires sophisticated robotics, particularly in parts handling, drilling, fastening, and trimming. Such robots developed for the aerospace industry are very expensive and beyond the means of the case company.

The developer of this innovation saw the potential to use low-cost automotive robots in a determinant assembly scheme. The insight was to "trick" the robots through innovative software programming into performing much higher precision operations than they were originally designed to do. In 2000, he formed an in-house "heavyweight" core team, recruiting three outsiders with limited aerospace experience to lead the development. Realizing, as well, that his company lacked the in-house resources to fully develop the full system, he started a collaborative effort with two universities, funded through a government program, to create an end effector for the robot. The innovator enjoyed strong company support, including the championing of a senior manager, and was able to garner around $4 million of funding for his project, with around 40% coming from outside resources.

The development program relied on collaboration with outside entities and a strong, internal, focused core team. In addition to working with universities, the innovator forged collaborations with other firms. Early in the program, the innovator took a tour to assess the state-of-the-art technology in Europe and the US, and struck an informal deal with leading robotics provider to use a key patent. The champion worked hard to keep his core team together during the project, and unlike for most other R&D projects, prevented his staff from getting pulled onto other programs. In addition, the innovator instilled a design philosophy of (in his words) "integration and simplicity," employing off-the-shelf technologies and software tools. In the end, the team met its development objectives on schedule and achieved .002-.001" tolerances—about a hundred times better than what the robots were achieving in automotive applications, at a fifth the cost of a typical aerospace robot.

In implementing his technology onto the factory floor, the innovator has been taking a phased, beachhead strategy, targeting the "dirty" areas of the plant (such as drilling, which creates a lot of carbon dust) for the first robotic applications. Future applications have been mapped out years ahead, and could serve as cornerstone of new company capabilities in flexibility and low-volume production.

Lessons Learned

- The project was initiated and led by a strong technical expert and employed a small core "heavyweight" team.
- The innovator used off-the-shelf components in novel ways and employed a simple design philosophy.
- The project had strong support from senior management.
- The innovator aggressively collaborated and insourced IP.
- The team worked at an early stage with production support and factory.

iii. Repair Center

Elevator Pitch: The case company offers state of the art repair of large aerostructures, leveraging its technical capabilities to enter the rapidly growing MRO (maintenance, repair, and overhaul) market. The fully certified repair center specializes in composites and metal bonding. It does a variety of civil and defense work, including the repair of spoilers, flaps, rudders, kruegers, ailerons, slats, fairings, engine cowls, landing doors for civil applications, and flaps, canopies, windshields, drop tanks, gun bay doors, radomes, and pods for military customers. *Success Criteria*: technical (yes), commercial (yes), financial (yes).

Major Innovations:

- Leverages the case company's engineering and manufacturing capabilities to enter the fast growing services market
- Creates new, on-the-spot solutions for difficult repairs, requiring novel problem solving methodologies, in a highly regulated environment
- Develops new capabilities in customer responsiveness while entering a much friendlier market, from 50 global competitors in the main aerostructure industry to 3 service providers in the regional repair market

Description: Since the early 1990s, airlines had been asking the pre-merger companies to offer MRO services. Local airlines at the time had to get aircraft structure repair done at remote companies, and wanted the company to offer its more convenient facilities for repair work. One airline in the early 1990s, for instance, offered the company a $10 million (US) contract to install new galleys on its airline fleet. Management, desiring to focus on composite aerostructure fabrication, declined to go into this business.

However, the company soon had no choice but to enter the repair business. In the mid-1990s, a company-designed composite "sandwich" structure for a major OEM developed a water ingress problem in service, causing face-sheet delamination. As part of the contract with the OEM, the company had to take back the parts and perform repairs. A customer from the local military saw this work during a visit to the factory and asked if case company could do repairs for his fleet. This time, management acquiesced. As part of the military work, the company had to repair commercial platforms modified for military use, such as the Boeing 707 and 767. A major airline, in turn, saw this work, and renewed its interest in having its own aerostructure repair work done for similar craft. At this time, in the late 1990s, management saw the larger opportunity, and created a full-blown MRO service as a business unit. The repair unit obtained FAA, CASA, and JAR certification, and has grown rapidly since then, enjoying a 100% CAGR in revenues with high margins. Emphasizing its tie-in to its parent OEM, it positions itself as "OEM certified Aerostructure Solutions at lower cost," offering a significant cost advantage to Airbus or Boeing-done repairs and a significant quality upgrade to the main independent repair firm.

The repair business has evolved into a unique position within the company, dealing directly with the end-customer (airlines in the military) in a very fast-paced, dynamic environment. Taking advantage of marketplace drivers include reduced airline in-house repair capacity, an industry-wide backlog of maintenance, and fleet that is in the air longer, the business addresses a potential market of 1200 regional aircraft served by only three major certified repairers. It has to perform often difficult composite and metal repairs with a fast turn-around time—as aircraft in repair are not earning revenue—leveraging many of the engineering and manufacturing capabilities of the case company, but in a faster "clockspeed" environment. By the dictates of federal regulations, the repair business operates separate to the main factory, employing its own team of engineers and repair specialists, and has developed its own unique culture. As a result, the business unit has adopted a highly flexible, intrapreneurial approach to repair. In theory, by helping the mainline organization "learn" from the repair culture, management could help the overall innovation-related capabilities of the company. Allowing the emergent culture to flourish while exposing production-related employees to it (*e.g.*, through rotations) could provide a positive, reinforcing feedback with the company's main-line engineering and manufacturing activities.

However, the "culture of production" currently dominant in the company seems to prevent a better synergy between the repair center and the mainline manufacturing business. Several interviewees in the fabrication side referred to the repair center employees as "cowboys," and even repair center managers admit they operate "right at the limit that the (parent OEM) will tolerate." Based on observations and interviews, it appears that the culture of production is domineering a needed "culture of service," which requires a flexible approach to solving problems, scheduling operations, and decisionmaking. To that end, company management has recently made the repair shop conform to manufacturing-based process standards, such as "go/no go" process-criteria for taking on new work. For the repair center's first three years, employees were able to authorize jobs up to $100,000 for customers if not deemed a significant risk; now, all jobs must go through a standardized, manufacturing-optimized decision process that has to be reviewed by senior management. As a result, decisions that make sense from a "service" perspective—such as taking on an unprofitable short-term repair for a favored customer, in anticipation for a longer-term relational contract of a profitable stream of work—are being overridden by manufacturing criteria.

An ongoing challenge for the repair center—a business model innovation for the company that puts in a faster clockspeed market in direct contact with end customers—will be meshing it with its mainline engineering and fabrication businesses. Clearly, the repair center is developing complementary capabilities that can help the company as a Tier-One supplier and developer of innovative products and services.

Lessons Learned:

- The project developed a new "culture of service" that is dynamic, customer focused, quick turnaround, employing at times very creative solutions in highly regulated market.

- The project innovated by effectively utilizing company capabilities, but separating out of mainstream environment.
- The project was opportunistic, based on warranty work for a design flaw that cascaded into a profitable business.

iv. One-Piece Composite Aerostructure

Elevator Pitch: The innovation is a one-piece composite aerostructure component solution for a small jet, the first time composites were employed in that application. *Success Criteria*: technical (yes), commercial (yes), financial (no).

Major Innovations:

- Employs product design that is highly differentiated within the industry
- Showcases a strong collaboration among manufacturing, materials development, and product design

Description: In the mid-1990s, senior leadership from the former private-run pre-merger company created a "Customer Creativity Center" (CCC) of six staff, led by the champion of the one-piece innovation. The CCC was organized as a "heavyweight" team, with experts in manufacturing, design, tooling, and planning working closely together to develop early-stage product concepts. The team sought market opportunities, bid on contracts, and developed rough prototypes of product concepts. The CCC was highly successful for the company, as it created creative solutions for aerostructure systems, and ultimately won the contract for the small jet application over eight competing suppliers based on its innovative (and not lowest cost) approach. This opportunity arose from a late-stage development problem encountered by the developer of a new small-jet platform. The jet suffered from a significant aft center of gravity problem, and the OEM needed to develop a new tailcone that had less mass. Standard tailcones were made of stainless steel or blends of titanium and stainless. The challenge was to make the tailcone lighter, and polymer composites offered promise—but the materials were fire-prone.

For the OEM, the CCC designed a composite tailcone that was not only fireproof but also formed from a single-piece. The complex design employed integrally stiffening structures (*i.e.*, using geometry as opposed to intrinsic material properties for stiffness) plus flexible mandrels in the tool. The innovators fireproofed the structure by borrowing a technique used in the building industry and qualifying it for aerospace. The innovative design won the OEM contract. Subsequently, the development program met all its technical goals, and the system is currently in production. However, the program has faced financial disappointment due to start-up difficulties with a tier-two supplier, which the company had to replace with a higher-cost firm that increased the program's costs. Thus, the project as such not only serves as a case in company innovation but as an early lesson in managing a Tier-One supply chain.

Lessons Learned

- The innovation was led by a technical expert and developed by a highly integrated, cross-functional "heavyweight" team.
- The program enjoyed strong senior management support.
- The program looked outside the industry to find ideas relevant to its application.
- The program developed a novel technical solution, but ran into problems with its supply chain implementation.

v. Lean Manufacturing Assembly Tools

Elevator Pitch: Shop floor technicians developed assembly tools employing lean principles that facilitate big reductions in assembly labor hours. *Success Criteria*: technical (yes), commercial (yes), financial (TBD).

