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The Next Q400: Evaluating the Evolutionary Options of a Turboprop

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THE NEXT Q400

Evaluating the Evolutionary Options of a Turboprop

By

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II. ABSTRACT

THE NEXT Q400: Evaluating the Evolutionary Options of a Turboprop
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The intent of this paper was to examine the possible future development that Bombardier Aerospace could make with regards to the DHC-8-Q400 turboprop. The venerable Q400 is a proven design that saw great success through the 2000’s and must now either be upgraded or replaced in order for Bombardier to remain competitive.

Three proposals were examined from a high level perspective:

1. A shortened design of the Q400;
2. An extension of the Q400 design;
3. And a clean sheet turboprop design.

Each proposal was reviewed on the basis of its merits in development cost, infrastructure requirements, technical requirements, and market demand for the particular configuration. Further to this, a survey of media reports on the market desire for new turboprop acquisition and competitive airframe developers design forecast was carried out.

Based on this evaluation, the extended design of the base Q400 was selected to be the best candidate for Bombardier to develop and therefore, remain successful in the aircraft development market.

III. ACKNOWLEDGMENTS

There have been a number of persons that have helped to make this paper possible.

I would like to thank Ryerson University as the institution that provided me with the theoretical background and practical experience in Aerospace Engineering. The faculty at Ryerson was always available for my numerous questions and supported me in developing the ideas that made up this paper. Specifically, Dr. Jason V. Lassaline provided me with the necessary guidance to keep things on track and the goal always in sight.

To my work group at Bombardier and the instructors at Flight Safety International, I thank them for their insights into the industry and technical information regarding the Q400.

And finally, I would like to thank my family and friends, who have always supported my love of flight and have always encouraged me to achieve anything I set my mind to.

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VII. NOMENCLATURE

AOA	Angle of Attack
APU	Auxiliary Power Unit
AR	Aspect Ratio
ATR	Avions de Transport Regional
BBD	Bombardier Aerospace
BHP	Brake Horse Power
CAAC	Civil Aviation Administration of China
C_D	Coefficient of Drag
C_L	Coefficient of Lift
D	Drag
dB	Decibels
DGCA	Directorate General of Civil Aviation
E	Endurance
EASA	European Aviation Safety Agency
ECS	Environmental Control System
EMB	Embraer Aerospace
FAA	Federal Aviation Administration
GE	General Electric
L	Lift
M	Moment
MTOW	Maximum Take-Off Weight
P&WC	Pratt and Whitney Canada
R	Range
SHP	Shaft Horse Power
STOL	Short Take Off and Landing
T	Thrust
TC	Transport Canada
W_C	Crew Weight
W_e	Empty Weight
W_f	Fuel Weight
W_P	Payload Weight (Passengers and Cargo)

1. INTRODUCTION

The modern industry of regional, low cost airlines has resulted in a strong requirement for relatively low seat count aircraft that are able to service short distance flights. Further to this, the resurgence of high fuel prices over the last decade has seen a return to the turboprop power plant in order to achieve the desirable relatively low fuel consumption. It is in this market that the Bombardier (BBD) Q400 turboprop has marked a successful stake for itself (Figure 1.1).

Figure 1.1 - SATA Bombardier DHC-8 Q400
(R. Madieros, 2011)

Of course, the success the Q400 enjoyed in the late 1990's and early 2000's has begun to wane as the next decade brings about newer technologies, not to mention an increase in competition. The introduction of the popular ATR-72 turboprop (See Figure 1.2) has put increasing pressure on Bombardier to reinvent its successful design and bring it into the new decade as a reliable, affordable, and practical choice.

Figure 1.2 - ATR ATR-72-202
(Wedelstaedt, 2011)

As such, Bombardier has a number of choices for its turboprop program that have the potential to bring about the increased demand for the design and return BBD to its top of the market place.

This report will look at the various requirements, market conditions, investments, and potential risks for the following three possible design options:

- Shortened Q400 design;
- Lengthening the current Q400 design;
- And a clean sheet turboprop to replace the current Q400 design.

Each of the above mentioned options have both positive and negative aspects, which, to varying degrees will directly affect the ability of the program to be fully successful. As such, this report will present the options from a project management purview to ensure that all encompassed requirements would be recognized and provisions for them made. Reasonable assumptions will be made to approximate costs, support elements, as well as developmental time frames. While they may be assumptions, they are of course based on the cases of other design programs that have brought about similar designs in the industry. It is important that the reader note that the evaluation and proposed designs conducted in this report are taken at a high level, and therefore, many details and or specifications are not exact and should not be understood to reflect a finalized and complete design.

Further to this, discussion and practical presentation of preliminary design of such options will be documented with particular influence of the effects on weight, performance, and structural requirements to develop such designs. Once again, realistic assumptions will be made and will follow common aircraft design theory which will be discussed in the appropriate section of this report.

Based on this review of the three stipulated options, the final report will provide the reader with a reasonable suggestion for the best option in reinvigorating the BBD name in the modern turboprop market.

2. THE Q400

Before analyzing where BBD can take the Q400 design to continue to be competitive in the future, it is important to revisit the past successes of the design. The Q400 comes from a long development of turboprops with a strong history in short take off operations and rugged designs. As such, the following section will review the history of the aircraft and a brief summary of the development and particular attributes that made it such a great success in the regional aircraft market.

2.1. HISTORY

The BBD Q400 stakes its lineage back to the de Havilland Dash 7 (See Figure 2.1) in the 1970’s. Originally designed as a Short Take Off and Landing (STOL) aircraft with particular reverence to the increasingly stringent noise level restrictions around airports, the Dash 7 saw limited success due to the relatively high maintenance of running four engines.

Figure 2.1 - de Havilland DHC-7
(M. Durning, 2011)

Regardless, the Dash 7’s sound design and strong airfield performance provided de Havilland with a good design foundation with which to further development (See Figure 2.2).

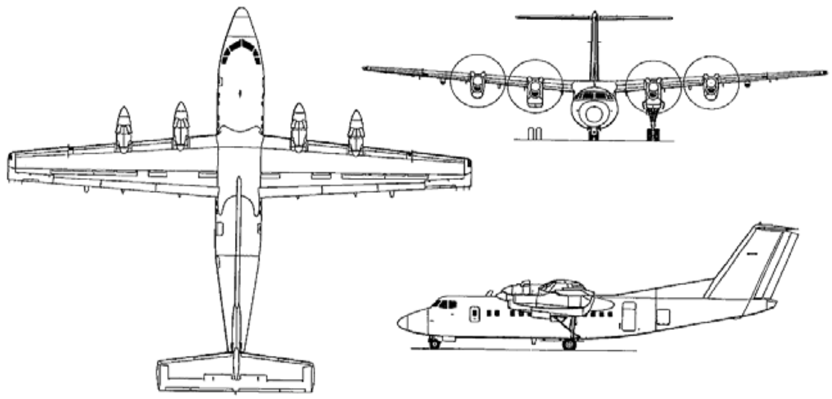

Figure 2.2 - de Havilland DHC-7 3-View
(Avistar, 2010)

In 1984, de Havilland introduced the Dash 8 Series 100 aircraft (See Figure 2.3), which retained much of the fuselage cross section of the Dash 7, though in hopes of enticing a greater number of airliners, only two engines were used to limit the maintenance and operating costs. Further to using only two engines, the Dash 8 utilized a wing better optimized for cruise, thereby sacrificing some of the short field performance that was characteristic of so many previous de Havilland products.

Figure 2.3 - de Havilland DHC-8 Series 100
(F. Camirand, 2011)

Subsequently, de Havilland was bought by Boeing and continued development of the successful Dash 8 series saw the introduction of the Series 300 and 200 respectively. The Series 300 increased the seating from the Series 100’s 40 passenger load to 56 passengers. This necessitated a change of the power plants from the Series 100’s Pratt & Whitney PW120 to the more powerful PW123, as well as an increased wing span, and two fuselage plugs (forward and aft extensions of the fuselage) to allow for the increased seating. As may be seen in Figure 2.4 and Figure 2.5, the Series 300 and Series 100 share the same general profile and fuselage design, while the Series 300 opted only for changes to the wingspan and fuselage length.

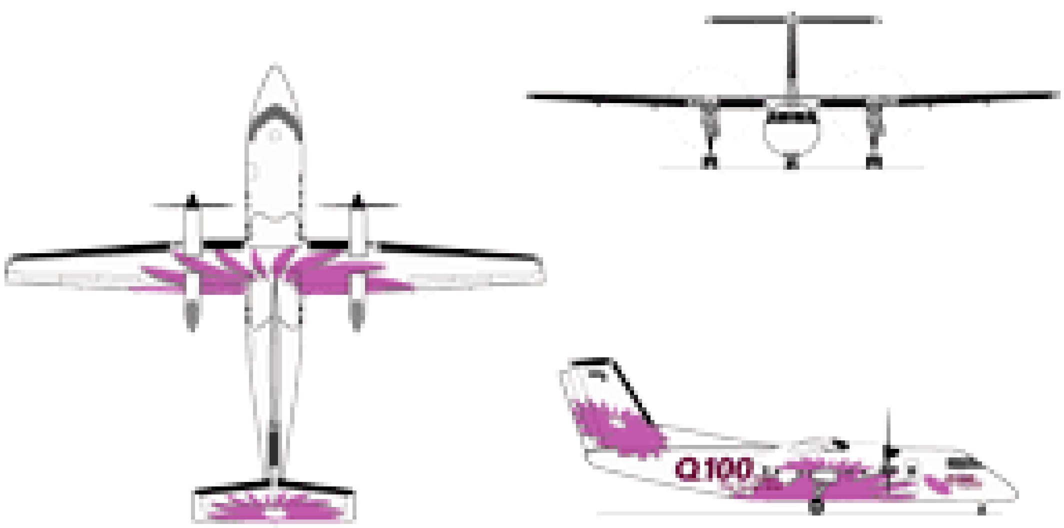

Figure 2.4 - de Havilland DHC-8 Series / Q100 3-View (Avistar, 2010)

Figure 2.5 - de Havilland DHC-8 Series / Q300 3-View
(Avistar, 2010)

The improved performance of the PW123 engine used in the Series 300 was then used to improve the economics of the original Series 100 design through the introduction of the Series 200 (See Figure 2.6). The Series 200 utilized the same airframe and systems from the Series 100, but with the use of the PW123, the increased performance saw increases in speed as well as more moderate fuel burn to improve the operating costs.

