Boeing: Meeting Customer's Needs, Now and Future

Engineering & Technology Management

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Abstract

In this class we were asked to select a company and develop a technology roadmap. The company we selected was Boeing because of our interest in the topic and the amount of information that is available through websites, magazines, and journals. The methodology that was used to analyze the aircraft industry was Porter's Five Forces. This helped us to focus our efforts as we brainstormed market drivers for our roadmap.

Once the market drivers had been identified, they were put into categories of passenger experience, performance, reliability, safety, and economy. The market drivers were then weighted on applicability, feasibility, impact, and risk. The next step was to create a list of product features. The product features are directly related to the market drivers. These were also weighted and placed into a Quality Function Deployment (QFD) chart which yielded the product features that have the highest priority. The features with the highest priority were selected to move to the technology analysis phase of the roadmap.

The next phase was to find the technologies that could be associated with the product features. The technologies that were required to support the product features were again put into a QFD chart, but were not narrowed down. We felt that we had a sufficient number of technology features to continue our study of the resources.

In the resource analysis the decision to either use in-house R&D, outsource, create a partnership or acquire the technology was decided. Once this was complete the Technology Roadmap was created with all of the interlinking dependencies.

The results of our research pointed toward efficiency as a major factor. Efficiency in production and in flight were key concerns, and the products and technologies that support efficiency ended up at the top of the prioritized lists. Our recommendations for Boeing are to invest in composites and 3D printing.

Introduction

The first step in creating a technology roadmap (TRM) is to know who you are as a company and what major factors impact your company’s success.In this project, we built a TRM from the perspective of Boeing and we looked atmany of the different technologies that they could use in both the near and distant future to maintain and grow on their success. Boeing has historically been a market leader in the commercial aircraft industry, but has seen some stiff competition from Airbus in the past decade. Their leadership has slipped to the point that they are competing with roughly half of the commercial market. This roadmap could help steer Boeing’s technological decisions as they try to innovate their way to greater market share. By building a roadmap, a company is looking at different possible areas to invest both financial assets and resources. In this roadmap we looked at various market drivers, product features, technologies, and resources to determine an optimized path and timeline that could help to ensure Boeing’s market relevance and dominance in the future.

Methodology

An analysis of the aircraft industry was completed using Porter's Five Forces Model to provide an understanding of the current aircraft industry. The use of Porter's Five Forces also assists in brainstorming attractive market drivers which will be discussed in the next section. This model looked at the threat of new entrants, the threat of substitution, the power of suppliers, the power of buyers, and the existing competition.

The treat of new entrants in the aircraft manufacturing industry is low, mainly due to high entry costs and technical complexity of the aircraft. An aircraft is essentially made up of many subsystems that have to function together. Data link systems, communication architectures, engine, etc. All these systems are extremely expensive and not many firms today have the resources to build them. [8]

The threat of substitution in the aircraft industry is low. The likelihood that someone will take ground transportation (car, train, etc.) is low for long distances. For domestic traveling, the threat might be a little higher but for international travel, the threat is low. When determining this, time, money and number of people should be considered.

The power of suppliers for the aircraft industry is moderate. Aircraft manufactures rely on high quality components in relatively low quantities for their final assembled aircraft [8]. Because of this, aircraft suppliers support different industries to avoid downturns and to keep production moving. This alleviates their dependency on the aircraft manufacturers.

The power of buyers in the aircraft industry is moderate as well. The commercial aircraft industry is dominated by both Boeing and Airbus. Buyers typically choose one or the other based upon contracts, pricing and features offered. The threat may increase depending on which company has better offerings.

The competition is high between Boeing and Airbus. Both compete heavily for long contracts to obtain sustainable growth. As the competition between airlines increases, airlines are forcing their pressure onto the commercial aircraft manufacturers to compete by producing new aircrafts with exceptional features, to make them more efficient and cheaper to maintain.