Major Innovations:

- Employs simple concepts and off the shelf components at very low overall cost to automate repetitive tasks

Description:

At the behest of the case company's parent OEM, the company began a lean manufacturing initiative in the late 1990s. Management created a dedicated, stand-alone lean manufacturing group that introduced concepts such as kanban "pull" inventory systems to the factory floor. In addition, this group periodically analyzed portions of the factory to redesign the workflow and equipment to lean principles such as "right sized" equipment, one-piece flow, rapid changeover/low setups, equipment versatility, and takt-time paced production. For these redesigns, this group held intensive, professionally facilitated workshops involving a mixture of engineers, factory workers, and lean experts. The facilitators—Japanese consultants with expertise in the Toyota Production System—led the teams through exercises such as value stream mapping and process re-engineering. For the re-engineering, the facilitators ran an accelerated, creative process development program emphasizing problem identification, decomposition, looking to nature to find solutions, pattern-identification/consolidation, and then rapid prototyping (what they call "trystorming") of multiple solutions.

Out of two of these re-engineering sessions came simple, inventive assembly machines that showcase many of the innate innovative capabilities of the company. Both machines were co-designed and built by workers on the factory floor who identified opportunities to replace repetitive, fatiguing hand labor with simple semi-automated assembly processes. The machines are examples of architectural innovation, utilizing off-the-shelf components (such as a bicycle chain and cog set) to save costs. In fact, both machines cost only a few thousand dollars to make (comparable semi-automated drilling and countersinking machines cost upwards ten times more) and were made completely in-house. In implementing the designs, the lean group did risk assessments, reliability tests, preventative maintenance schedules, operating procedures, and training programs before fully integrating them into the factory. Both save significant time for operations. One machine has cut the drill time for a hole by 60%, and overall cycle time for the operation by 20%. More importantly, as "bottom up" innovations designed to make assembly work easier, they have received strong support on the floor. According to the cell leader responsible for the machine, the machine has led to "(workers) arguing to do countersinking instead of trying to get away from it."

Lessons Learned

- The innovations were developed by a highly integrated, cross-functional "heavyweight" team, including people on the factory floor.
- The programs employed creative front-end processes to create the innovative solution.
- The innovations integrated off-the-shelf componentry in novel ways.
- The innovations were "pulled" from real problems inside the factory

c. Pattern Identification within the Cases

What patterns, if any, emerge from the cases? From the case descriptions and lessons learned, Table 6 summarizes the cases across several perspectives: the type of innovation; how the idea for the innovation was generated; which part of the organization led the development; how the development team was structured (*e.g.*, heavyweight, autonomous, lightweight, or functional); how the project was funded; whether the innovation was planned (deliberate) or opportunistic (emergent); how senior management was involved; the level of experimentation employed in the innovation's development; how much the customer was involved in the development; and the general fit within the overall firm's culture.

Table 6. Summary Analysis of Innovation Cases

	Military retrofit	Low-cost Automation	Repair Center	One-Piece Aerostructure	Lean Machines
Stage	Final testing	Final testing	On the market	On the market	Implementation
Type of innovation	Architectural	Architectural	Business	Architectural	Architectural
Idea/concept generation	Bottom up/ customer	Bottom up/outside	Customer	Customer/bottom up	Bottom up
Leadership	Technical	Technical	Business/Technical	Technical	Technical
Core development team	Heavyweight, x-discipline	Autonomous, outsiders	Autonomous, outsiders	Heavyweight, x-discipline	Autonomous, x-discipline
Investment	~$4M External/ internal	~$4M External/ internal	~<<$1M Internal	~?, Internal	Negligible, Internal
Strategy development	Emergent	Hybrid	Emergent	Deliberate	Hybrid
Sr. mgt. involvement	Champion	Champion	Champion	Champion	Minimal
Level of experimentation	High	High	High	High	High
"Customer" involvement	High	Low	High	High	High
Capabilities fit	High-aerostructures, systems	High-manufacturing, systems	High-aerostructure, design,	High-aerostructure and systems	High-manufacturing
Cultural fit (practice)	Low-non core market	High-lower labor costs	Low-business model	Low-non core market	High-lower labor costs

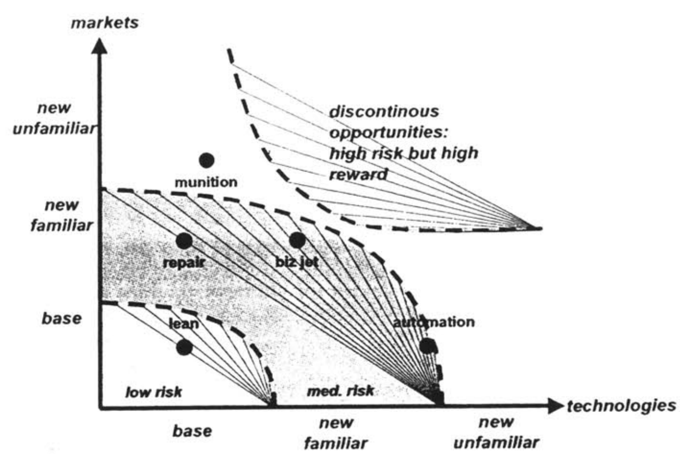
From Table 6, a case company "pattern" of innovation emerges:

- All cases were successful in meeting technological criteria, most were successful in commercial criteria, yet only one has had financial success to date (one has not been successful, the other three are "to be determined");
- All cases had ideas generated from employees or outside parties (customers or affiliate organizations) as opposed from "top down";
- Four of the five cases employed architectural innovation;
- All projects had low investment requirements, with two obtaining external funding;
- All cases had technical leadership (as opposed to, say, financial or marketing leadership), and had high levels of experimentation and prototyping;
- Three of five had autonomous teams, the other two were heavyweight;

- Four of five had emergent or hybrid (*i.e.*, elements of both deliberate and emergent) strategies;
- Four of five had senior management involvement and high levels of end customer involvement (two are more "push" projects); and
- Three of five had poor fits with the company's core business model.

Furthermore, the projects show a strong similarity in their level of risk. Abetti (2000) created a framework for project risk based on a composite of market and technological factors. He classifies technological and market risk into three categories: base, new familiar, and new unfamiliar.[52] Figure 16 plots the five cases against the technological and market risk axes. The risk isoquants (regions of equivalent risk) are shown in dotted lines; the farther out from the origin, the greater the risk.[53] The discontinuous opportunities (similar to Christensen's disruptive classification) are in the upper right region of the graph and represent the high risk/high reward projects most associated with "breakthrough" innovations. The projects at the case company tend to cluster in the "medium risk" area, with a roughly even spread of market and technical risk. The level of market risk in the projects—including the arguably successful repair and retrofit projects—is somewhat surprising considering management's explicit strategy of market focus. However, the major takeaway from Figure 16 is that the medium level of project risk highlights the general tolerance of the company, even for innovative projects.

Figure 16. Technological and Market Risk of Innovation Cases



[52] "Base" implies the use of technologies embedded in existing products for technical risk, and marketing to existing customers for market risk. "New familiar" implies technologies researched within the company but not yet in its products for technical risk, and serving known but currently unserved customers for market risk. Finally, "new unfamiliar" implies the use of technologies not researched within the company for technical risk, and marketing to new customers for market risk.

[53] As well, the isoquants tend to skew towards the market risk axis, as Abetti feels that market risk for a given level of familiarity is more uncertain than technology risk.

d. Innovation Pathway

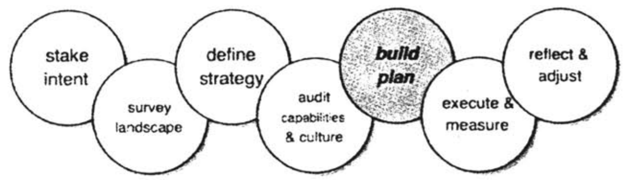
From the patterns identified in the cases, an innovation pathway for the company emerges. An innovation plan (proposed in the next section) should strongly utilize this pathway, using its lessons to strengthen the firm's ideal innovation capabilities and building formal mechanisms to aid the development of future innovations. The pathway implies that within the case company, successful innovations:

- Have "bottom up" or customer generated ideas;
- Employ heavyweight, focused, interdisciplinary teams led by engineer or technology expert with strong knowledge of technology;
- Have strong support from senior leadership;
- Focus on emergent strategy (*i.e.*, business cases need to be open ended and opportunistic);
- Have heavy levels of experimentation/prototyping/trystorming;
- Have low costs and leverage external funding;
- Have a very strong capabilities (but not necessarily business model) fit to the company; and
- Tend to be low-to-medium risk.

Many of the pathway's lessons match "textbook" factors for innovation success. Abetti (*ibid.*) for instance lists support from senior leadership, a strong match of capabilities, strong market coupling, strong technology expertise within team, commitment of resources, a low to medium risk perspective, and adherence to company strategy among his eleven success factors. However, while the factors in the firm's innovation pathway are certainly not unique, the combination of them is. The patterns that emerged through the documented mini-cases showcase how to successfully navigate through the company's unique strategic, political, and cultural environment. The proposed innovation plan that follows aims to "pave" the pathway laid down by the company's innovation pioneers, reinforcing its lessons to create more formal, lasting mechanisms that should facilitate a higher volume of innovative products and services in the future.