Figure 2.6 - de Havilland DHC-8 Series 200 (Sonnenberg, 2010)

In 1998, BBD, now the owners of de Havilland, entered the larger 70-78 passenger seat market with the introduction of the Series 400 (See Figure 2.7 and Figure 2.8). Based around the new Pratt & Whitney PW150 turboprop engine, the Series 400 improved the economics of the design even further. With the standard Series 400 and the increases in fuel prices through the 90’s and early 2000’s, the economics of an advanced turboprop design with jet like speeds brought BBD, now the owners of de Havilland, a profitable and long lasting design. The Series 400 not only retained common short take-off performance and relative quietness with the previous Dash 8 designs, but also brought about uncharacteristic high speeds for turboprop aircraft, approaching the speeds common, at the time, only to that of regional jets. The ability to transverse the regional airways with high speed and relatively low fuel consumption made the Series 400 design one of the most successful turboprops of the decade.

Figure 2.7 - Bombardier DHC-8 Series 400
(J. Whitebird, 2011)

With the success of the Series 400, BBD began redevelopment of the Series 200 and 300 with the introduction of an Active Noise and Vibration Suppression (ANVS) system and subsequently renamed the Dash 8 range the Q-Series (Q200, Q300, and Q400) to emphasis this fact. With the strong economical basis and relative comfort of the new ANVS system, the Q-Series aircraft saw even greater success, with the ultimate recognition of having over 1000 aircraft sold.

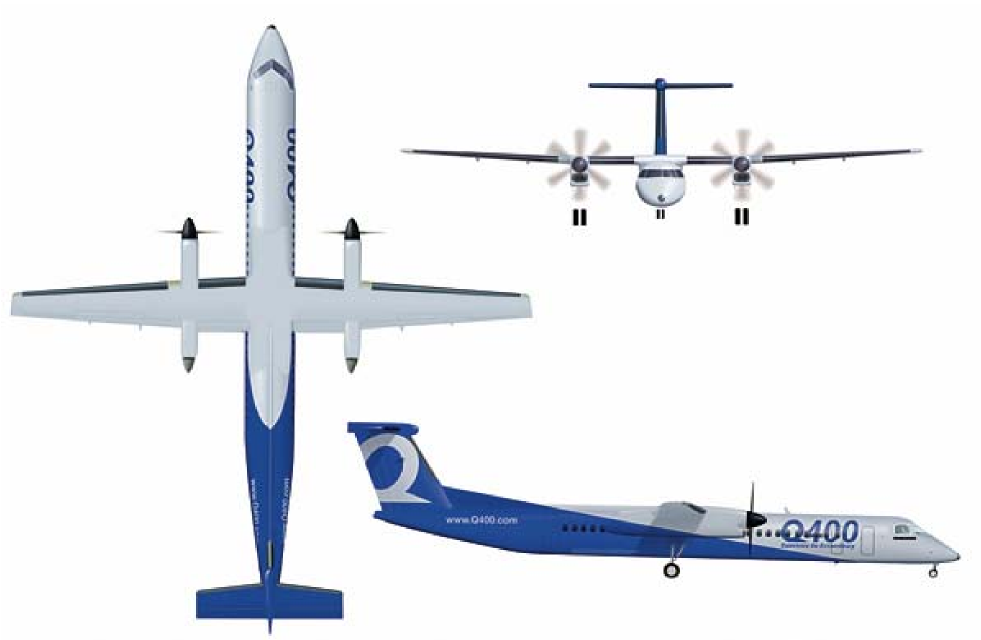

Figure 2.8 – Bombardier DHC-8 Q400 3-View
(Avistar, 2010)

2.2. Specifications

Whether designing an all new aircraft or redesigning a proven airframe, it is important to take into account the specifications of aircraft already developed in order to make the necessary assumptions and estimations for the new aircraft. As such, this section will review the publically released information regarding the performance, design, and capabilities of the current BBD Q400. Knowing these specifications will, especially in the case of the shortened and elongated design suggestions, provide a strong basis on which to move forward with the design.

The Q400 has the following basic specifications for the general aircraft configuration:

Crew: 2
Flight Attendants: 2-3
Passengers: 68-78

Maximum Takeoff Weight: 64,500 [lb]
Maximum Landing Weight: 61,750 [lb]
Maximum Payload: 18,696 [lb]
Empty Weight: 37,804 [lb]
Fuel Capacity: 11,724 [lb]

Maximum Range (200 [lb] x 70 PAX): 1,296 [NM]
Maximum Cruise Speed: 350 [kts]

Takeoff Length (SL, ISA, MTOW, HGW): 4,430 [ft]
Landing Length (SL, MLW, HGW): 4,250 [ft]

Maximum Operating Altitude: 25,000 [ft]

As may be seen from the above specifications, the Q400 provides a very versatile and strong performance airframe, especially when compared to the specifications of most turbofan powered models.

Figure A.1 in the A demonstrates the physical dimensions of the aircraft. As may be seen in the figure, the aircraft utilizes a high aspect ratio (AR) wing optimized for cruise. With a wingspan of 93 [ft] and 3 [in], the aircraft is capable of retaining reasonable takeoff runs, while achieving valuable high speed performance.

Figure 2.9 shows the general structural break down of the Q400. Of particular note, the changes made to the original Dash-8 Series aircraft to design the newer Series 400 airframe may be seen.

To enable the greater capacity of the 400 series aircraft, two fuselage plugs were added, fore and aft of the central fuselage section which houses the wing box.

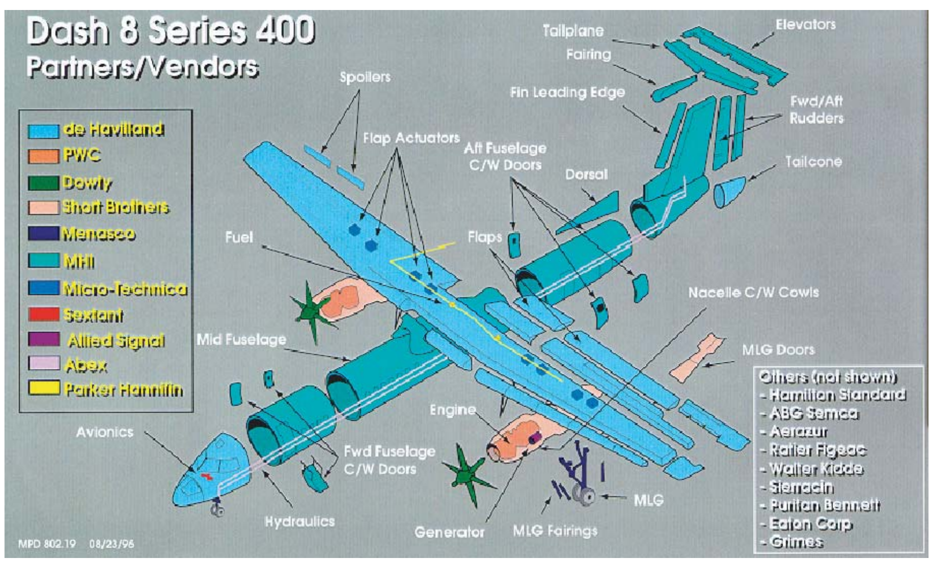

Figure 2.9 - Bombardier Q400 Breakdown
(Flight Safety Toronto, 2004)

One of the unique features of the Q400 design is its onboard Auxiliary Power Unit (APU). Such units are particularly useful for operations at airports that do not have ground start carts or for operators who wish to operate the air conditioning while running only one engine (The hydraulic system running the air conditioning is tied to the starboard side engine) which is not available on any other similarly sized turboprops.

3. THE MARKET

The ever-increasing competition in the regional aircraft market has seen resurgence in the acquisition of new aircraft in order to mitigate the increasing operational costs. As such, aircraft manufacturers strive to have the best information available in order to make educated decisions in how they should proceed with their development programs.

This type of research and market projection may be segregated into three distinct market requirements:

1) What the customer wants / needs;
2) What the competition is developing;
3) And what suppliers are able to provide.

The first item is a culmination of numerous factors and requirements that span many different cultures and operational environments. Therefore, BBD must take into account where its product will be used, the aircraft that are currently used by the operators, as well as associated costs with operating an aircraft, such as fuel prices. BBD and its competitors spend large sums of cash to hire the best experts in market research and even then, it is still difficult to pinpoint the exact requirements of these operators. Thus, it would be impossible to suggest that this paper would be able to review and make recommendations on all of these requirements, but this section will attempt to provide a high level review of the requirements cited by potential customers for a newly developed turboprop program by BBD.