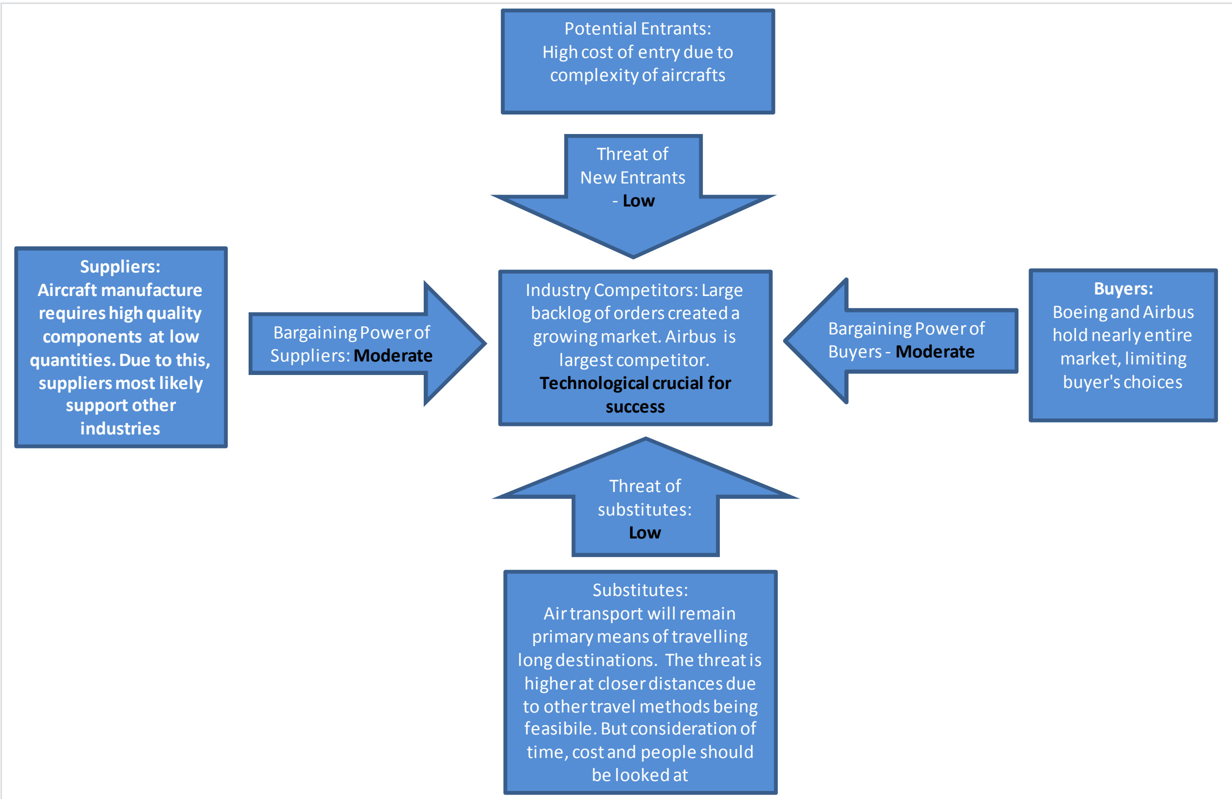

Figure 1: Porter's Five Forces

Market Drivers

To identify market drivers we used a combination of literature review and group mindmapping to come up with and prioritize our list. We found after our first presentation that we had used some of our initial technology focused ideas to create a bias in our market drivers list toward lightweight technologies. Further development of our Market Drivers list enabled us to remove that bias and take a more holistic view of the entire business of Boeing's commercial airliner manufacturing.

Further prioritization and weighting was done by considering which commercial factors were most critical to Boeing's success, then identifying the related Market Drivers and their relevance. We weighted the Market Drivers to aid in the prioritization. One thing to note is that the Market Drivers are dependent upon the usage of the aircraft. Long haul aircraft have a greaterneed for efficiency than the short flights. We have tailored this roadmap to be balanced between the different use cases.

Product Features

When determining product features that would apply to our Market Drivers, we considered some of the products that are being currently developed, but we also considered products that have not been commercialized yet. This range enabled us to get a view of the current state of the industry, plus a forward look into the future. We found products that are currently being researched, and products that are only being theorized. Many of these products will not be developed, but some of them will. It is these products that may be developed that have opportunity for innovation.

Technologies

Our list of technologies had to stay very broad and generic in order to maintain relevance. If we tried to focus in on specific technologies under development, our roadmap would lose legitimacy if those specific technologies failed to reach feasibility. When we developed our technology list, we left the specifics to the experts who are designing these improvements, and only made a list of the types of improvements that are needed. This allows our roadmap to maintain relevance regardless of the technology that is utilized.