F. Building the Innovation Plan

1. Propose Solutions to Fill Capability Gaps



Finally, now that the firm's innovation capabilities have been identified and audited, and its local innovation culture mapped, the next step is to build a plan to fill the capability gaps and reinforce the innovation pathway. As discussed in section II.B.3.c, the practitioner has many options for creating the plan.[54] This thesis will propose specific solutions to address each capability gap identified in section III.E.1 (and summarized in Table 5), group the solutions into packages, and then rank them on relative cost, timing, and their fit with the local innovation culture. The rankings are based on the author's first-order estimates; a more rigorous exercise could involve a planning team employing more formal tools such as GANTT, CPM, or ToC frameworks for resource projections and full capital budgeting proformas for financial estimates. However, the first-order estimates should suffice for the purposes of this thesis.

Proposing effective solutions presents similar problems to the earlier exercise of forming an "innovation space" and listing "ideal" capabilities—the subjective nature of the task precludes an overly-formal and mechanical approach. In a similar manner to proposing ideal capabilities with respect to the circumstances of the firm, this thesis draws upon best practices and the literature to propose solutions for strengthening the firm's capabilities. The solutions are summarized in Table 7.

[54] While planning is often considered a formal or "deliberate" exercise, methodologies exist that encourage "emergent" strategic execution. One methodology, described by Christensen (2003), called "discovery driven planning," is compatible with an emergent approach. This method involves creating long-term targets, outlining the factors and assumptions required to meet those targets, and then creating a "plan to learn," testing these critical assumptions and adjusting them as necessary as the company moves forward.

Table 7. Solutions to Strengthening Capability Gaps

resource or capability	*status*	*proposed solutions*
Differentiating Technology	medium	a. creation of Chief Technology Officer, responsible for technology road mapping, benchmarking, and resource allocation to differentiating projects; b. shifting of a portion of R&D spending to higher-risk (*e.g.*, radical or disruptive) projects, as opposed to current bulk of allocation to low-to-medium risk innovations. c. creation of R&D team dedicated to investigating disruptive technologies
Differentiating Engineering	medium	d. offering of engineering services for products outside of the company's core market offering similar design challenges.
Customer Understanding	weak	e. integration of mainline manufacturing and engineering business with repair center—which deals directly with airlines and military customers—within regulatory constraints. f. implementation of formal, regular procedures for market analysis, environment scanning, and futuring
Idea Generation	weak	g. implementation of formal process to solicit, develop, and resource new ideas from within the staff and closely aligned external parties h. creation of formal innovation champion and innovation site team
Integration	medium	i. implementation of integration-fostering formal design and engineering processes, such as TRIZ
Intrapreneurship	weak	j. creation of incentives for management to support for risk taking k. formalizing of linkage to parent OEM internal venturing group
Networking	medium	l. formal encouragement of internal networks, through the creation of technology and social clubs m. creation of external linkages to non aerostructure firms
IP Management	weak	n. creation of Chief Technology Officer, responsible for management of intellectual property portfolio

For strengthening the differentiating technology capability, two solutions could be helpful: the creation of a Chief Technology Officer (CTO) role on the senior management team, and the formal allocation of resources towards disruptive or higher-risk activities. While leadership has undertaken technology-strategy related activities over the past few years, currently no senior manager on the leadership team has formal responsibility for managing the firm's technology portfolio. The CTO would be responsible for benchmarking competitors, creating technology roadmaps for the company, and ensuring a balanced resource allocation based on the desired mix of projects. In that vein, a formal allocation towards higher risk projects could be beneficial to the company. As discussed throughout this chapter, the case company's innovation strategy—and overall strategy—hinges on technology differentiation, and differentiating among fifty strong global competitors requires the investigation of "cutting edge" products and processes.

However, the company's current business model tends to disfavor "filter out" potentially disruptive, higher-risk technologies. First, the company spends, as mentioned, a relatively low level on non-OEM contracted R&D, and this R&D spend is almost exclusively geared towards sustaining, near-term innovations. Second, for new ventures (such as the innovation cases discussed in III.E.2), the company uses what it calls a "wrap rate" the average cost of an employee-hour, based on taking the company's overall costs and dividing it by its overall headcount—when charging employee time. The company's average cost pricing of labor disincentivizes new, higher-risk business opportunities by burdening them with a high cost structure. Compounding this is management's insistence on a two-year payback for all R&D and new venture products, essentially requiring not just a cost of capital of over 40% (which is likely much greater than most of it's projects' cost of capital), but also a short-term positive cash flow. As a result, the company's resource allocation models significantly disfavor the investments necessary for providing a long-term differentiation capability. A fixed allocation of funds towards disruptive projects—*e.g.,* a fixed percent of revenue per year, without near-term payback requirements with labor priced at marginal, not average, cost—could be one solution. Another could be a "disruptive team" within the R&D group that would be dedicated to researching disruptions through architectural (*i.e.*, integrating off-the-shelf components or processes in novel ways) disruptions. More on this specific strategy is detailed in Appendix B.

For increasing the differentiating design and engineering capability, the company could begin to offer engineering services. Currently management, desiring to focus its resources on its core OEM customers, is under pressure to justify keeping its underutilized systems engineers on staff. The company would solicit projects outside its core markets, though fitting with its core structural and systems-based capabilities, to maintain a systems-capability even when the bulk of its mainstream engineering work is for control surfaces design and engineering. This strategy is employed by Porsche Engineering, which not only does work for Porsche and also other automakers but also has designed forklifts, wind turbines, and bicycles. Taking on outside projects would not only enable the company to maintain a systems capability but also expose the engineers to other industries, potentially giving them ideas they can bring into the core business. The Wright Brothers, for instance, used insights from bicycle design to engineer their first airplane.

For increasing the customer knowledge capability, a fruitful solution for the firm could be better utilizinhg its own customer-linked assets. In undertaking the second audit of the company and documenting the repair center (section III.E.2.b.iii), the author discovered that the repair business unit within the firm that has daily contact with the end customers of its products: airlines and military procurement personnel.

However, this interaction is largely compartmentalized within the business unit and not leveraged for generating new ideas within the engineering and manufacturing arms. Better integrating the mainline businesses with the repair center—*e.g.*, through more aggressive employee rotations, inviting engineers and assembly workers into customer meetings, etc.—could help unleash this currently underutilized customer knowledge base. As well, the under-resourced business development group lacks resources to do regular, formal market analysis, environment scanning, and futuring exercises. Funding and implementing regular market-research activities that investigate, say, the seven areas of opportunity in Drucker's "Discpline of Innovation" (1985), or holding regular scenario planning activities could be of great value to the company in helping it better understand its core markets and new opportunities.

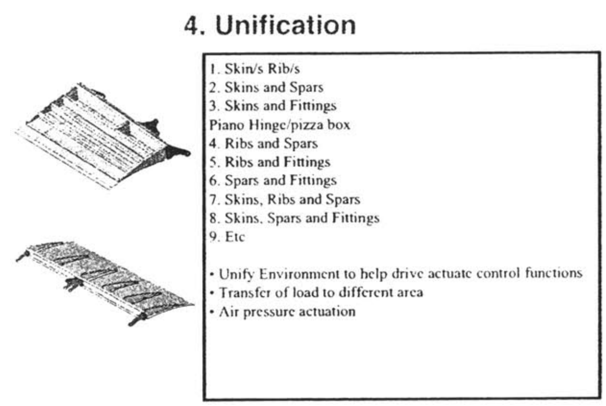
A solution to strengthen the idea generation capability that is commonly applied throughout industry (Von Stamm, 2003b) is a formal process to generate, downselect, and nurture ideas within the staff. Many strong ideas, without a formal lack of support, can get lost within the formal networks of an organization. Such an "idea development" process can be relatively simple, like an employee suggestion program, or it can be more elaborate, following a stage-gate process with rigorous gates and go-no go decision points.[55] However, von Stamm (*ibid.*) reminds us that it is important that such a process "should not become end in itself...if applied to strictly and rigidly it can hinder the development of new processes." The idea is to encourage strong flows of ideas, with rapid processing, logical filtering, and high levels of iteration and feedback. To facilitate the idea development process, a formal innovation champion or even site team (*e.g.*, staffed by employees given an hours allocation to focus on innovation-related tasks) can be employed to run the program and mentor the employees as they develop their ideas.

To help bolster the company's integration capabilities—clearly showcased by the architectural innovations in the case studies in III.E.2.b—the company could employ formal techniques and front-end processes to aid its employees' natural integrative insights and talents. Engineering, R&D, and product development could allocate a portion time at the front end of all products to enable such creative work. Several front-end processes exist that could aid the company in formal architectural and integrative innovation. For example, the lean process-development workshops described in III.E.2.b.v employ such techniques, but are currently not employed within engineering. As well, techniques such as TRIZ and related "structured creativity" methodologies can help engineers and designers formally employ integration into their work (Mann, 2001; Goldberg, et. al., 2003). TRIZ is the theory of "inventive problem solving" that tries

[55] Moncada-Paterno-Castello, et. al. (2003) for instance describe a very formal methodology by the Joint Research Center of the European Commission that "facilitates planning at all stages of the innovation process", with strong filtering and early market analysis. Patterson (1999) also takes a very process-heavy, mechanistic view (based on an assembly line process) for his idea development process, which he calls his "innovation engine."

to formalize and systemize innovation. Based on a Russian scientist's study of two million patents to find system-based patterns and commonalities, TRIZ posits a very small number of inventive principles that govern most innovation. For instance, when looking at a new project, engineers and designers decompose the functions of the proposed process or product, and identify "contradictions" among functions—e.g., an airplane part has to be strong and light. Then, engineers can examine how similar contradictions have been solved in other applications for integrative ideas. As well, engineers examine whether the elements can be subtracted, multiplied, divided, or unified, creating a new innovative architecture. Figure 17 shows some of the results (specifically, the functional unification brainstorm) of a TRIZ session the author organized during the internship with case company engineers to investigate new innovative architectures for a generic control surface product. While proven to be effective (*ibid.*)—*e.g.,* advanced multi-blade razors that "multiply" the number of razor blades and slim-line DVD players that "subtract" the display are TRIZ-related examples—this thesis does not explicitly recommend TRIZ; what is important is for the company to allocate resources, and processes, that facilitate integrative engineering and design.