The second important consideration in market research lies in understanding what the competition is doing, or will be doing. This is an even more difficult task than that of the previous operators' requirements. Understanding the development plans of competitor aircraft makers gives the company an intangible advantage. The development and release of a rival design can either spell doom for a new design or the lack thereof may provide a hole in the market that would be perfect for a new design. As such, BBD must take the competition into account when looking at its new turboprop to ensure the success of the design, and the section on Competition will attempt to provide a high level analysis of the current industry conditions.

Granted that what the competition and what customers want is the ultimate driver of innovation for an airframe manufacturer, the supporting components of that airframe play an important role as well. Airframes, while accounting for a great percentage of the weight of the final product, contribute a much lesser extent to the overall functionality and performance of said aircraft. As such, airframe manufacturers are also dependent on the technologies and components that its suppliers are able to bring to the design in order to have a truly successful product.

3.1. FORECASTING

Whether the analysis of market demand and requirements is conducted by an internal team or outsourced to another company or group, the following basic stipulations are used:

- Forecast for short (2 year), intermediate (5 year), and long (10+ year)terms;
- And must be tailored to the target markets.

(Program Management and Execution, 2011).

Splitting forecasts into the above mentioned timeframes (which may vary depending on the product cycle) allows for the manufacturer to set out a development strategy that not only takes into account the current design but also its impact on other future developments. Thus, these forecasts will take into account numerous factors that will support not only the initial phase of the product roll out but will also provide details on how the design will fair through its maintenance, in-service, and resale life (Program Management and Execution, 2011).

Bombardier recently released its market forecast for aircraft from 20 seats to 149 seats (See Table A.1 in the Appendix). Of particular note, Bombardier chose to expand its projections out to 20 years, most probably to account for its new CSeries program. For the purpose of this paper, the important figures to review are the number of aircraft to be delivered in the 20-59 seat markets and the 60-99 seat markets, as it is within this seating span that the design proposals are principally targeted for. For the 20-59 seat market, 300 new aircraft deliveries are expected to be made over the next 20 years. For the 60-99 seat market, Bombardier has forecast demand for 5,800 new aircraft (Bombardier Aerospace, 2011). Therefore, this forecast has suggested a strong market shift from the smaller capacity aircraft to those breaching the 100 seat capacity airframes.

ATR (Avion de Transport Regional) has also in the past year released its current interpretation of the market conditions for regional turboprop aircraft (See Table A.2 in Appendix). The figures of interest in this document suggest a larger segment of the market exists for the sub 60-seat airframe, namely up to 550 new units to be delivered in the next 20 years. But once again, the forecast for the 60-90 seat category is the most robust, with 1,250 new units to be delivered. Even then, ATR’s document suggests that 90+ seat turboprops will also see significant market share, with a proposed 1,150 new units entering the market (ATR, 2010).

ATR’s forecast also provides insight into a recent trend with regional operators, namely the move away from small turbofan powered jets into larger seating markets, leaving turboprops to dominate the shorter range, and smaller capacity routes. This particular point is reflected by a number of regional operators as noted in Section 3.2. This once again bodes well for the turboprop market and is a strong indication that the major turboprop manufacturers are confident that there is a market for their particular products over the next 20 years (ATR, 2010).

3.2. DEMAND AND LOCALITY CONSIDERATIONS

The market for commuter and regional based airlines is an endeavor of minimized costs to compete on the very smallest of margins. Thus, it is in the best interests of regional airlines to utilize aircraft that give them the lowest operating, capital, and break-even costs possible. As such, the importance of tapping into these requirements ensures that aircraft manufacturers will be able to bring to market a desirable product.

Beyond considerations of product life, the market survey must also consider the specific target audience for the design. The regional market, while generally serving communities within 1500 [nm] of each other, may not be globally centralized. A North American regional operator does not run its business the same way a European operator does. Nor do the customers of an African operator expect the same types of amenities as that of a far-East Asian operator. This presents a unique consideration for airframe manufacturers. People from different cultures and different operation environments must accept their product.

Further to this, there is the ever-present requirement imposed by the local government bodies. Granted that the European Aviation Safety Agency (EASA), the Federal Aviation Administration (FAA), and Transport Canada (TC) share similar standards that are in fact based on accepted requirements, there are other government bodies of nations that may have more stringent standards that must be met. The governing aviation authorities of India (Directorate General of Civil Aviation) and China (Civil Aviation Administration of China) each have their own stringent requirements that not only reflect the operating nature of the respective region, but may also impose restrictions on foreign made equipment to protect their local manufacturing base.

This has been a particular issue that is not new to Bombardier Aerospace, who has been in talks with Russian officials regarding the certification of the Q400 to operate in Russian airspace. This kind of market is primed for the introduction of the Q400 and its subsequent designs by BBD as Russian operators seek to replace their aging Soviet era airframes such as the Antonov An-24 (See Figure 3.1), which are becoming increasingly costly to operate and have seen safety concerns rise in recent years (Kaminski-Morrow, ATR more certain over prospects for 90-seat turboprop, 2011).

Figure 3.1 - Antonov An-24RV
(P. Gorbunov, 2011)

Clearly, these considerations complicate the market and thus must be apparent in the final evaluation when considering the introduction of a new product. Bombardier already has a well-established customer base in the European, North American and Australian markets, with increasing interest in the emerging markets of India. Thus, any new development of the Q400 program must continue to cater to these customers while allowing for new inroads in other markets.

Well-established airliners are generally more easily interpreted as they often have a direct link with the manufacturer, either through maintenance programs or in-service monitoring. Of course, this is not limited only to Bombardier customers that operate the Q400, but may be influenced by operators who use other Bombardier products as well.

Skywest, in its plans to merge with United, has begun its search for a replacement for its Bombardier CRJ-200 jets (See Figure 3.2). Skywest, like many other airliners, continues to feel the squeeze that the increasingly expensive cost of fuel has on operating small jets on relatively short distance routes. Thus, there is a strong interest in switching to turboprop aircraft, such as the Q400 or its successor (Ranson, 2011).

Figure 3.2 - Delta Connection CRJ-200 Operated by Skywest (A Hunt, 2011)

But beyond wanting just any turboprop, Skywest's president Chip Childs has stated that the current offering of turboprops do not provide the necessary operating cost structure that would be an optimal replacement for the CRJ-200. Child's sees possibilities in a DHC-8 Q300 design that has been improved using modern avionics and power plants. This would prove to be one of the prime factors in supplying a shortened Q400S design that features the speed and economics of the base Q400 with a smaller capacity that would suit the routes specific to airliners like Skywest (Kirby, Turboprop Industry Growth Switches On and Off, 2011).

Bombardier’s legacy Q400 customers, including Horizon, Colgan, and Flybe continue to look at their options for expanding their operations. While satisfied with their current fleet of Q400’s, all three operators have begun voicing their wish for an aircraft with greater capacity while having similar performance capabilities. Specifically, a 90-100-seat turboprop from either Bombardier or ATR appears to be the prime candidate for their fleet renewals (Kirby, Turboprop Industry Growth Switches On and Off, 2011).

Flybe is a rather interesting operator, basing its current fleet of Q400s at its hub at London City airport (See Figure A.6 in A Appendix). There are a number of requirements that operators must be able to satisfy in order to operate out of this particular airport (Flybe, 2011). The airport is situated in a highly populated area, thus requiring the observance of strict sound restrictions. Secondly, while located conveniently near the center of the city, it is marred by a relatively short runway (London City Airport Ltd., 2011).

Skywork, a Berne-based Q400 operator has been seeing its capacity also limited and thus has made public its wish for a 90-seat turboprop as well. Though, as a clear example of current market perceptions, Skywork’s Chief Operating Officer, Rolf Hartleb has stated "We talked to manufacturers and I think they have not encouraged us to wait [for] a 100-seater in the [turboprop] market. I think that is not what they're planning" (Kirby, Skywork Studying 100-Seat Aircraft for Fleet Expansion, 2011).

This is a rather interesting point, as it speaks to the essential consideration of timing the introduction of a new product to market. In this case, the need for the 100-seat turboprop aircraft is there, yet airframe manufacturers, including Bombardier have yet to satisfy it.

3.3. COMPETITION

This section will present a view of the development plans of BBD’s competitors in the regional aircraft market. Competitors such as Embraer of Brazil or ATR of France and Italy have been in and out of the market over the last two decades and have contributed to the turboprop market with varying designs and philosophies, which are markedly different from that of BBD. Thus, as a global and competitive player, BBD must consider the development plans and market posturing that these companies are taking in order to optimize the introduction of the next Q400 iteration.

ATR is a coalition of Italian Aliana Aeronautica and EADS of France and has seen success designing and producing an all turboprop lineup for a number of decades. ATR took a similar path to de Havilland in that it began its development with the 50 seat ATR-42 (see Figure 3.3), progressing with the ATR-72, a stretched variant with a 72 passenger capacity (ATR, 2011).