Resources

Our Resource Analysis started by going back over our Market Drivers, Products, and technologies to ensure we had the correct prioritizations applied. We found that the deeper we went with the Road map, some of our earlier Market Drivers or Product Features would lose their relevance as they were either covered by other areas, or did not have helpful contributions to the roadmap.

Technology Roadmap Development

Market Drivers

The commercial airliner market is very competitive. The current market leaders are Boeing and Airbus, both holding roughly half of the market. Boeing's airplanes usually cost between $100 and $200 million. Their lifespans exceeddecades, and they are responsible for producing hundreds of millions of dollars in revenue over at least 50,000 flights.[1] With such extensive use and money on the line, it is critical that the aircraft are optimized for their intended use. With this in mind, we chose our Market Drivers to be fundamental to the core values of a commercial aircraft. These core values include reducing operating costs, increasing the revenue potential of each flight, and keeping passengers happy.

The list of Market Drivers that we came up with(figure 2) during our brainstorming and mind mapping sessions was extensive, and included high and low priority market drivers. We increased the value of our list by applying weights to the Market Drivers as a form of prioritization. We can then use these weights to further help us prioritize the Product Features in the next step. After removing the Market Drivers that had a low priority and impact to our Road Map, we ended up with 4 drivers. These are Comfort, Fuel Efficiency, Payload Capacity, and Safety. Each of these drivers contributes in a meaningful way to at least one of the core values that we determined earlier.

	Code	Market Drivers	Definition
Passenger Experience	D1	Low Cabin Noise	Refers to a reduction in cabin noise.
	D2	Increased Comfort	Refers to increasing the comfort of the passenger (e.g. more space more leg room, wider seats).
	D3	In-Seat Entertainment	Refers to features that are available for passenger entertainment.
Performance	D4	Increased Fuel Efficiency	Refers to the reduction of fuel usage.
	D5	Increased Payload	Refer to total weight capacity the aircraft can carry.
	D6	Increased Capacity	Refers to an increase in total volume/space of the aircraft.
Reliability	D7	Low Maintenance	Refers to inspections and overhauls.
	D8	Low Part Failure Rate	Refers to less frequent part replacements.
Safety	D9	Increased Personal Safety	Refers to increased survivability.
	D10	Durability	Refers to stronger, corrosive resistant components.
Economic	D11	Reduced Aircraft Cost	Refers to aircraft's purchase price.
	D12	Crewless Flight	Refers to automated services and navigation without need for flight attendants or pilots.

Figure 2: Market Drivers

Product Features

With our Market Drivers established and weighted, we move on to the next step in the TRM process which is determining relevant product features and gaps.(Figure 7) Again, for this step, our brainstorming and mind mapping sessions yielded a large list of product features. (Figure 3) These features all had varying degrees of applicability, feasibility, impact, and risk. We prioritized these products by determining the degree of relation between each Product Feature and each Market Driver in a Quality Function Deployment (QFD). (Figure 4) With this chart, we were able to determine which product features would have the greatest impact on our Market Drivers and core values.

Code	Product Features	Definition
PF1	Entertainment System	Refers to passenger entertainment experience and options.
PF2	Alternate Propulsion	Refers to alternate power sources for sustainable propulsion.
PF3	Lightweight Durable Materials and Components	Refers to materials that reduce the overall weight to durability ratio of the aircraft.
PF4	Fuel Efficient Engine	Refers to engines that uses fuel more effectively.
PF5	Aerodynamic Design	Refers to an aircraft design that reduces drag.
PF6	Efficient Take-off and Landing Procedures	Refers to an improvement in fuel efficiency during take-off and landing.
PF7	Acoustically Optimized Cabin	Refers to internal cabin noise reduction
PF8	High Strength Cabin	Refers to increase fuselage strength to enable higher ambient pressure, and more pressurization cycles.
PF9	Increased Power Output	Refers to increasing thrust while maintaining efficiency.
PF10	Larger Capacity Fuel Tank	Refers to wing structure and fuel storage design.
PF11	Impact Resistant	Refers to management of the force of impact to various areas of aircraft.
PF12	Space Efficient Aircraft Design	Refers to increasing usable space by changing design.
PF13	Space Efficient Seat Design	Refers to increasing passenger capacity by changing the seat design, material, or layout.
PF14	In-flight Automated Service System	Refers to automated services to passengers without need for flight attendants.
PF15	Personal Survivability Seats	Refers to crash or incident survivability.