Figure 16. Application of TRIZ-based Methodology to Flap Design: Task Unification



Solutions for strengthening the remaining capabilities are relatively straightforward. The level of intrapreneurship can be improved by encouraging management to support employee venturing and risk taking. Incentives could be based on management performance as measured by the employee survey, which tracks staff opinions on measures such as how the company tolerates failure and encourages new ideas. As well, the parent OEM has an internal venturing group (which this thesis is precluded from discussing in detail due to confidentiality issues) that has programs that aid employee entrepreneurship, such as business plan competitions for exploiting company IP. Corporate venturing programs such as Lucent's New

Ventures Group (Chesbrough, 2003) have been successful not just in leveraging company intellectual property, but also in helping foster an intrapreneurial environment within companies.

For strengthening the networking capability, the company should consider programs to foster internal and external networks in the company. Internally, hobby and technical clubs could unite people from different functions and business units in areas that could help the company innovate; for instance, the author found at the company "underground" and informal groups of employees across functions experimenting with new materials and products on their own time. Formalizing these groups could not only help interlink employees but also help the company foster an intrapreneurial, experimental, and creative environment.

Finally, for IP management, the CTO position mentioned earlier could also be in charge of a company IP portfolio and strategy. The CTO would be in charge not only of managing the company's IP—including a protection strategy—but also coordinate with external networks, business development, and R&D to look at insourcing and outsourcing IP with external parties in an "open innovation" agenda. Given the company's skills and importance of architectural innovation, licensing external IP—such as in the automation case in section III.E.2.b.ii—will be increasingly valuable.

2. Grouping and Prioritizing the Solutions

The solutions proposed above show several interdepencencies and some redundancies, suggesting that they can be grouped together into "meta" solutions. The author grouped the solutions summarized in Table 7 and described above into four themes:

- ***front-end focus***→(g) formal process to gen/downselect ideas + (h) innovation champion + (i) TRIZ methodologies + (l) informal networks
- ***new R&D***→(b) funding channel for differentiation + (c) disruptive engine + (m) external linkages
- ***open innovation***→ (a,n) CTO/IP strategy + (k) internal venturing + (j) managerial incentives
- ***new markets***→ (d) engineering consulting + (e) integration with repair + (f) market exploration

Each group—front-end focus, new R&D, open innovation, and new markets—represent a collection of highly aligned and reinforcing solutions that, collectively, should help strengthen the company's ideal capabilities. All could arguably be implemented. However, the list of proposed solutions is long. With limited resources and time, the company may need to prioritize its actions, implementing the most effective or powerful groupings first. Accordingly, the author performed a quick ranking of these groups according to four equally weighted criteria: the estimated cost of the program, the time to completion, the fit within the company's culture, and the estimated impact to the company's overall innovation strategy. The results are shown in Table 8. Clearly, these rankings are subjective, as the categorical rankings are hard, if not impossible, to objectively measure, and one could argue a variety of weightings for the categories. However, the relative rankings—front-end focus the highest, followed by open innovation, then new R&D, and finally new markets—appear to be logical and consistent with the methodology in Chapter II.

Table 8. Ranking of Solution Groups

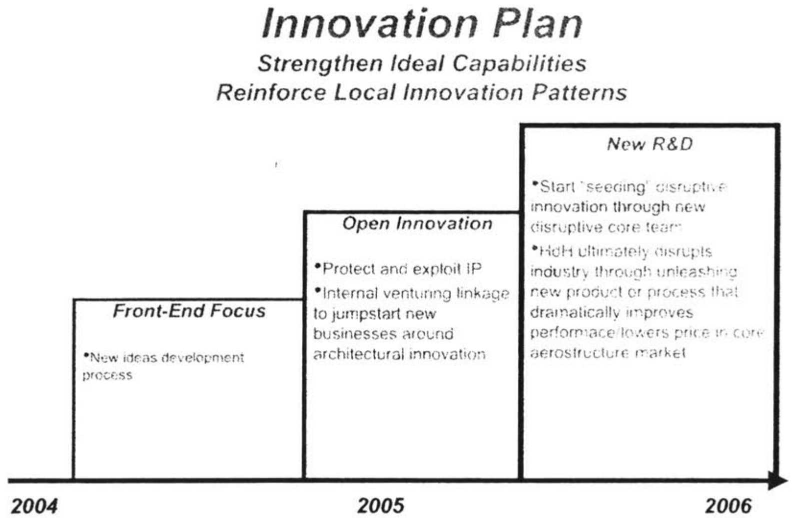
	cost (1=most expensive, 4=least)	timing (1=longest implementation, 4=shortest)	cultural fit (1=poorest fit, 4=strongest)	impact (1=lowest NPV, 4=highest)	total
front-end focus	4	4	4	1	13
new R&D	1	2	3	3	9
open innovation	3	3	1	4	11
new markets	2	1	2	2	7

The front-end focus activities, particularly a idea development process, are inexpensive and quick to implement, and require minimal change to the shared values of the company. They get the highest ranking even with the author's assumption that they provide the lowest overall impact. Open innovation, by scoring relatively high across the board, comes just behind in second. New R&D, in turn, ranks just ahead the of new markets. From this ranking, an innovation plan based on the methodology emerges: first implement the front-end focus activities, next the open innovation, and finally a new R&D. In the longer term, as resources allow, new market activities should be pursued.

3. The Three-Stage Plan

The three-stage plan (Figure 17) proposes a best-practices tool that consolidates the solutions in section III.F.1. This section briefly describes the proposed tools, the innovation capabilities addressed (as some of these tools may have "spill over" benefits to other capabilities), how it fits within and reinforces the innovation pattern, and the status of its implementation. The appendix gives full detail to the front-end focus initiative.

Figure 17. Case Company Innovation Plan



a. Front-End Focus

solutions: (g) formal process to gen/downselect ideas + (h) innovation champion + (i) TRIZ methodologies+ (l) informal networks

proposed tool: a process-based management procedure to foster early-stage idea generation and development, with innovation manager.

summary: the process-based management tool is fully described (and scrubbed of company references) in the appendix.

capabilities addressed: idea generation, networks (as employees will collaborate on idea development), customer understanding (as employees will work with real market needs in creating ideas).

local innovation path compatibility: the tool leverages outside resources (it was co-developed with an affiliated organization), builds in senior management support, and focuses on core capabilities.

local innovation path reinforcement: the tool encourages bottom up decision making, emergent strategy, teaming, technical leadership

implementation status: co-created with another business unit, ready for resourcing and actioning by management.

b. Open Innovation[56]

solutions: (a,n) CTO/IP strategy + (k) internal venturing + (j) managerial incentives

proposed tool: implementation of the parent OEM corporate venturing program, which also links to a corporate IP management functional group. Formal appointment of senior manager as Chief Technology Officer.

summary: The parent OEM has a corporate venturing program, similar to Xerox Technology Ventures or Lucent Ventures, which works with the OEM's business units and affiliates to encourage the use of company IP to create new business ventures outside of the company's core markets, as well as help the units manage and outsource their IP. For a full explanation on corporate venturing programs, the reader should consult Chesbrough (2003).

capabilities addressed: intrapreneurship, networking, IP management.

local innovation path compatibility: the venturing program leverages outside resources, builds in senior management support, focuses on core capabilities.

local innovation path reinforcement: the tool encourages encourages bottom up decision making, emergent strategy, teaming, and technical leadership.

implementation status: the venturing program was re-introduced to the company informally during the internship; two proposals from staff were generated, one of which received funding. Formal introduction by senior management awaits. As well the CTO role was proposed to senior leadership during a final review presentation, with no action to date.

c. New R&D

solutions: b) funding channel for differentiation + (c) disruptive engine + (m) external linkages

proposed tool: position a forthcoming R&D activity, the composites research center, on a disruptive path (Christensen, 1998 and 2003), with dedicated funding and strong linkages to outside parties.

summary: the proposed disruptive strategy for the research center is in Appendix B.

capabilities addressed: differentiating technology, differentiating engineering, IP management.

local innovation path compatibility: the venturing program leverages outside resources, builds in senior management support, focuses on core capabilities.

local innovation path reinforcement: the tool encourages bottom up decision making, emergent strategy, teaming, and technical leadership.

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[56] The author spent a significant amount of work on the internship on introducing this tool into the case company as well as helping to launching two ventures; due to aforementioned confidentiality issues and to protect the identity of the case company, this thesis can not go into detail on this activity.

implementation status: the composites research center has been proposed, and the strategy is currently to focus on sustaining innovations. The disruptive strategy has not been fully developed or proposed but could provide the subject for a future LFM internship.