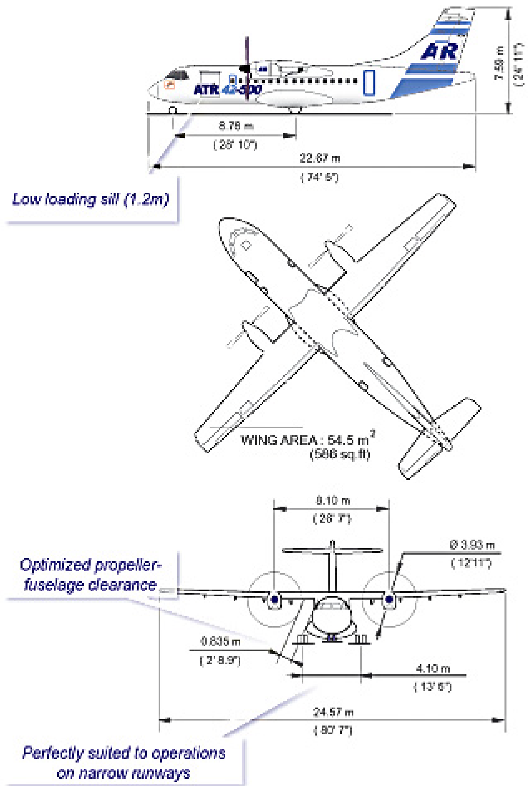

Figure 3.3 - ATR 42-202
(ATR, 2011)

ATR has recently released an avionics and interiors upgrade to their venerable designs with the release of the ATR 42-600 and 72-600 (See Figure 3.4).

Figure 3.4 - ATR 72-600
(ATR, 2011)

As described by ATR, the new turboprop will demonstrate the following basic features and performance figures:

Crew: 2
Flight Attendants: 2-3
Passengers: 60-72

Maximum Takeoff Weight: 50, 265 [lb]
Maximum Landing Weight: 49, 273 [lb]
Maximum Payload: 17, 173 [lb]
Empty Weight: N/A
Fuel Capacity: N/A

Maximum Range (200 [lb] x 70 PAX): 825 [NM]
Maximum Cruise Speed: 276 [kts]

Takeoff Length (SL, ISA, MTOW, HGW): 3,500[ft]
Landing Length (SL, MLW, HGW): 3,000[ft]

Maximum Operating Altitude: 21,000[ft]

(ATR, 2011)

As is clearly apparent by these figures, the ATR 72-600 made a number of tradeoffs in performance and economics in order to be the most competitive entry into the market yet released by ATR. The following paragraph further describes the importance of these tradeoffs and the effects the have had on the final product.

The tradeoffs are an integral part of the definition of ATR’s differing design philosophy from that of BBD. For instance, ATR maintained a shorter take-off run and landing distance in order to cater to smaller airport operators. This is particularly appealing to operators that are in less developed countries, which have airport infrastructure that may be limited in terms of length and quality. In contrast, BBD compromised takeoff and landing distances to further refine the Q400’s cruise performance, which is more appealing to operators utilizing finished and modern airports that are further apart.

This tradeoff is also apparent in the relative ranges that the two aircraft are capable of. ATR sacrificed MTOW substantially in its ATR 72-600 design. This is a direct limiting factor on the range the aircraft is capable of achieving. The MTOW limits the fuel that the aircraft is able to carry, thus less fuel will limit its range. Of course, the reduced range may still be more in line with ATR’s target customers, who may be assumed to require range less than that of Q400 customers.

Clearly the ATR 72-600 is a directly competitive entry to the BBD Q400, but ATR has already voiced its opinions on its next design. Specifically, ATR believes that by 2012, it will have the technological requirements and customer base to begin to flesh out a larger, 90-seat design (Kaminski-Morrow, 2011).

Embraer’s (EMB) historical footprint in the turboprop market began with development of the EMB-110 and subsequently the EMB-120 (Figure 3.5).

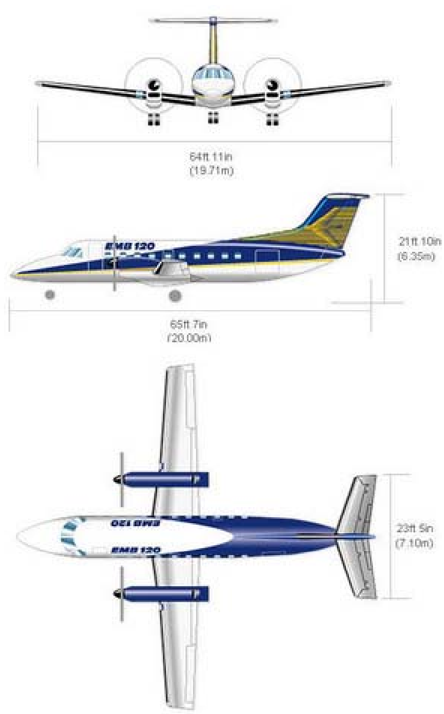

Figure 3.5 - Embraer EMB-120
(Avistar, 2010)

These aircraft concentrated on the smaller, short-ranged market. With a relatively short production run of only 367 aircraft, it may be questioned as to how successful the design actually was (Avistar, 2010). This does not, however, discount the valid design features and attempt to target a specific market. Of particular note, the EMB-120 features a large percentage of commonality with the larger, and more successful EMB-145 twin jet regional aircraft (See Figure 3.6). This fact is important both from the standpoint of production and operational use of the aircraft (Avistar, 2010).

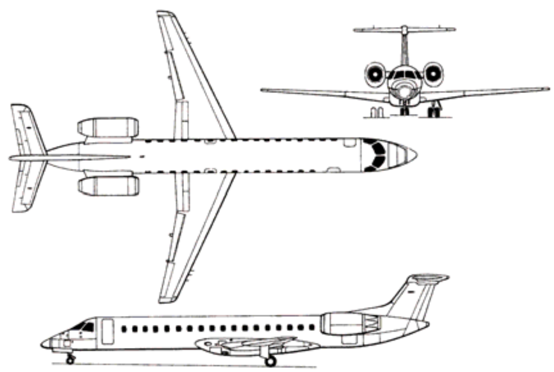

Figure 3.6 – EMB-145
(Avistar, 2010)

In the case of production, commonality allows the manufacturer to merge production lines, suppliers, and components in order to mitigate final costs that would press the margins earned with the aircraft. For operators who utilize a common fleet, EMB capitalized on the fact that operators could call on parts and supplies common to their entire fleet. This makes it easier to keep aircraft operating when parts or components fail in the field, and ultimately will limit manufacturing costs for the operator.

As mentioned in the *Forecasting* section, splitting forecasts into three distinct time frames (the actual lengths of these time frames may change from manufacturer to manufacturer), companies must tailor their development strategy to achieving their company goals in their respective time. For instance, a company may take the view of fulfilling a market segment in stages to satisfy the customer requirements while mitigating the costs associated with supporting a development through a low demand time period. This type of instance has been exemplified by Embraer’s recent decision to split their development into a medium term to re-engine their venerable E-Jet line of aircraft (See Figure 3.7) and development of a clean sheet aircraft to replace the fleet in the longer, ten-year time frame (Boynton, 2011).

Figure 3.7 - Embraer EMB-170 E-Jet
(Henig, 2010)

As in Embraer’s E-Jets, Bombardier must decide the timeline of release for their product, not only in relation to meeting the requirements of their customers, but also offsetting the developments of their competitors.

3.4. Supplier Considerations

Bombardier can implement the most advanced techniques in design and ergonomics for its new iteration of the Q400, but without the support of key components, its product will not be able to deliver the necessary performance expected by customers. Therefore, BBD is dependent on primary suppliers of these key components to be successful.

It is important that in the context of evaluating the next form of the Q400, that supplier requirements and capabilities are also evaluated. Engines are a prime example of such components that are closely tied to the overall performance figures of the new design.

Pratt & Whitney Canada has been the sole supplier for the Q400 line engines throughout the production run. The P&WC PW-150A (See Figure 3.8) is a proven design offering the necessary thrust at a reasonable rate of fuel consumption that has been a large part of the success of the Q400 in the past. Thus, it would be logical to access P&WC’s ability to have a new engine ready for implementation of the new design.

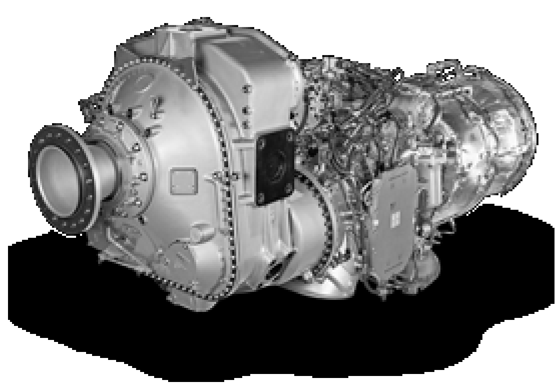

Figure 3.8 - Pratt and Whitney Canada PW-150A Turboprop Engine (Pratt and Whitney Canada, 2011)

According to media reports, P&WC has already initiated research and development into the introduction of a 5000-7000 [SHP] turboprop tailored to the 90-seat aircraft. It is already estimated that the new iteration of P&WC’s engine would realistically be ready for market around 2016 (Michels & Compart, 2011).

Of course, engine makers also have competition to deal with, which for Bombardier, may work to its advantage in procuring the best performing engine for a competitive price point. General Electric (GE) has also been touting the development of its CPX38, a civilian variant of its already in production GE38 turbo-shaft helicopter engine (See Figure 3.9).

Figure 3.9 – GE38 Turbo-shaft Engine (MTU, 2011)

Though the GE38 engine is a turbo-shaft at heart, its configuration and core are easily converted to the configuration required for a turboprop aircraft in the 90-seat category (Michels, GE Sees Demand For Larger Turboprops, 2011).

4. SHORTENED Q400S DESIGN PROPOSAL

The BBD Q300 design saw great success in its time, serving the 40-50-seat market effectively. Nonetheless, the design is decades old, and through the 90's and early 2000's, competitor manufacturers ventured into this market keen to take up where the Q300 left off. The Saab 2000 was one such competitive example, which, while technologically advanced, failed to achieve a substantial market, thus resulting in only having 60 examples built. The purpose of the proposed Q400S (S for Shortened) is to reengage the 50-seat market segment by bringing the modern technological advancements of the Q400 airframe, modern avionics and systems into a shortened airframe.