Figure 3: Product Features Table

The Product Features that we extracted from this process include Alternative Propulsion, Advanced Composite Materials, Efficient Engines, High Strength Cabin, and Personal Survivability Seats. Each of these products makes a significant contribution to at least one Market Driver. From this list, we determined availability, gaps and timelines for deployment.

Our gap analysis (Figure 7) showed that Alternative Propulsion has the longest implementation timeline “since there currently are not any other viable energy sources foreseen in the coming years.”[2]Due to the unforeseen nature of alternative methods of propulsion, it is difficult to speculate on what benefits may be achieved. However, to make the implementation marketable and worthwhile, it must promise a significant increase in fuel efficiency.

Product Features Vs. Market Drivers	
Strong Relationship	3
Medium Relationship	2
Weak Relationship	1

Priority	
High	> 4
Medium	3 - 4
Low	< 3

			Market Drivers				
			Increased Comfort	Increased Fuel Efficiency	Increased Payload	Increased Personal Safety	
			D2	D4	D5	D9	Priority
Product Features	Entertainment System	PF1	2				2
	Alternate Propulsion	PF2		3	2		5
	Lightweight Durable Materials and Components	PF3		3	2		5
	Fuel Efficient Engine	PF4		3	2		5
	Aerodynamic Design	PF5		2	1		3
	Efficient Take-off and Landing Procedures	PF6		2		1	3
	Acoustically Optimized Cabin	PF7	2				2
	High Strength Cabin	PF8	3			2	5
	Increase Power Output	PF9			3		3
	Impact Resistant	PF11				3	3
	Space Efficient Aircraft Design	PF12	1				1
	Space Efficient Seat Design	PF13	1			1	2
	In-flight Automated Service System	PF14	2				2
	Personal Survivability Seats	PF15	2			3	5

Figure 4: Market Drivers vs. Product Features QFD

Advanced Materialscan reduce the weight of an aircraft and increase its durability. This product has one of the most significant impacts on our Roadmap since it affects Comfort, Fuel Efficiency, and Safety (3 out of 4 Market Drivers). These materials are currently being used in production, and will continue to be improved and implemented to a greater extent.

As long as fuel remains one of the largest operating costs of an airline, engine efficiency will remain a top priority. There have been major advancements since the invention of the jet engine and the first jet airliner, yet the increase in efficiency has not been able to keep up with the rising cost of jet fuel. This is especially true for the past decade. During the 2000's jet fuel prices have more than tripled while fuel burn is down by an almost negligible 0.3%. To maintain sustainability in the industry, uncontrollable fuel prices must go down, or controllable engine efficiency must increase at a faster rate. This is seen in Figures 5 and 6.