G. Conclusion

This thesis begins by describing the need for renewed innovation within the aerospace industry. It emphasizes the fundamental need for differentiation, particularly among companies specializing in manufacturing. Simply, "running in place" with operational efficiency is not a sustainable strategy with the entrance of ultra-low cost global competitors and the rapid diffusion of practices from Toyota Production to Six Sigma. The thesis then presents a methodology for developing an innovation strategy and plan that was designed for a midsized aerostructures manufacturer. Finally, it describes the execution of this methodology as a case study, providing a detailed assessment of the aerostructures industry, a careful analysis of the company and its existing "innovation culture," and a specific innovation strategy and plan for the company. The plan is based on determining "ideal" capabilities needed to execute the strategy and concrete actions the firm could take to reinforce them, consistent with its local culture.

While the methodology was created for the objectives of the LFM internship, its modular architecture should make it applicable to a wide variety of firms. While the specific modules and approaches taken in the case study were clearly specific to the conditions of the case, the methodology emphasizes circumstance-based strategy development and understanding the local culture—in essence, a deep understanding of the company's environment and praxis before strategic actions are taken. In particular, the contextual emphasis of the methodology addresses a general weakness in the literature of "one size fits all" approaches, where innovation "books of the month" prescribe solutions that may not be applicable to every firm.

In particular, at the beginning of the LFM internship, the author had many preconceived notions of what an "innovative" company was, and what non-innovative companies could do to become more cutting-edge. Innovative companies, to the author, were highly creative firms such as IDEO or Apple that created fast product cycle, highly innovative new products on a regular basis using advanced product-development techniques. Desirable innovation strategies centered around—from start to finish—disruptive approaches akin to Southwest in the airline industry or the commonly referenced example of mini-mills in the steel industry. However, once immersed in the company the author realized that the company's history, culture, environment, and operations made it ill-suited, in the near term, to his favored innovation strategies. In response, the author developed and executed the methodology to create a more tailored innovation strategy to the company, focused on differentiation, using existing components in novel ways, collaborating with outside firms, and balancing products and processes and core and new markets. As well, the resulting strategy and plan ultimately included the exploration of disruptive technologies—but in a new, external entity that would not interfere with its core competence in sustaining innovations.

Ideally, the methodology and its execution helped develop a plan for the case company that is strategically beneficial and will help it compete and survive in a competitive marketplace—while being realistically actionable. Moreover, the thesis discovered and highlighted the company's unique culture of innovation as evidenced by the case studies in section III.E.2. In fact, the case company seems to have a strong "underground" culture of innovation, which management should reinforce through the recommended actions of the strategy and plan.

Of course, the thesis's "answer"—the proposed innovation strategy—raised many questions that were not fully addressed in this thesis, or in the literature, and may merit future study:

- How can a practitioner best analyze and audit a company's capabilities? While the study of industries is mature (*e.g.*, Porter's models), the literature is generally lacking in good company analyses and resource audits. This scarcity may be due to the resource-based view's relative immaturity, but clearly better tools are needed to analyze, measure, audit, and check a company's resources and capabilities.
- Similarly, how can a practitioner define a firm's ideal capabilities given a specific strategic position? The thesis presented a host of examples of the literature discussing "ideal" capabilities, but in general the database is unsatisfactory. Given the abundance of case studies in the innovation arena, an exercise to carefully map the circumstances of the industry and firm—in addition to the specific actions taken by the firms—would greatly help the understanding of which capabilities reinforce specific strategies.
- Once case studies of innovation are discovered within the company, how should the practitioner turn common themes into a tangible "map" that can be used to aid future innovations? The literature appears sparse in providing tools to create maps from common themes, and given the importance of understanding a firm's local culture, more rigor in creating the map could be useful for the methodology.
- Finally, what is the best way to create an innovation plan to reinforce a firm's "ideal" capabilities? The methodology proposes actions, puts them into common groups, and then stages them into a three-phase plan. However, with a multitude of plan-building approaches available, the thesis's method may not be optimal for implementation for other cases. Exploration

into other plan-building methodologies suited to this methodology could be a worthwhile research endeavor.

Finally, from the perspective of the study of innovation, the author hopes the reader leaves with three important themes: 1) the importance of front-end processes, 2) the necessity of balancing theory and observation, and 3) the significance of fitting strategy within culture. A front-end emphasis—not only the focus of the first stage in the proposed plan and the subject of the Appendix—is an overriding premise of the methodology itself. Simply, the practitioner must do a lot of homework up front in understanding the circumstances and context of the firm and industry. Such up-front effort can have strong impact in creating an actionable and effective strategy in the long run. Second, innovation strategies must balance—ideally sequentially as in the methodology—abstraction and practicality, as they need to incorporate idealized principles that are immersed and tested in the reality of the company.

Finally, cultural compatibility is critical; too many innovation strategies in the literature hinge on early-stage culture change. Culture-change is ultimately necessary, but it takes a long time; in the meantime, this thesis argues that a lot can be done by strategy practitioners within a firm's existing culture. Moreover, the methodology shows that developing the strategy around the existing culture may not be a constraint, but an opportunity for promoting new innovation. As argued in Chapter II and demonstrated in the case study, the firm likely has "lead innovators" that have successfully navigated this culture to create new products or organizational change. In fact, the discovery of several lead innovators in the case study may have been the most interesting result of the case: the company has a distinct innovation pathway that led to a surprising amount of "emergent", or unplanned, innovation. In the end, understanding how the lead innovators have succeeded and building a strategy to reinforce their path—while also emphasizing the development of the firm's specific ideal innovation capabilities—should create a strong innovation foundation for the case firm, helping it meet its objectives of moving from a commodity, low-cost firm to a differentiated, high value competitor.

Appendix: Idea Generation Process-Based Management Tool

Innovation Program: Second Stage
"Think Outside the Flap": Capturing and Developing Innovative Ideas

I. Executive Summary

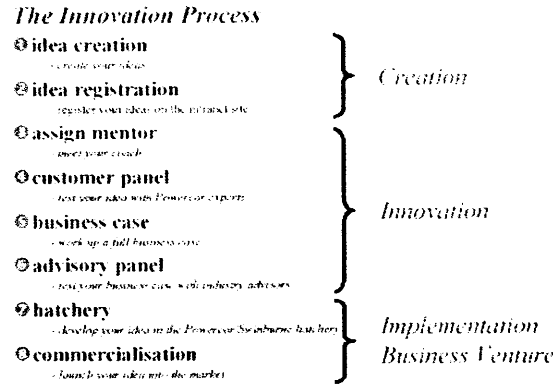
The second stage of the company's seven-year innovation program will be the implementation and resourcing of a basic process-based-management (PBM) system. The PBM will capture innovative ideas within the company and provide basic resources for their early-stage development. Through the PBM framework, this innovation process will be owned by the GM of Engineering, and run by an Innovation Manager, who will evolve it through a continuous PDCA cycle. What follows is "version 1.0" for the Innovation Manager and site teams to evolve.

II. Goals

- Establish a basic system to capture and explore innovative ideas
- Foster company-wide participation and capture distributed intelligence
- Link to a similar program at affiliate, creating opportunities for cross-disciplinary innovation
- Record and create database for innovative ideas (necessary for IP protection)
- Reinforce kaizen principles by rewarding employees for "keeping their eyes open" for improvement opportunities
- Lay groundwork for developing company-owned IP that will ultimately lead to proprietary products

III. Benchmark

Many companies have a dedicated innovation program where employees can submit innovation ideas to be fostered by the company. One powerful benchmark is Powercor's eighthgate program, which combines the innovation capture of the PBM with the commercialization/VC focus of a corporate venturing program.



Faced with the emergence of a deregulated and more competitive marketplace, Powercor (with 600k customers and 1000 employees) created the eighthgate program, "eight key stages that are designed to facilitate the creation, investigation and implementation of ideas to deliver cost savings and new revenue streams for the core business." The first four stages are akin to the PBM, with the latter four akin to a corporate venturing process. The eigthgate process is well thought out and has been executed very skillfully, with careful attention to internal marketing, customer input, linking to external resources, and incentives/rewards for the employees. Implementation of the PBM should achieve similar objectives. That said, this document will refer to eightgate as a benchmark, and management as well should consider linking with Powercor on implementation issues.

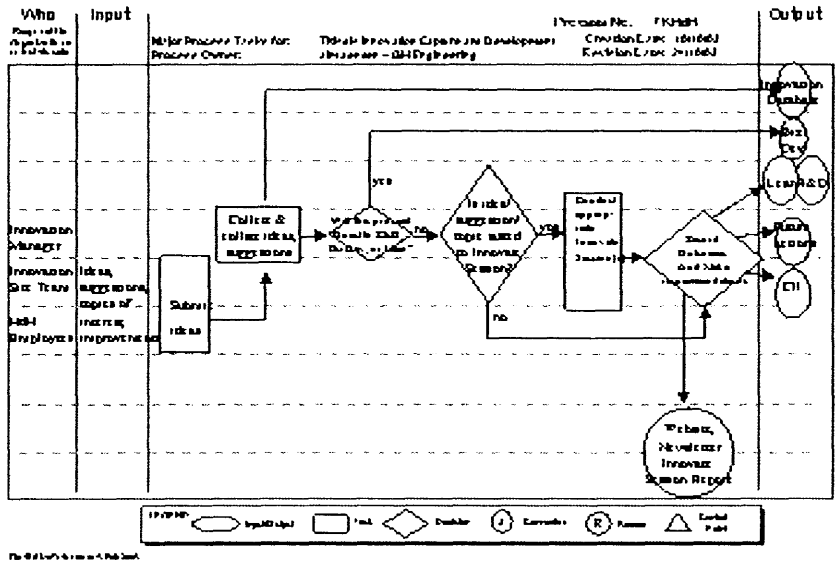
IV. Process Flow

In "Drilling down" the PBM process (attached) the following details who is responsible, the major process tasks, and the outputs.