This section will take an in-depth look at how a shortened Q400 concept would fare in modern market conditions while balancing the triangular requirements of cost, time, and product quality. The following will be discussed for this particular concept:

- Performance and configuration requirements;
- Technical Specifications;
- And Feasibility;

4.1. Q400S DESIGN REQUIREMENTS

The inherent design requirement in the shortened Q400 proposal is ensuring that the airframe be able to profitably carry a maximum of 50 passengers. Further to this, market research for a design shows that the operators are specifically looking for an aircraft to replace their current fleet of jet and turboprop 50 seat aircraft. Therefore, depending on their current fleet, each operator is looking for some specific requirements.

In the interest of balancing cost of investment and the quality of the product, it is in the interest of BBD to specifically define what requirements it can actually satisfy in its design and build. Thus, the following will define the requirements expected of the design and evaluate the costs of implementing them.

Since there are two distinct classes of aircraft that operators are attempting to replace (Jet and Turboprop), each must be looked at separately.

Those operators currently operating turbojet-powered aircraft are primarily concerned with lowering their fuel consumption per passenger seat. Generally speaking, a 50 seat turbojet aircraft will be established for use in markets that are only able to support flights with such a small load. Therefore, it would be difficult to introduce greater capacity where it wouldn't be supported. So instead of increasing the number of seats for a jet transport, a switch to a 50-seat turboprop would be quite logical. A special note for operators switching from turbojet to turboprop aircraft, the range of the aircraft would be significantly different. Therefore, the Q400S design would have to be able to support operations of significant range in order to achieve orders from this market segment.

For those operators utilizing turboprop aircraft in the 50 seat category already, the case for replacing it with a shortened version of the Q400 design must be made with more advanced avionics and improved fuel efficiency with the newer and more powerful PW 150A engine.

Based on the above, the Q400S design would have to meet the following general specifications in order to achieve significant market share:

- 40 to 60 seat capacity;
- 1000 - 1500 [NM] range;
- 300-360 [kts] cruise;
- Modern Avionics Suite;
- And a cost break-even point between 30-40% capacities (15-20 seats filled).

It is on these general requirements that the Q400S design will be evaluated and reviewed in the following sections. These requirements represent the very basics for a successful design.

4.2. Q400S TECHNICAL SPECIFICATIONS

The Q400S is intended to retain as much of the current Q400's infrastructure and design as possible. As such, the technical changes are restricted to those that would reduce weight and size of the cabin to achieve the lower, 50-60-seat capacity.

Based on the previously mentioned requirements, a rudimentary sizing was developed utilizing Raymer's Rubber Engine Weight Sizing technique. The method used a standard mission segment typical of a regional airliner:

1) Engine start and Taxi;
2) Takeoff
3) Climb
4) Cruise
5) Loiter
6) Descent and Approach
7) Aborted Landing
8) Loiter
9) Decent and Approach
10) Landing

Based on this mission, the sizing analysis was conducted using the baseline BBD Q300 and Q400 series aircraft. Upon conducting the sizing based on these aircrafts' weights, a suitable correction factor for the method was determined. This correction factor was then applied to Raymer's model in order to determine a realistic sizing for the Q400S.

Therefore, the following specifications were determined by the Raymer method:

Crew: 2
Flight Attendants: 2
Passengers: 58

Maximum Takeoff Weight: 52,070 [lb]
Maximum Payload: 18,696 [lb]
Empty Weight: 28,640 [lb]
Fuel Capacity: 8,330 [lb]

Maximum Range (200 [lb] x 58 PAX): 1,600 [NM]
Maximum Cruise Speed: 360 [kts]

Maximum Operating Altitude: 25,000 [ft]

Reference Table A.3 in Appendix for further specifications.

Beyond this, the aircraft should retain the Thales based Q400 Next Gen cockpit currently in use to maintain commonality with the type.

Figure 4.1 shows the authors view of a potential Q400S design. Further drawings with basic dimensions for the Q400S may be found in the Appendix, Figure A.3.

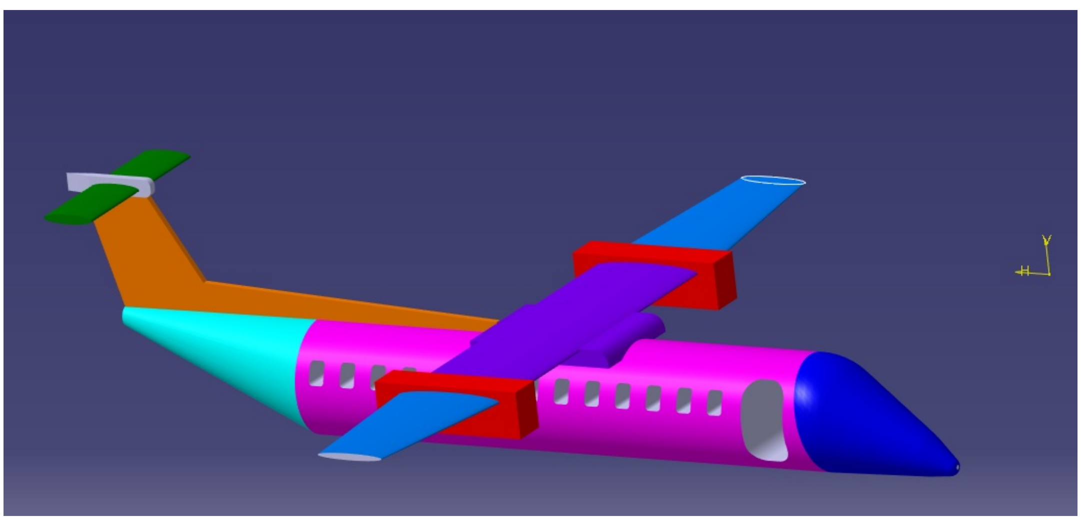

Figure 4.1 - Q400S 3D Render

4.3. Q400S DESIGN FEASABILITY

The Q400S design has a great advantage in that Bombardier has already produced a 50-seat design in the past, namely the DCH-8 Q300. Thus it is the intention of this proposal to utilize the same cross section of the current Q400 model, with the same positioning of the wing and empennage components as on the Q300. This would minimize costs in changes to the production line, allowing for full integration with the current infrastructure Bombardier already has in place at its Toronto-Downsview site.

Though based on a certain assumptions regarding progress in design and materials, the weights calculated for the Q400S would suggest that to carry the same payload of the Q300 would require significantly fewer penalties in performance. This of course is further enforced by the increased speed inherent in the new design, with a 75 [kts] increase in cruise speed.

The use of the legacy cockpit currently found on the Q400 would allow the Q400S to maintain commonality with the Q400; allowing operators that would fly both types to interchange components and cross train their crews with minimal issues regarding flight deck operations.

Another distinguishing feature from the Q300 would be the inclusion of an Auxiliary Power Unit (APU) with the aircraft. While the Q300 was only able to operate its air conditioning unit with engines running, the ability to use an APU to power the Environmental Control System (ECS) prior to engine start, a comfort to passengers sitting on board waiting for the aircraft to depart.

The Q400S design would be the lowest cost proposal in terms of physical unit cost as well as investing in infrastructure, parts and materials.

There are of course issues with the design proposed here. To achieve the 360 [kts] cruise speed would require the use of the PW-150A engine or a variant of it. With this engine being optimized for the 70-seat market segment, there is a high-level fuel consumption penalty. This issue has been echoed by BBD in response to customer’s request for a 50-seat turboprop.

> "You need enough chairs to cover the speed," says director of market development Jerome Cheung, who adds that 50-seat high-speed turboprops had struggled to meet large-scale demand.
>
> (Kirby, Turboprop Industry Growth Switches On and Off, 2011).

Furthermore, to balance the speed range and weight stipulated, the aspect ratio (AR) of the aircraft has been reduced from 13 on the Q300 to 12.46 on the Q400S, which is more in line with that of the Q400. This should help with the take-off and landing performance, but will require substantial changes to the wing design and structure.

5. EXTENDED Q400X DESIGN PROPOSAL

The 90-100-seat arena has been largely exclusive to pure turbofan engine designs and has therefore been seen as one of the largest potential markets for turboprop powered aircraft to move into. Traditionally, the turboprop was often regarded as solely purposeful for the 50-seat class due to restrictions in speed and size. This of course was subsequently rendered an old fashioned view with the success of the 78 seat BBD Q400 design and the ATR 72-500 design, both of which cater to the 72 seats plus market. It is therefore quite conceivable for the designs of turboprops to take the next logical step up to the 90-seats-plus market.

In the past, restrictions in engine performance limited the performance that a 90-seat turboprop aircraft would have, but with the introduction of new turboprop designs by General Electric (GE) and Pratt & Whitney, the required thrust for such a design is well within reach.

The possibility of an extended design of the BBD Q400 has seen much interest in the aviation community. The appealing nature of a 90 seat, fuel efficient design has many attributes that are very attractive to cash strapped regional airlines.

Thus, based on the generalized analysis above, this section will examine in detail a possible proposal for an extended design of the Q400. Here the reader will find a definition of specific requirements which a Q400X (X standing for extended) will be required to fulfill, technical specifications of the design, and finally, an analysis of the feasibility of the design, both in terms of investment and market return.