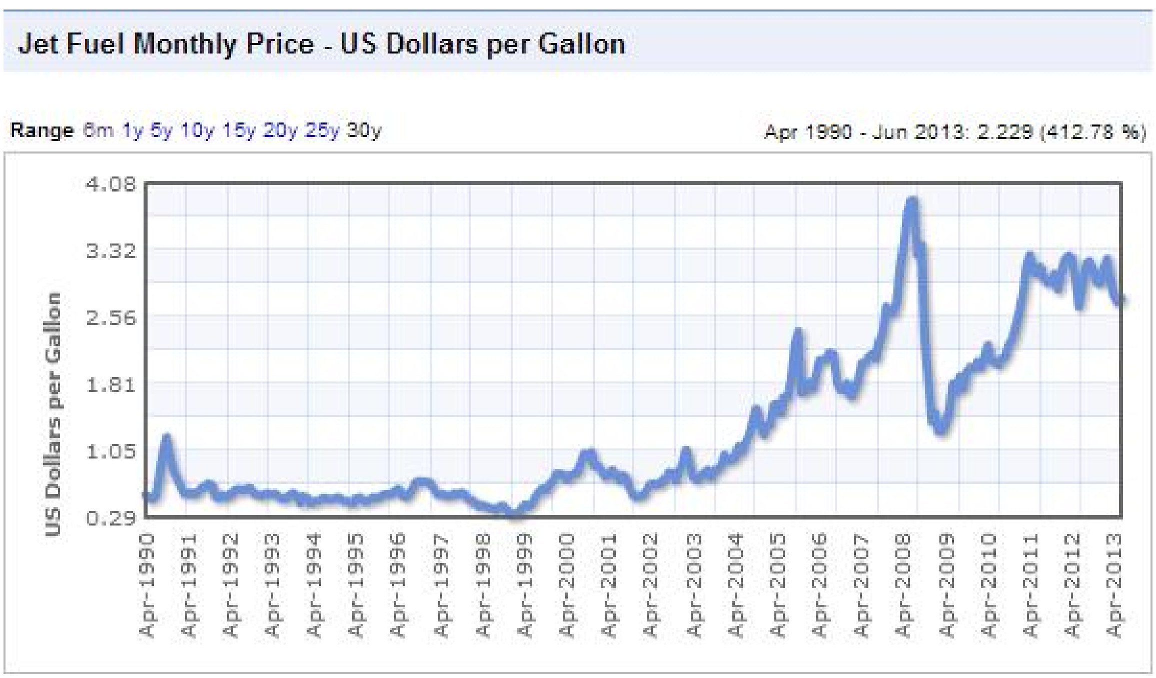

Figure 5: {3}

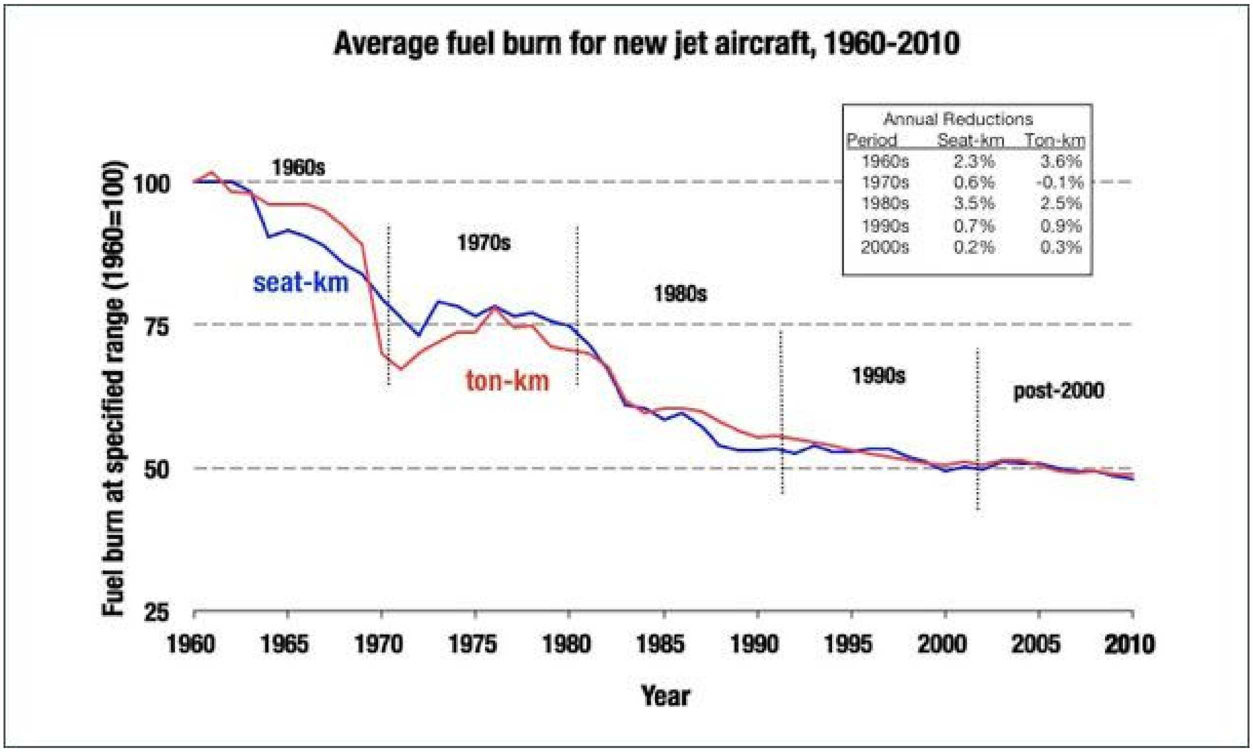

Figure 6:{4}

Personal comfort on an airplane is usually very dependent on the individual preferences of the passengers. However, one improvement we can all appreciate is a highly pressurized cabin to reduce the feeling of altitude sickness, jet lag, and sinus/ear issues that affect many people (especially babies).“At typical cruising altitudes in the range 36,000–40,000 feet, air pressure in the cabin is equivalent to the outside air pressure at 6,000–8,000 feet above sea level.”[3] Since aircraft lifespan is generally measured in compression/decompression cycles, having a resilient and high strength cabin that can hold greater pressures with less stress will improve the comfort level of all passengers, increase the lifespan of the aircraft, and reduce the costs of maintaining the structural integrity of the cabin.