A. **Who** GM of Engineering, is the process owner for the PBM. The three stakeholder groups are 1) the innovation manager, 2) the innovation site team, and 3) employees.

   1. **Innovation Manager** The innovation manager will run the process and would have several responsibilities within the company. Within PDM, the manager would be responsible for working with the affiliate innovation manager to market the program and encourage submissions, collect and collate suggestions via the innovation website, filter them according to set criteria, contact innovators about their ideas, schedule and lead weekly Innovate sessions, make recommendations to process owner as to follow ups (e.g., submit to xxxxx, submit to business development, record and table for future action, link to external parties), and help mentor innovators in follow up activities. In addition, the innovation manager would have supplementary tasks including development and maintenance of the company IP database, working with the xxxxx phantom works technical fellow responsible for Australian R&D, liking to outside companies (*e.g.*, the local innovation roundtable), chairing the innovation site team, working with the R&D manager on commercialization/licensing opportunities company technologies, working with business development on

customer and market research (e.g., creating and maintaining an aerostructures 'wish list' of customer needs), and working with the SLT on developing and managing a technology portfolio strategy for the company.



2. **Innovation Site Teams** Two core groups of 8-10 employees across functional groups—one at each site— that will meet for one hour a fortnight to evaluate filtered innovation ideas and track their progress through the Innovate sessions. In addition, team members will help run Innovate sessions and implement innovation "quick hits" to foster a more innovative culture within the company.

3. **xxxxx Employees** All employees will be encouraged to submit ideas via the intranet using a simple form to go through the PBM process. Each innovator will be contacted by the innovation manager to discuss briefly the idea and guide it through the appropriate channel.

B. **Processes** the Innovation Capture and Development has three major tasks, three decision gates, and one record.

1. **Submit Ideas** the company will host an 'innovation homepage' to be shared with affiliate organizations (and linked on the intranet) containing a simple online form as well as a database of expertise within the two companies and a calendar of innovation-related events. Employees will fill

out their ideas (in rough, quick, bullet form) for funneling to, and evaluation by the Innovation Manager. The ideas ultimately will go into a searchable database for record keeping.

a. **When would people submit an idea?** Experience with programs such as eigthgate show that employees have "internal' (e.g., operations) and "external" (e.g., market) ideas that can get prematurely filtered from consideration for implementation. Ideas could flow from many avenues:
   i. from employees who see factory improvement/innovation ideas that have not been adequately actioned on in traditional channels
   ii. from employees with general interest in aviation and aerospace who see a market gap or opportunities
   iii. from employees with hobbies/avocations with market potential that could complement the company's core capabilities (computers, cars, hobbying, recreation)
   iv. from employees who may have read something in a magazine that merits further discussion (e.g., smart materials for control surfaces), saw an interesting presentation at a conference, etc.

b. **Form Contents** The ideas page will contain a standardized, very simple online form (shared with xxxxx and R&D/lean/transformation) with the possibility of paper/pencils and manual submission where computers are not prevalent (e.g., areas of the factory floor). The innovator will fill out three fields:
   i. Give a brief description of your idea or topic of interest (e.g., operations improvement, new product, new market opportunity, new technology)
   ii. What is unique or innovative about the idea?
   iii. How will your idea benefit the company?

2. **Collect & Collate Ideas** The innovation manager will receive automatic emails of the submissions and perform a preliminary evaluation, contacting the innovator as necessary for clarification.

   a. **Response** The innovator will receive an automatic reply email telling them that the system received their idea, and that the innovation manager is reviewing it and will contact the innovator about next steps. Depending on the volume/throughput of ideas (see below), the email should also provide a response timeframe to provide the innovator a realistic expectation of when his/her idea will be evaluated.

b. **Throughput** A key issue is the rate of throughput of ideas entered into the system and the time it takes the innovation manager to properly evaluate and understand the ideas. eighthgate, as a benchmark, had 120 ideas registered in 18 months from 1000 employees, a rate of 0.0067 ideas/person-month, imputing to approximately 10 submissions a month. However, if the initial submission rate were greater due to 'pent up' demand, this role should be staffed with people 'on call' at the beginning of the program as to not create a large backload up-front that will discourage future idea submission.

c. **Innovation Database** All ideas will be tracked and recorded in an innovation database. The database will be accessible and searchable on the innovation homepage. More importantly, the database will serve as a record for potential IP protection such as patenting.

3. **First Decision Gate** The innovation manager will first evaluate the idea to see if it should be forwarded directly to another business activity or group. Ideas of this sort require no further 'brainstorming' or development, i.e., are of either limited scope or are actionable without further early-stage development. Three major groups have been identified, with each maintaining an internal database of ideas for actioning based on those groups' criteria for concept evaluation and resourcing.

   a. **Lean/Operations** Ideas directly forwarded lean/operations would include simple, directly actionable improvement/innovation ideas for the factory floor, such as those identified at workshops and related lean events. An example could be a proposal for new ways to organize tools or materials at a specific cell. Lean managers with compile these ideas in a lean ideas database, perform a quick evaluation of the concept using its established evaluation tools, contact the innovator, and as feasible work with cell leaders to implement the changes.

   b. **R&D** Ideas directly forwarded to R&D would include specific composite process innovation ideas, which would flow into the R&D PBM. An example could be a proposal for a novel method of laying down fiber or tape. The R&D manager may decide to flow the idea back into the innovation PBM if he/she feels it is of sufficient promise and requires more early-stage development; similarly, the R&D manager may flow ideas from the R&D idea submissions page into the innovation PBM if he/she feels those ideas require early-stage development.

c. **Business Development** Ideas forwarded directly to business development will be identified business opportunities requiring no further conceptual development. An example could be a proposal for an extension of a current product line to a new customer. Similar to the cases above, the business development general manager could flow the idea back into the innovation PBM if he/she feels it is of sufficient promise and requires more development.

4. **Second Decision Gate** After reviewing whether the idea should be forwarded to another business group, the innovation manager will assess whether the idea can progress to an appropriate Innovate session. The manager will compile the ideas and provide a "recommendation" on whether to push the idea to an Innovate session, to be reviewed at the fortnightly innovation site team meeting.

   a. **Evaluation Criteria** For each idea not immediately forwarded, the innovation manager will do a quick assessment (~20 minutes), filling out a form evaluating the idea under the criteria below. The goal is not to perform a detailed due diligence, but to do a "quick and dirty" qualitative assessment that will borrow heavily on the innovation manager's skill in assessing business opportunities and knowledge of the company and the aerostructures market. Below is a criteria list which will evolve into a standardized review form for this and the third gate (step 6).

      i. **Classification**: operations, technology, market opportunity, or product
      ii. **Timeframe**: short (<1 yr), medium (1-3 yr) or long term (>3yr)
      iii. **Operations** core evaluation criteria (**TBD** by lean group)
      iv. **Technology, Market, or Product** evaluation criteria
         1. **Strategic Fit** (ranked on a 1-5 scale)
            a. Can this idea apply to the aerostructures market?
            b. Does this idea involve composite materials?
            c. Does this idea potentially fit with a Tier-One systems supplier model?

d. Does this idea fit within the company's current resources? Future resources (e.g., higher volume, liquid molding, generalist engineering, services)?

2. **"Disruptive" Potential** (ranked on a 1-5 scale)
    a. Is the idea/technology radically different than current practices?
    b. Is the idea/technology lower performance but simpler/more convenient/less expensive?
    c. Does the idea/technology offer benefits to new/less-demanding customers ("nonconsumers") that currently don't participate in the mainstream aerostructures market?
3. **IP assessment**: Does the idea use and/or develop unique company IP? (1 to 5 scale)
4. **Customer assessment**: Does this address an identified customer need? If yes, to a current xxxxx customer or a new customer?

v. **Optional evaluation criteria** (if convenient information exists, otherwise, these are pushed to later evaluation)
    1. **Competitive assessment**: Are there competing companies known offhand that are exploring this idea/product/market?
    2. **Technology assessment**: What is the maturity of the technology? Does the company have direct experience with it?
    3. **Market potential**: What is the order of magnitude assessment of market size?
    4. **Cost assessment**: What is the order of magnitude assessment of development, investment, and manufacturing costs?
    5. **Risk assessment**: What are the major risk areas?
    6. **'Open' innovation assessment**: Does the idea leverage other company or organizations in the company?"

b. **Site Team Meeting** The innovation site team at the relevant innovator site will review all evaluated submissions at its fortnightly meeting and decide (based on majority vote, if necessary) on the next action. Based on the decision, the innovation manager will contact the innovator by phone to discuss the decision and the next steps:

i. **Proceed to Innovate session** If the assessment scores well and the site team feels the idea has merit, it will forward it to the appropriate Innovate session.