5.1. Q400X DESIGN REQUIREMENTS

As with the shortened design, the extended Q400 design is attributed to filling the gap in the larger turboprop market. As such, a number of operators looking for a new aircraft to add to their fleet will be primarily replacing turbojet or turboprop aircraft in the 80 – 90 seat capacity market. Currently, there is no turboprop aircraft in production that is capable of carrying 90 passengers, and therefore, it is a gap in the market that represents a great need.

In the case of current turbojet operators, like those operators utilizing 50 seat regional jets, the requirement for a 90-seat turboprop stems from the requirement for lower fuel consumption. It is here that the Q400X invariably has its appeal in replacing current regional turbojets. As with the Q400S, the Q400X will have to suffice with a shorter range compared to other current turbojet 90-seat models, though during regional operations, it is common that a range of 1000 – 1500 [NM] is all that is required.

The current turboprop operators would look to the Q400X design to increase capacity on their current routes where turbojets would be uneconomical and smaller capacity turboprops cannot support the demand. As such, this is a unique advantage for the Q400X designs which, fully exploited, and has the potential to fill a strong market sector.

Beyond the above-mentioned compliments of the Q400X design, the extended design also has an advantage of commonality with the original Dash-8 Q400. Market research shows a clear link that operators wish to maintain commonality in their fleet. This is of course for some fundamental reasons namely:

- Maintenance personnel training may be reduced;
- Replacement parts may be common across different models;
- Pilot training may be simplified across models;

Fleet commonality plays an important role in aircraft acquisition; therefore the Q400X would be particularly suited for the task, especially for operators currently flying the standard Q400 model.

As such, the following basic requirements would be necessary for a successful Q400X design:

- 80-100 seat capacity;
- 1000 – 1500 [NM] range;
- 300 – 360 [kts] cruise speed;
- And commonality in avionics and systems with standard BBD Q400.

Based on these requirements, the following Q400X proposal will be evaluated.

5.2. Q400X TECHNICAL SPECIFICATIONS

Like the Q400S proposal, the Q400X is intended to retain the overall look of the current Q400, while introducing the improvements in performance through better materials, new power plants, and an extended fuselage to accommodate the increased number of passengers.

The following are the sizing and basic performance parameters computed for the proposed design using the Raymer Rubber Engine Weight Sizing method previously discussed:

Crew: 2
Flight Attendants: 4
Passengers: 90

Maximum Takeoff Weight: 72, 810 [lb]
Maximum Payload: 23, 300 [lb]
Empty Weight: 39, 320 [lb]
Fuel Capacity: 10, 190 [lb]

Maximum Range (200 [lb] x 90 PAX): 1,300 [NM]
Maximum Cruise Speed: 360 [kts]

Maximum Operating Altitude: 25,000 [ft]

The reader may reference Table A.3 in the Appendix for further specifications.

Based the above specifications, a render of the proposed Q400X design may be seen in Figure 5.1 and its dimensions are visible in Figure A.4 of the Appendix.

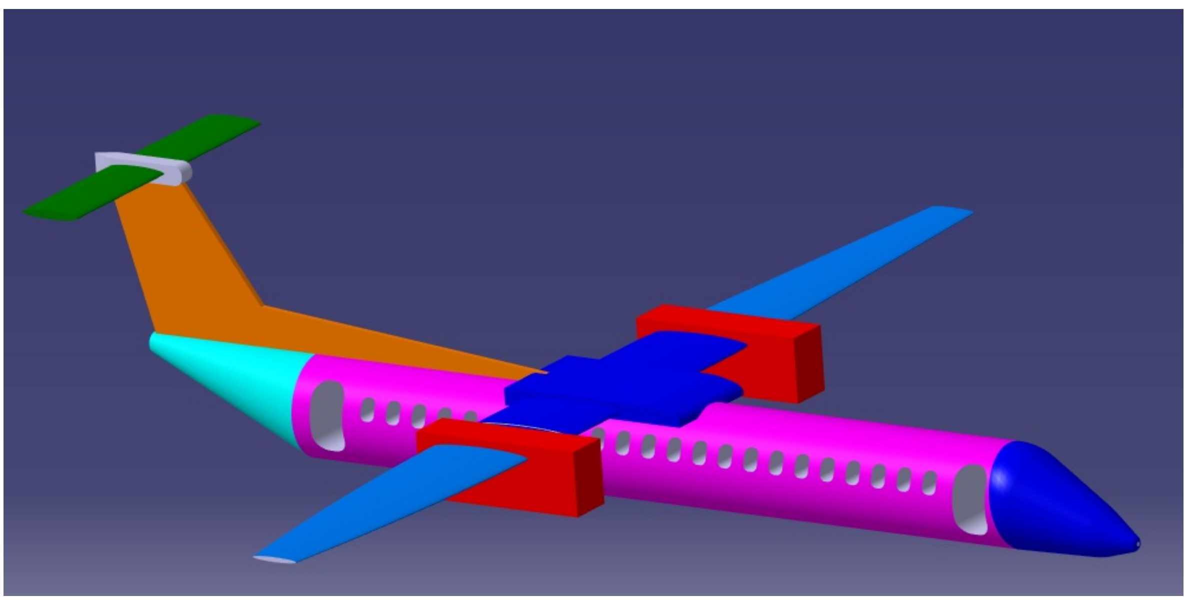

Figure 5.1 - Q400X 3D Render

In order to maintain commonality with current Q400 operators, the Q400X design should use the Thales based Q400 avionics suite. Also, while the Q400 does already have an APU, the Q400X should offer customers an in-air operable unit to improve system reliability.

5.3. Q400X DESIGN FEASABILITY

The Q400X design has many desirable attributes that appear to be in high demand from the market at large. As mentioned in the Market Analysis section of this paper, operators see the need to increase their capacity on a number of routes and to replace their aging and fuel guzzling regional jet aircraft.

As may be seen from the proposed specifications, the design achieves the desired velocity and payload with a reasonable increase in the weight of the aircraft. A penalty in range and airfield performance would be required to offset the use of the new engines in the 7000 [SHP] range.

Like the Q400S, the Q400X retains the basic fuselage cross-section, wing and empennage positions. As with the transition between the Q300 and Q400, Bombardier could extend the fuselage “plugs” to achieve the required seating arrangement.

The use of current manufacturing infrastructure and support equipment is another feature of this design, lowering the required investment in the project by BBD. This could be used to lower the unit cost of the aircraft or to increase the profit margins of sales.

Retention of the Thales avionics suite will ensure that pilots are interchangeable in operations that have operated the Q400, like Flybe and Horizon. Passengers would also be confronted with a familiar interior across types, which may have a qualitative effect on customer retention and satisfaction.

For operators that are achieving their optimal load with 70 passengers, the Q400X presents another opportunity in having enough space on board to introduce an executive seating arrangement for some passengers. This would attract business consumers that often fly inter-city routes that the regional operators service.

The ability to operate the APU in air is another significant advantage for operators. The basic ECS of the Q400 relies on both engines operating, thus sacrificing the comfort of passengers if one of the engines becomes inoperable in air. With an air-operable APU, the pilots would be able to start the APU to power the ECS as well as other systems in the case of an in-air engine shutdown. Of course, an APU capable of in-air operation could potentially be used at all times; the power generated by modern APU’s is much greater than the power used by aircraft systems. Therefore, in terms of normal aircraft operations, the engines are capable of supplying ample electrical power, while leaving the APU off and limiting unnecessary fuel consumption by the unit. Once again, it is an ever present requirement that any and all fuel used during aircraft operation is optimized in terms of performance output and fully utilized.

As may be seen in the parameters stipulated, the range of the Q400X is less than that was originally proposed. This was a conscious sacrifice to achieve the other customer requirements. Note though that the majority of operators utilize the Q400 on routes of 1,200 [nm] or less, thus the 1,300 [nm] standard should not be too great of a problem.

While retaining the Q400’s cockpit in the Q400X is a compliment to fleet standardization, it should be noted that the Thales avionics suite is still based on the original Q400 cockpit released in 1998. Therefore, it represents 13-year-old technology, something new operators may be wary off.

Another detriment to the Q400X design is the tunneling effect of such a long fuselage has. The two by two seating arrangement forces for a long and slender fuselage. Beyond the requirements for substantial structural reinforcement and weight penalties, passengers may have qualitative issues with the perception of being in such a fuselage.

6. QX DESIGN PROPOSAL

The purpose of a clean sheet proposal is for BBD to take full advantage of the modern design techniques, systems, materials, and engines to engage the market place with a truly revolutionary design. Therefore, unlike the previous two proposals, the QX design would not be restricted by the original Dash-8 design, instead being able to optimize the new turboprop to achieve the full potential of such a design.

Though a free-hand design would allow for the incorporation of every requirement and want that customers might have, BBD would have to confine the scope of such a design in order to properly manage cost. While the application of some of the technology and aerodynamic theories now available to designers, a full case review must be made to evaluate what can practically be achieved in the new aircraft design.

Furthermore, there is the obvious human side to aircraft design that must also be considered. Generally speaking, the customers of a regional airline expect to board an aircraft that looks typical, or in other terms, a design that actually looks like a classic airplane, at least to a certain extent. This type of factor speaks to the comfort and trust that a new design must instill in customers to be successful. For example, while forward swept wings may represent some aerodynamic advantages (though not practical for a relatively slow speed air transport), customers may be uncomfortable with the design, thus would be wary of buying tickets on such flights. Human factors such as these are often difficult to quantify, and thus, new designs must be innovative, while maintaining a relatively classical look to both achieve aerodynamic refinement and customer confidence.

While the above briefly alludes to some of the major requirements of the new QX design, the following sections will present a thorough review of the proposal to evaluate if this path would provide BBD with the most return on its investment.