Our final product feature to discuss is Personal Survivability Seats. Increasing safety is always a priority for obvious reasons. Safety is highly regulated, and individuals may choose not to fly with a certain airline if they feel that the flights are not safe. While there is extensive work being done to increase the safety of the airplane itself and reduce the frequency and severity of disasters, introduction of a seat designed to increase the survivability of a crash may increase demand for those flights.

Code	Product Features	Definition	Gap
PF1	Entertainment System	Personal entertainment experience	Expanding in-flight internet access, and allowing devices during takeoff and landing are some of the needed improvements.
PF2	Alternate Propulsion	Types of alternate propulsion options	Research on biofuels, synthetic fuels, and others are required
PF3	Lightweight Durable Materials and Components	Materials that reduce the overall weight of the aircraft	Advanced composites and 3D printing are some of the technologies that are being developed
PF4	Fuel Efficient Engine	Engines that use fuel more effectively	More efficient designs are being researched, including "LEAP" that features a ceramic composite material replacing traditional alloys
PF5	Aerodynamic Design	Designs that increase the aircrafts aerodynamic features	Reducing drag and improving aerodynamic performance is needed
PF6	Efficient Take-off and Landing Procedures	Reduce the need for runways	Magnetically driven carrier installed on runways for takeoff, capturing landing energy to use for taxiing on the runway
PF7	Acoustically Optimized Cabin	Internal noise reduction	Sound absorbing materials are implemented, further sound isolation is under development
PF8	High Strength Cabin for High Pressure	Increase fuselage strength	Improved materials and structural designs are needed
PF9	Increase Power Output	Increase in HP and Torque	Increasing the power of the engine, while maintaining efficiency is a constant challenge
PF10	Larger Capacity Fuel Tank	Fuel storage design	Reducing the size of structural components could provide more space for additional fuel
PF11	Impact Resistant	Resists direct impact to various areas of aircraft.	Stronger composite material, damage tolerance, designs that transfer the force of impact away from passengers
PF12	Space Efficient Aircraft Design	Increase useable space by changing design	TBD
PF13	Space Efficient Seat Design	Changing seat design, material, or layout	There are many designs being tested, The most space saving designs come from adjusting the position of the passenger. These designs will have to be tested for comfort
PF14	In-flight Self Service System	Refers to automated services to passengers without need for flight attendants	There is currently a "skytender" in development, but it still requires an attendant to operate it. In the future, this could be completely automated
PF15	Personal Survivability Seats	Refers to crash or incident survivability	Current work includes rating the seats for 16Gs of force without injury, and reducing the flammability. Future improvements may include airbags or other supplementary restraint systems

Figure 7: Gap Analysis Table

Technology Analysis

This section of our Roadmap is devoted to the Technology that is required to realize the Product Features that have been determined above to meet the Market Drivers that were initially discussed. We brainstormed and mind mapped technologies to come up with a list. (Figure 8) We then prioritized that list using a QFD to relate the Technologies to the Products. (Figure 9) This process gave us a condensed list of Technologies that were the most influential to our Roadmap. These technologies include Ceramic Engine Design, Additive Manufacturing, Composite Materials, Electrical Power Distribution, Alternative Fuel Storage, and Supplemental Restraint Systems.

Code	Technology Features	Definition
T1	Engine Design	Refers to the designs that are compatible with alternative fuel and provide improved efficiency.
T2	Manufacturing Techniques	Refers to the techniques that take advantage of or enable other enhancements.
T3	Composite Materials	Refers to materials that improve the strength to weight ratio of the aircraft.
T4	Power Distribution System	Refers to systems that distribute power from engines to auxiliary components.
T5	Fuel Storage System	Refers to methods of storing different types of fuel.
T6	Supplemental Restraint System	Refers to next generation passenger restraint system.

Figure 8: Technology Table

Ceramic Engine Designs have just recently been implemented to a very slight degree, but have already shown to increase the efficiency of engines by 15%[4] Usage and efficiency will certainly increase as the technology matures.