ii. **Record and Make Recommendation** If the assessment does not score well and/or does not have a strategic fit with the company, the site team will move the idea to step 6 (Record Outcome and make Recommendations)

5. **Conduct Appropriate Innovate Sessions** Innovate sessions will be regular, innovation-focused workshops facilitated by the innovation manager and/or members of the site team, and will serve as the company's main early-stage development resource. The sessions will be from 1-2 hours in length and will use one of three standardized formats that will evolve under the leadership of the innovation manager: multiple-idea brainstorms, single-idea brainstorms, and idea development sessions. The site team during its evaluations will put the idea in the appropriate session format, and depending on the idea's maturity, can cycle it through multiple (and most likely sequential, from multiple to single to development) sessions until it reaches the recommendation stage. The minutes of all meetings will be posted in the innovation web portal, and ideas will be "tracked" through this system and reviewed during site-team meetings.

a. **Multiple-Idea Brainstorms** In these 'early stage sessions', 6 innovators will work with the innovation manager to 'pitch' their idea to the other innovators and receive feedback. Each idea will receive 10-20 minutes (depending on the meeting length). Depending on the ideas received, these meetings can be focused along a theme (e.g., "bond shop innovations") or across subject areas. Innovators will get to hear and comment on fellow innovators' ideas, and ideally internal links will be created in these sessions. The outcome will be early peer feedback on the ideas, which will steer them—depending on the maturity—to successive Innovate sessions or directly to another channel such as an affiliated corporate venturing program. Depending on the quantity and quality of ideas, it is anticipated that this stage will "filter" ideas so that some are tabled to further action, the bin, or back to the innovator for resubmission, i.e., step 6.

b. **Single-Idea Brainstorms** These sessions are for the most promising early-stage concepts identified by the site-team, and can be direct submissions or the most promising ideas from the multiple-idea brainstorm session. The innovation manager with 2-3 members of the site team, and staff "experts" where relevant (e.g., operations or technology leaders), will perform a focused brainstorming session to develop a single concept using an evolving, standardized format. Again, depending on the quantity and quality of ideas, it is anticipated that this stage will also "filter" ideas so that some will move directly to step 6.

c. **Idea-Development Sessions** The most mature ideas identified by the site-team will move to an idea-development session, which will examine key aspects of the idea for development using methodologies such as TRIZ (i.e., structured innovation) for design, root cause analysis/TPS tools for operational improvements, or strategy frameworks (e.g., SWOT, 4P, 3C, etc.) for market issues. The outcome of this session will be "mature" concepts ready for step 6.

6. **Record Outcome and Make Recommendations** The site teams, led by the innovation manager, will review relevant innovation ideas that have reached this stage and are ready for a decision on how to proceed, based on the criteria established in step 4 (the second decision gate). Ideas that have been flagged for this stage (either as early recommendations by the innovation manager for tabling or as output from the Innovate sessions) will be directed into one of several channels, which the process owner will review after the meeting for final approval.

a. **Forward to an Internal Business Activity Group** (e.g., operations/R&D/business development). If after the Innovate sessions the ideas are determined to be best positioned in one of these groups, according to the criteria listed in step 3, the site team will forward the ideas, with all relevant Innovate notes and evaluation records, to the appropriate business group. The benefit to these groups will be a "scrubbed" and early-stage developed list of concepts that could benefit them. The innovation manager will track ideas forwarded to the groups and link information on their progress back to the innovator, helping facilitate action as needed.

b. **Forward to Corporate Venturing Group** Ideas that show promise market, technology, or product potential but are beyond the current resource limits of business development or R&D can be forwarded to an affiliated corporate venturing group, a well resourced and highly effective commercialization channel. The venturing group will then evaluate the concepts and take the most promising ones forward through its phases and gates for potential spin-ins or spin-outs. The group thus can act as a funding and maturing mechanism for exploring promising innovation activities in the shorter term (i.e., during this First Stage plan), potentially providing the company with "matured" spin-in business opportunities or royalty/transfer payments for ideas that are spun-out or moved to other xxxxx BUs.

c. **Future Action/Filed** Ideas that do not meet the company's criteria or fit within the business groups, or were filtered earlier due to not meeting strategic/market/technical criteria will be filed, registered, and tabled for "future action," with a paragraph explaining the rationale sent to the innovator and encouragement to evolve the idea and generate others.

C. **Measurement (KPIs)** The short term measurement of an innovation program is very difficult; without short term dollar flows or direct indicators like labor time, the challenge is identifying meaningful data to measure with which to evolve and improve the program.

a. Short term

i. # ideas submitted by employees
ii. # ideas forwarded to other business groups
iii. # ideas evaluated by innovation manager
iv. time per evaluation by innovation manager
v. # ideas tabled/binned before Innovate session
vi. time per evaluation by innovation site team
vii. # ideas forwarded to Innovate sessions
viii. # Innovate sessions held
ix. % employee satisfaction (based on anonymous email) of Innovate sessions
x. # ideas tabled/binned after Innovate session
xi. # ideas forwarded to cell leaders
xii. # ideas submitted to the corporate venturing group
xiii. # concepts forwarded to business development
xiv. # submissions/#successful internal implementations
xv. customized employee surveys for innovators in the process (e.g., see xxxxx Innovation Culture survey)
xvi. focus groups of employees engaged in the process
xvii. venturing group metrics e.g., # proposals into Phase I, II, III, etc.
xviii. links to the employee survey (e.g., "I feel encouraged to come up with new and better ways of doing things")
xix. anecdotal successes also could play a key role for marketing/PR

xx. external audits

b. Long term

i. # improvement ideas implemented from concepts

ii. labor/cost savings achieved from concepts

iii. # of patents and/or trade secrets generated from concepts

iv. # press articles/media articles generated from concepts

v. royalties received from company concepts

vi. internal transfer payments from affiliated companies received from concepts

vii. % of company business (by revenue) generated from concepts

viii. % of company business (by volume) generated from concepts

ix. % of company profits generated from concepts

V. Challenges/Risks

The first-stage plan has several challenges that need to be addressed for its successful execution.

A. **Resourcing** The process will require the resourcing of an innovation manager and a bucket of hours to run the Innovate sessions. However, this early-stage process is tantamount to HR, finance, and "non-tangible" activities that make it difficult to estimate a ROI or NPV. Long-term financial returns will be clear if concepts from this process make it to the venturing program (bringing in resources to the company), get implemented on the factory floor, and/or lead to new IP and products. Management should treat the program as a cost-area and evaluate the program in the short term in terms of its strategic and cultural goals for the company; revenue forecasts can be generated but will be very difficult to substantiate given that the ideas that will lead to revenue have yet to be defined.

B. **Incentives** Management should consider incentives and rewards to employees for ideas that successfully get implemented in the factory, make it through venturing phases, or turn into revenue-producing IP or products. Currently, the program's incentives are hours that the innovator can spend in Innovate sessions maturing his/her concept. Management could also consider reward, recognition, or pay programs as supplements.

C. **Linkages and work flow to business groups** A key issue will be the linkage of this program to other innovation efforts at affiliated companies, specifically R&D, the CTC, and lean/transformation efforts. How will the groups link (e.g., could the innovation manager meet with the leaders of these groups monthly? Could people on the innovation site-teams be from these groups?). As well, how the business groups handle the "output" of this process directed at them (e.g., operations improvement ideas) needs to be defined and extra work, if generated, needs to be quantified.

D. **Innovation Areas not Addressed** This first-stage innovation program takes a "baby step" in building innovation capabilities for the company and sews the seeds for its ultimate development of indigenous IP, products, and services. A full seven-year strategic plan for innovation is being developed (forthcoming) that takes a more comprehensive view; however, in the short term, management may want to address issues relevant to long term innovation but not covered in this first stage proposal.

   a. **IP management** Currently the company has no formal, proactive IP management plan or strategy in place; IP management has been a contractual function to date. The company should assign a member of the SLT to be Chief Technology Officer in charge of developing and protecting the company's IP portfolio. The IP portfolio can help guide resource allocation decisions.

   b. **Market development** The company has excellent business development leadership, but is under-resourced and focused primarily on OEM projects. The company may want to consider spending resources to understanding end-customer needs, looking at the future direction of markets (e.g., scenario planning), and looking at lateral markets that could provide disruptive opportunities in the aerostructure space (see Christensen's *Innovator's Solution*).

   c. **Cultural change** This plan indirectly helps create a more innovative culture at the company; however management may want to evaluate how "innovative" its culture is through industry-standard surveys and take appropriate actions, as fostering an innovative culture can help areas outside of the innovation program (e.g., morale, labor productivity) that can be measured in the employee survey. Simple, low cost actions may be effective. The site team could be a strong conduit in helping implement cultural change.

References

Abetti, Pier, "Critical Success Factors for Radical Technological Innovation: A Five Case Study," *Creativity and Innovation Management*, **9** (4), December 2000.

Afuah, Allan, *Innovation Management: Strategies, Implementation, and Profits,* New York, Oxford: Oxford University Press, 1998.

Andrews, Kenneth, *The Concept of Corporate Strategy,* Boston, MA: McGraw-Hill, 1987.

Arnold, Erik, and Thuriaux, Ben, "Supporting Companies' Technological Capabilities," Technopolis, Ltd. white paper, 1997.

Ashley, Steven, "Flying on Flexible Wings," *Scientific American*, **289** (5), November 2003.