6.1. QX DESIGN REQUIREMENTS

Any time an airframe manufacturer decides to undertake a new, clean sheet design, there are a number of priority requirements that must be evaluated and set. This requires a proper and comprehensive review of the market actually wants from the product. Hence, a review for proposal of a new aircraft design is often considered a project in and of itself. While this paper’s intention is to evaluate a number of proposals, this section will provide a high level review of the typical design requirements for the new QX design.

Therefore, the following basic configuration must be retained when evaluating this proposal:

- 80-100 seat capacity;
- 1000 – 1600 [NM] range;
- And 300 – 360 [kts] cruise speed.

Beyond this, it would be imprudent to not take into account other development programs being undertaken by the company. In BBD’s case, the development of the CSeries narrow body, medium range passenger turbojet has been in development for years and is attempting to make headway in the market (See Figure 6.1 and Figure 6.2). Of particular note, the CSeries sports a 5 abreast seating arrangement. This has been shown to have the appeal of the comfort of wide-body aircraft while retaining the required weight and structural requirements optimized for regional flight. Therefore, the QX design may benefit from a new cross section design that does away with what some passengers might suggest is a long and somewhat claustrophobic effect of the elongated Q400 fuselage.

Figure 6.1 - Bombardier CSeries CS300
(Bombardier, 2011)

Figure 6.2 - Bombardier CSeries 5-Abreast Seating Configuration
(Bombardier, 2011)

A clean sheet design also provides the opportunity to replace aircraft systems that have contributed to difficult operation or problems in dispatching the aircraft. Namely, it is the optimum opportunity to review the systems that were a detriment to the customer’s operation of the aircraft and supply the new design with more refined systems.

The Q400, like its predecessors, relies on air inflated “boots” along the leading edges of its wings, vertical stabilizer, and horizontal stabilizer. This basic design is an essential part of the de-icing system for the aircraft, inflating upon ice detection by the crew, and in turn, causing ice to break up along these surfaces. This system has a long operational use in turboprops and is seen as a relatively cost-effective solution to icing protection. Of course, it is also a system that contributes to in-service issues as has been noted by Horizon Air (Gillie, 2010). Thus, it is a prime system to be replaced in the new design. Taking the proven designs of its CRJ-700/900 and Global Express line of aircraft, Bombardier could leverage electronically heated leading edges to improve the reliability of the system.

6.2. QX TECHNICAL SPECIFICATIONS

The new QX design will attempt to utilize much of the new technologies and materials used in the CSeries design. This includes the incorporation of the 5 abreast seating arrangement and new, Rockwell Collins Avionics suite.

Figure 6.3 depicts a render of the proposed QX design and Figure A.5 in the Appendix presents the basic dimensions. Some of the key changes to the standard Q400 design would be a relocation of the horizontal stabilizer, the addition of winglets and optimized wing geometry, as well as a substantially widened fuselage cross-section. The lowing of the horizontal stabilizer from the typical Bombardier T-tail configuration was to mitigate the effects of deep stalls associated with a horizontal stabilizer positioned such that it may be blanketed by the wings wake at high angles of attack. The inclusion of winglets and new wing geometry would improve cruise performance by reducing wing tip vortices and improve low speed stability while retaining cruise performance. Finally the increased cross-section would allow for the 5-abreast seating configuration that is currently being developed for the BBD CSeries.

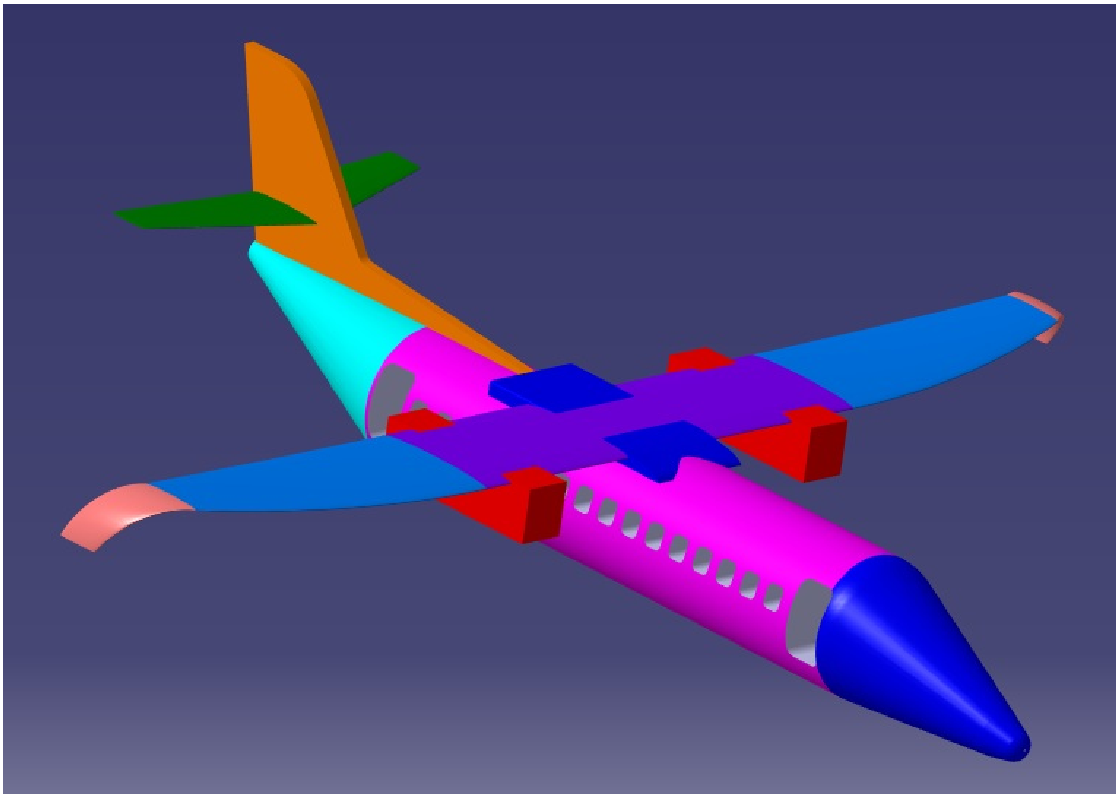

Figure 6.3 - 3D Model of QX Proposal

Based on the performance and payload requirements and utilizing Raymer's Rubber Engine Weight Sizing method, the following was calculated to be a feasible design for the QX:

Crew: 2
Flight Attendants: 3
Passengers: 78

Maximum Takeoff Weight: 67, 660 [lb]
Maximum Payload: 20,300 [lb]
Empty Weight: 35,860[lb]
Fuel Capacity: 11,500 [lb]

Maximum Range (200 [lb] x 78 PAX): 1600 [NM]
Maximum Cruise Speed: 360 [kts]

Maximum Operating Altitude: 25,000 [ft]

Reference Table A.3 in Appendix for further specifications.

6.3. QX DESIGN FEASABILITY

The proposed QX design is intended to be a clean-sheet replacement design for the venerable Q400, thus it is primarily targeted for current Q400 operators and ATR-72 operators with seating capacities of 60-80 seats.

The technical parameters calculated above suggest that with modern materials and design techniques, the QX would be able to achieve a further 400 [nm] over the legacy Q400 while increasing payload by 2,000 [lb]. These parameters would be potentially achieved while still maintaining the current maximum take-off weight of the Q400, with an approximate increase of 3,200 [lb].

The larger cabin cross section would allow for a roomier and more comfortable experience. Furthermore, operators that would purchase the CSeries range of aircraft would find commonality in parts and interiors, thus improving the customer experience and allowing for pilots, crews, and maintenance teams to cross train on the fleet.

The QX design features an increased AR over the Q400 at 13.55. This will be a detriment to the take-off and landing performance of the aircraft, but it will be offset by the fuel efficiencies and increased range of the aircraft. Of course, the increased range of 1,600 [nm] may not be of great importance to current regional turboprop operators with typical routs of 1,200[nm] and less distances.

In taking into account the development cost of the CSeries and the length of time to develop it, Bombardier would require the longest lead-time of the three proposals if it selected the QX design. As $3.6 billion dollar investment, the CSeries was a costly endeavor that doubtlessly took up a vast amount of company resources. Thus, Bombardier may not be quite prepared to undertake another large and costly development program.

7. PRODUCT DEVELOPMENT SELECTION

The selection of a final proposal, especially one that will financially and strategically affects the position of a global manufacturing company, is not to be taken lightly. The complexity of aircraft design and the market its products must satisfy have many facets, both technical in nature and qualitative in other attributes. Thus, for the purpose of this exercise, the following basic parameters were utilized to evaluate the three proposals against the benchmark the current Q400 in operation.

Avionics

Avionics takes into account the factors of commonality for the purpose of operators already operating aircraft with similar aircraft suites. It also takes into account the age and technological capabilities of the systems.

Comfort and Ergonomics

This attribute takes into account the passenger experience, both in terms of aesthetics and comfort of the cabin design.

Cost

The quintessential attribute, cost incorporates the monies required for investment and development of the proposal.

Cruise Speed

The speed which the aircraft is able to safely transit from departure to destination.

Development Resources

The reliance on commitment of resources, including materials, tools, and technical manpower.

Development Time

The time required from initial design definition to production ready aircraft.

Infrastructure

The ability of the proposed design to utilize the already in place infrastructure, including plant sites.

Payload

The passenger and cargo load the aircraft is capable of carrying during its mission

Performance

The take-off, landing, and handling qualities of the design proposal.

Range

The distance the aircraft is able to transit with full fuel and stipulated payload and speed.