Additive Manufacturing has also begun implementation in the airline industry. This technique can reduce part count, reduce cycle time, improve performance, reduce weight, increase strength, increase simplicity, reduce maintenance, increase aerodynamics, and the list can go on. [5] This technology is poised to revolutionize the manufacturing industry, and airliner manufacturing is no exception. The technology has been utilized to make small components of the aircraft, but with more development, the technology could be used to create entire sections or perhaps the whole plane itself.

Composite Materials currently show the most promise for a lightweight and durable material replacement for aluminum. “Today, the benefits of components and products designed and produced in composite materials – instead of metals, such as aluminum and steel – are well recognized by many industries. Some of the advantages include:”[6]

High Strength-to-weight ratio	Corrosion Resistance
Wear Resistance	Stiffness
Fatigue Life	Temperature-Dependent Behavior
Thermal Insulation	Thermal Conductivity
Acoustical Insulation	Low-Electrical Conductivity
Visual Attractiveness	Radio translucent

Table 1 (8)

While the use of Composite Materials has seen a significant increase over the past decade, there remains plenty of opportunity for increasing the proliferation of its use. Key technological and procedural hurdles remain such as reducing cost, and proving long-term safety and resilience.

Techonlogy Features Vs. Product Features	
Strong Relationship	3
Medium Relationship	2
Weak Relationship	1

Priority	
High	10 >
Medium	5 to 9
Low	< 4

Technology Features		Product Features: Alternate Propulsion	Lightweight Durable Materials and Components	Fuel Efficient Engine	Space Efficient Seat Design	Personal Survivability Seats	
		PF2	PF3	PF4	PF13	PF15	Priority
		1	3	2	1	2	
Engine Design	T1	3		4			7
Manufacturing Techniques	T2		9	6			15
Composite Materials	T3		9		2		11
Power Distribution System	T4			4			4
Fuel Storage System	T5	3		2			5
Supplemental Restraint System	T6					6	6

Figure 9: Technology vs. Product Features Table

Resource Analysis

Our Resource Analysis was conducted by assessing the most likely scenarios for acquiring the resources needed to produce the technologies we identified. From Boeing's perspective, we determined that 4 resource categories were required. These categories include In-House R&D, Outsourcing, Partnerships, and Acquisition. (Figure 10) Both In-House R&D and Acquisition give Boeing the benefit of patents, or technology ownership. These categories will be applied to technologies that are in line with Boeing's mission and strengths, and are critical to the uniqueness and performance of the aircraft. The other categories, and specifically Outsourcing, will be used when a technology is outside of Boeing's expertise, or the product is a commodity. In this scenario, the finished product will be purchased, or technology will be leased to meet the needs of the aircraft.

Technologies for In-House R&D include Composite Materials and Alternative Fuel Storage. Acquisition plans consist of Additive Manufacturing. Technologies that will be outsourced include Ceramic Engine Design and Electrical Power Distribution. Finally, technologies to be worked on in partnerships include the Supplemental Restraint Systems.

Code	Resources	Definition
R1	In-House R&D	Development of technology by employees to be owned by Boeing
R2	Outsourcing	Purchase finished material from private company
R3	Partnership	Work with entity to implement technology
R4	Technology Acquisition	Identify technology in the form of patents or company and purchase for use

Figure 10: Resource Table

Technology Roadmap

The technology roadmap was created using all of the information that had been gathered up to this point. As it is shown in figure 11 the market drivers and product features with the highest weights, as derived from the QFD, are shown and the time frame in which they will be accomplished. It was decided to include all of the technologies and resources to ensure there was an adequate amount of information for a thorough roadmap. The links between product features and technologies are indicated with arrows.