Aviation Daily, "Discounts on A380s Might Hurt other Airbus Sales," *Aviation Daily*, 12 September 2003.

Birkler, John, et al., *Competition and Innovation in the U.S. Fixed-Wing Military Aircraft Industry*, Arlington, VA: RAND, 2003.

Boeing Company, The, "A Brief History of the Boeing Company," Seattle, WA: Boeing Historical Services, 1998.

Boeing Company, The, press release, "2003 Current Market Outlook," 17 June 2003.

Buderi, Robert, "Boeing's Slow-Death Hand," *Technology Review*, **106** (7), Sep 2003.

Bureau of Census, *Statistical Abstract of the U.S.*, 2002, December 2002.

Burgelman, Robert and Rosenbloom, Richard, "Technology Strategy: An Evolutionary Process Perspective," *Research on Technological Innovation, Management, and Policy*, **4**, 1989.

Burgelman, Robert, Maidique, Modesto, and Wheelwright, Steven, *Strategic Management of Technology and Innovation,* Boston, MA: McGraw-Hill, 2001.

Business Aviation, "Bombardier Studies of Large Regional Jet Continue," 23 June 2003.

Brown, Stuart, "Honda Gets Its Wings," *Fortune*, **149**(4), 23 February 2004.

Chesbrough, Henry, *Open Innovation*, Cambridge, MA: Harvard Business School Press, 2003.

Christensen, Clayton, *The Innovator's Dilemma*, Cambridge, MA: Harvard Business School Press, 1997.

Christensen, Clayton, "The Rules of Innovation," *Technology Review*, June 2002.

Christensen, Clayton, *The Innovator's Solution*, Cambridge, MA: Harvard Business School Press, 2003.

Cooper, Robert, "Doing it Right: Winning with New Products," Product Development Institute white paper, 2001.

Curry, Andrew, "Taking Wing," *Smithsonian*, **34** (9), Dec 2003.

Derby, Paul, "Shake-up in Aerostructures Sector Urged," *Flight Daily News*, 15 June 2003.

Dodgson, Mark, *The Management of Technological Innovation: An International and Strategic Approach*, Oxford: Oxford University Press, 2000.

Drucker, Peter, "The Discipline of Innovation," *Harvard Business Review*, 1985.

Economist, The, "High Times," special *Economist* edition on "The Future of Flight," **369**, Issue 8354, 13 December 2003.

Fine, Charles, Notes from 15.769, Operations Strategy, MIT Sloan School of Business, 2004.

Fleming, Lee and Sorenson, Olav, "Navigating the Technology Landscape of Innovation," *MIT Sloan Management Review*, Winter 2003.

Frost and Sullivan, *World Aircraft and Engine Maintenance, Repair and Overhaul Markets*, report 5790-22, San Jose, CA, 1999.

Frost and Sullivan, *World Unmanned Aerial Vehicle Markets*, report A282-16, San Jose, CA, 2002.

Fyke, Aaron, *Organizational Policies Which Promote Innovation in the Product Development Process*, MIT Leaders for Manufacturing Masters Thesis, May 2002.

Goldberg, Jacob, Horowitz, Roni, Levav, Amnon, Mazursky, David, "Finding Your Innovation Sweet Spot," *Harvard Business Review*, March 2003.

Hamel, Gary, "Waking Up IBM: How a Gang of Unlikely Rebels Transformed Big Blue," *Harvard Business Review*, July-August 2000.

Hargadon, Andrew and Sutton, Robert, "Building an Innovation Factory," *Harvard Business Review*, May-June 2000.

Henderson, Rebecca, and Clark, Kim, "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms," *Administrative Science Quarterly*, **35** (1), March 1990.

Hunter, David, "Cytec," *Chemical Week*, **165** (39), 29 October 2003.

Jamison, Andrew and Hard, Mikael, "The Story Lines of Technological Change: Innovation, Construction, and Appropriation," *Technology Analysis & Strategic Management*, **15** (1), 2003.

Lawson, Benn, and Samson, Danny, "Developing Innovation Capability in Organizations: A Dynamic Capabilities Approach," *International Journal of Innovation Management*, **5** (3), September 2001.

Mann, Darrel, "An Introduction to TRIZ: The Theory of Inventive Problem Solving," *Creativity and Innovation Management*, **10** (2), June 2001.

Markham, Stephen, "Moving Technologies from Lab to Market," *Research•Technology Management*, November-December 2002.

Maynard, Michelle, "In a Shaky Present, Boeing Weighs Risks of Building a Jet of the Future," *The New York Times*, 3 December 2003.

Mecham, Michael, "No Surprise, Foreign Suppliers Play Big Role in 7E7," *Aviation Week & Space Technology*, 24 November, 2003.

Miracle, D.B. and Donaldson, S.L, *ASM Handbook Volume 21: Composites*, ASM International, 2001.

Moncada-Paterno-Castello, Pietro, Rojo Jaime, Bellido Felix, Fiore Frederic, Tubke, Alexander, "Early Identification and Marketing of Innovative Technologies: A Case Study of RTD Result Valorisation at the European Commission's Joint Research Centre," *Technovation*, **23**, 2003.

Neely, Andy and Hii, Jasper, "Innovation and Business Performance: A Literature Review," Report for the Government Office for the Eastern Region of England, Judge Institute of Management Studies, University of Cambridge, 1998.

Neely, Andy and Hii, Jasper, "The Innovative Capacity of Firms," Report for Government Office for the Eastern Region of England, Judge Institute of Management Studies, University of Cambridge, 1999.

Negroponte, Nicholas, "Creating a Culture of Ideas," *Technology Review*, February 2003.

Paré, Guy, "Enhancing the Rigor of Qualitative Research: Application of a Case Methodology to Build Theories of IT Implementation," *The Qualitative Report*, **7** (4), December 2002.

Patterson, Marvin, *Leading Product Innovation: Accelerating Growth in a Product-Based Business,* New York: John Wiley & Sons, 1999.

Peters, Tom and Waterman, Robert, *In Search of Excellence*, New York, London: Harper & Row, 1982.

Peters, Carine and von Pottelberghe, Bruno, "Measuring Innovation Competencies and Performances: A Survey of Large Firms in Belgium," working paper, 2003.

Porter, Michael, *Competitive Strategy: Techniques for Analyzing Industries and Competitors,* New York : Free Press, 1980.

Porter, Michael, "What is Strategy?" *Harvard Business Review*, **74** (6), Nov/Dec 1996.

Prahalad, C.K, and Hamel, G., "The Core Competence of the Corporation," *Harvard Business Review*, May-June 1990.

Prahalad, C.K. and Ramaswamy, Venkatram, "The New Frontier of Experience Innovation," *MIT Sloan Management Review*, Summer 2003.

Prencipe, Andrea, "Exploiting and Nurturing In-House Technological Capabilities: Lessons from the Aerospace Industry," *International Journal of Innovation Management*, **5** (3), 2001.

Quinn, James, "Managing Innovation: Controlled Chaos," *Harvard Business Review*, May-June 1985.

Reinersten, Donald, "Taking the Fuzziness Out of the Fuzzy Front End," *Research•Technology Management*, November-December 1999.

Schwartz, Peter, *The Art of the Long View*, New York: Doubleday/Currency, 1991.

Shiba, Shoji, *Concept Engineering*, Cambridge, MA: Center for Quality of Management, 2000.

Sorenson, Jesper, Notes from 15.900, Introduction to Strategy, MIT Sloan School of Business, 2002.

Sorescu, Alina, Chandy, Rajesh, and Prabhu, Jaideep, "Sources and Financial Consequences of Radical Innovation: Insights from Pharmaceuticals," *Journal of Marketing*, **67** (4), October 2003.

Tushman, Michael, and Charles O'Reilly III. "Ambidextrous Organizations: Managing Evolutionary and Revolutionary Change" *California Management Review* **38** (4), 1996.

United States International Trade Commission (USITC), *Competitive Assesment of the U.S. Large Civil Aircraft Aerostructures Industry*, publication 2001.

Utterback, James and Abernathy, W.,"A Dynamic Model of Process and Product Innovation", *The International. Journal of Management Science*, **3** (6), 1975.

Volery, Thierry, "Radical Innovation in Corporations: How to Exploit Disruptive Opportunities and Develop an Entrepreneurial Spirit?" paper to the Corporate Entrepreneurship and Innovation Conference, Melbourne, Australia, August 2003.

von Stamm, Bettina, *The Innovation Wave, Meeting the Corporate Challenge,* West Sussex, England: John Wiley & Sons, 2003a.

von Stamm, Bettina, *Managing Innovation, Design, and Creativity*, West Sussex, England: John Wiley & Sons, 2003b.

Walsh, Steven, and Linton, Jonathan, "The Competence Pyramid: A Framework for Identifying and Analyzing Firm and Industry Competence," *Technology Analysis & Strategic Management* **13** (2), 2001.

Wilhelm, Mark, "Aircraft Applications," *ASM Handbook Volume 21: Composites*, ASM International, 2001.

William, G, "Emerging Aircraft," *Business & Commercial Aviation*, **92** (5), May 2003.

Wilson, S., Dissel, M.C., Probert, D.R., Katzy, B.R., "Sustaining Product Innovation in the New Economy: The Case of Siemens Switzerland," University of Cambridge Institute for Manufacturing white paper, 2002.