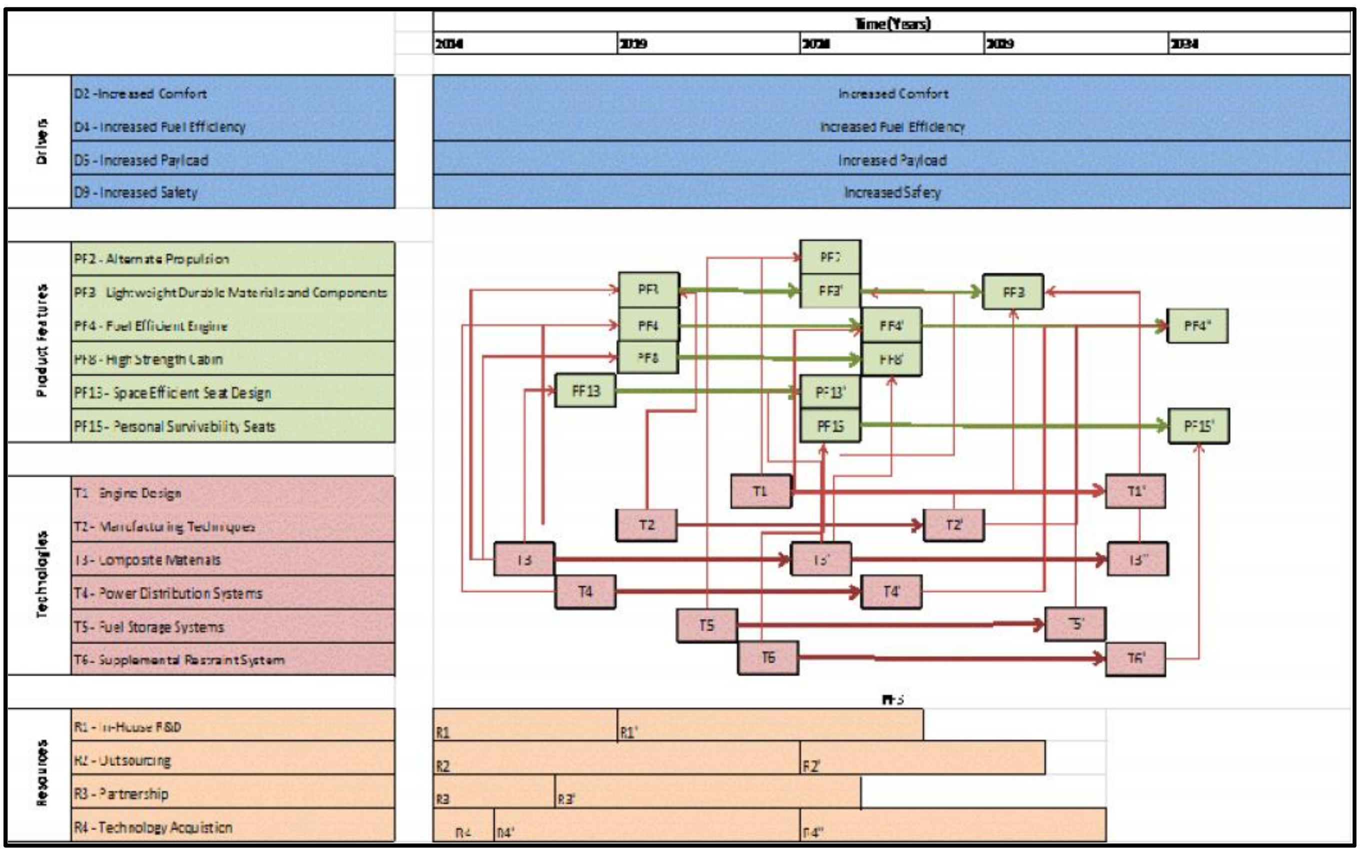

Figure 11: Technology Roadmap

Conclusion

We have shown the key Market Drivers for Boeing, and how they were determined. We weighted those Market Drivers and correlated them to Product Features, Technologies, and finally to Resources to create a picture of the future of the commercial aircraft industry. This roadmap highlights the importance of efficiency in the future. This efficiency needs to be realized both in the manufacturing of the aircraft and in the effectiveness of its fuel usage. A few of the key take-a-ways from this research is that strong, lightweight, and durable materials need to be developed and implemented in a greater extent, and they need to be implemented using a more effective manufacturing method, such as 3D printing, or additive manufacturing. These improvements would do the most for the airline industry. Another important efficiency gain would be an improved source of propulsion. This could be an alternate fuel, or an alternate engine design that is not the traditional jet. There is a lot of research around this, but nothing on the immediate horizon. This is a great opportunity for a future engine that is as revolutionary as the jet was in the 40's and 50's. We also recommend that Boeing continue to innovate in personal safety. As always, preventing a crash is better than surviving one, but people might pay more for their seats if they knew that they were engineered with their life and safety in mind. If Boeing focuses on these improvements and succeeds, they should be able to keep up with and surpass their major competitor, Airbus.

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