Weight

The maximum take-off weight and empty weights of the proposed designs. Attribute affects structural requirements as well as other performance requirements.

Based on these parameters, the decision matrix found below as Table 7.1, was completed. A percentage value was applied to each of the attributes to reflect the relative importance to the final design and its operational use. A score of 1 to 5 was then applied for each aircraft against each attribute to generate a final score that is used to evaluate the best design proposal.

Table 7.1 - Aircraft Proposal Decision Matrix

Attribute	Percentage	Q400	Q400S	Q400X	QX
Avionics Commonality / Age	5	3	4	4	4
Comfort and Ergonomics	5	3	3	3	5
Cost	15	N/A	3	3	1
Cruise Speed	5	3	3	3	3
Development Resources	5	N/A	3	3	1
Development Time	15	N/A	3	3	1
Infrastructure	5	N/A	4	4	1
Payload	15	3	1	5	4
Performance	5	3	3	2	4
Range	10	3	4	2	4
Weight	15	3	4	3	5
Total	100	36	61	65	59

In terms of avionics and piloting systems aboard the proposed designs, all aircraft would reflect the relatively modern systems used on board other current BBD products, thus establishing common operating requirements. Though the QX design would have the potential for the newest flight deck, it would suffer from commonality with previous Q aircraft, and thus a balanced score was applied to it as well.

The extension and shortening proposals would allow for use of the current interior from the NextGen Q400 aircraft, while the QX proposal would incorporate the wider interior reminiscent of the CSeries, with the potential for greater comfort.

The cost both in terms of development and cost for the operator would primarily be lowest for the Q400S and Q400X designs, as these require the least amount of time and resources for development and utilize many of the current systems already in use. The QX design would also require the greatest price tag for the final customer, which when competing with ATR, any great increases in cost may oust it out of the competitive running.

With the common speed requirement imposed by the design proposals, all proposals benefit from the 360 [kts] cruising speeds. Thus, all three proposals are scored equally.

Like cost, development time and resources are a direct influence on the ability of the manufacturer to produce an aircraft in a timely fashion without starving other development programs of technical expertise. Thus, the QX design would require the greatest investment by BBD while the Q400S and Q400X, would be equally taxing on the available resources.

With the NextGen Q400 currently being built at the Toronto-Downsview site, the use of the current manufacturing facility would be relatively simple for implementation of the Q400S and Q400X designs. The QX would require a complete redesigning of the factory or development of a new facility.

Payload is one of the greatest differentiating factors of the three proposals. With the greatest seating capacity, the Q400X design would have the potential to give operators the lowest operating cost per seat.

The Q400X would be required to sacrifice some of its performance figures in order to increase its payload capacity. With the latest refinements in aerodynamics and structures, the QX would allow for the greatest potential in performance enhancements of the three designs.

Range for the Q400S and QX designs would be relatively equal, while the Q400X would have to sacrifice some for its increased payload requirements. Of course, range for regional operators is not always the most important characteristic, and the Q400X still retains substantial range to make it attractive to the target market.

The QX design would benefit from the greatest weight savings, while to support the enhanced payload, the Q400X would have to be reinforced, thus requiring a weight penalty. Though this attribute has one of the greatest effects of all on the operational use of the aircraft, the refinements to all three proposals would limit the affects and make all three proposals reasonably attractive.

The results of the review demonstrated that the Q400X design proposal would be the primary choice for BBD to implement as its next design iteration of the Q400 program.

8. CONCLUSIONS

Bombardier has a long history of aircraft design upon which to tap the engineering and mechanical know-how to develop the next Q400 design. By leveraging this knowledge and strong customer base, BBD could provide the market with yet another success story.

The selection of the Q400X design proposal was based on a number of tangible factors that suggest BBD would be able to optimize the cost and time to develop the aircraft, while bringing to market a desirable product in a timely fashion that would limit the ability of competitors to counter.

It is important that the reader note that all evaluations, whether market or technical, were completed at a high level for the purpose of the overview of the proposals that this paper was intended to purvey. Nonetheless, the attributes and basic requirements outlined are a necessity for BBD to incorporate should they elect to produce an extended Q400.

On a final note, there is nothing that limits the incorporation of other performance, environmental, or systems in the Q400X proposal. For example, the incorporation of new leading edge anti-ice protection systems to replace the inflatable boots may be a wise decision. Also, to mitigate the age of the current Thales avionics suite, BBD could introduce the Rockwell Collins avionics suite intended for the CSeries design. While these do have cost and development time ramifications, there improvements in reliability and capability may offset these detriments to an acceptable extent.

Whatever path it selects, BBD must continue to reinvent its product line in order to remain competitive and enter the next generation of turboprop regional airliners.

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A. APPENDIX

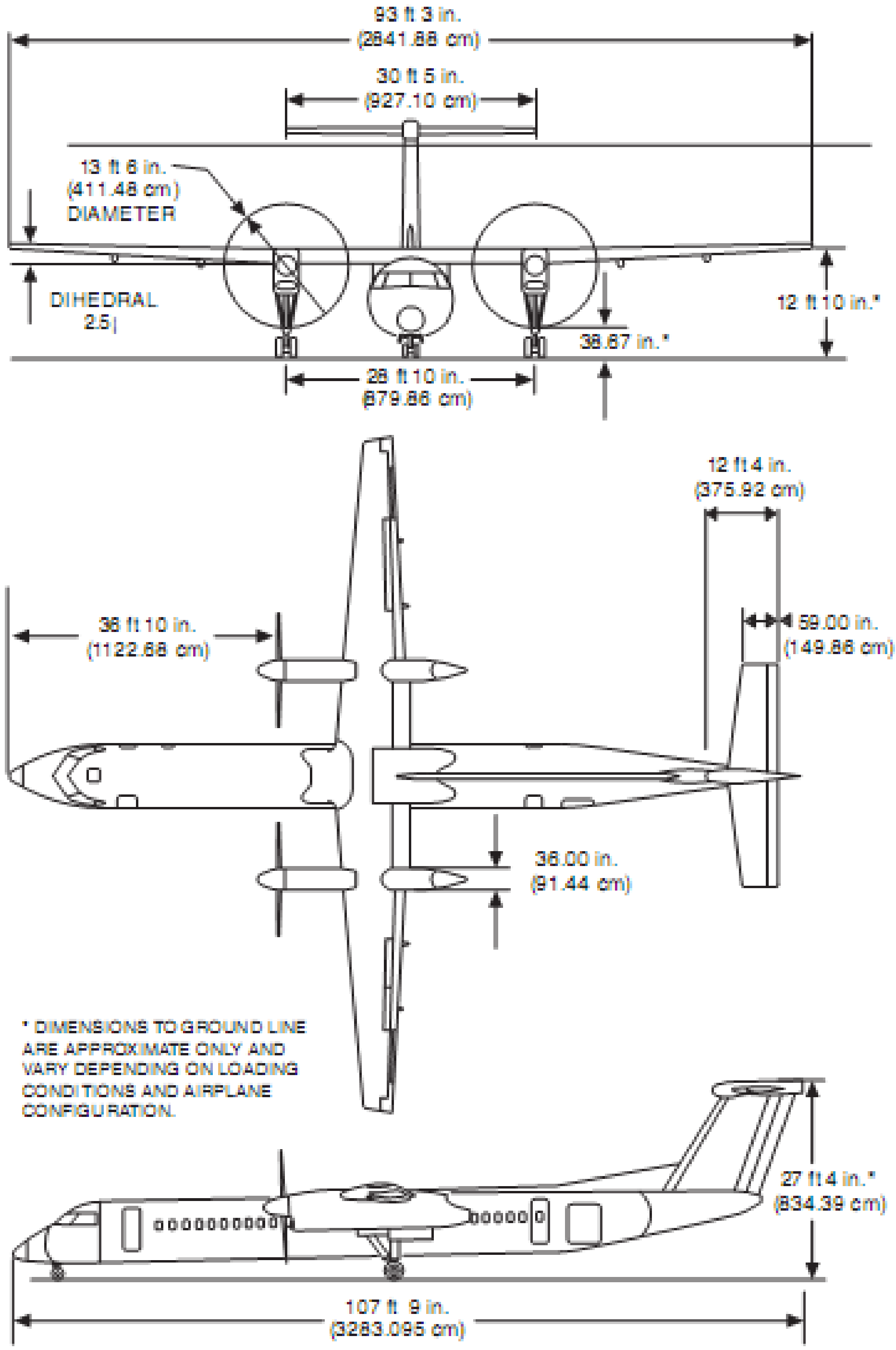

Figure A.1 - Bombardier Q400 Fuselage Dimensions (Flight Safety Toronto, 2004)

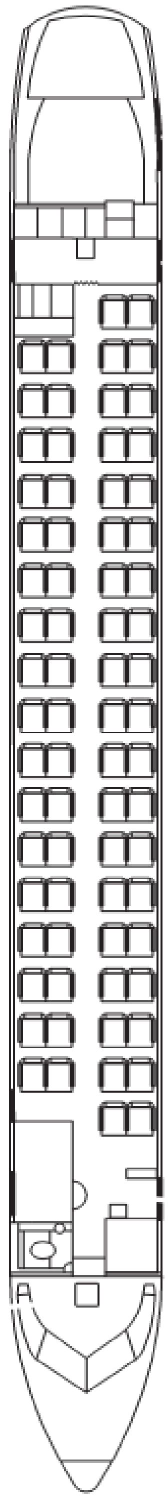

Figure A.2 - Sample Q400 Interior Configuration (72 Seats)
(Flight Safety Toronto, 2004)

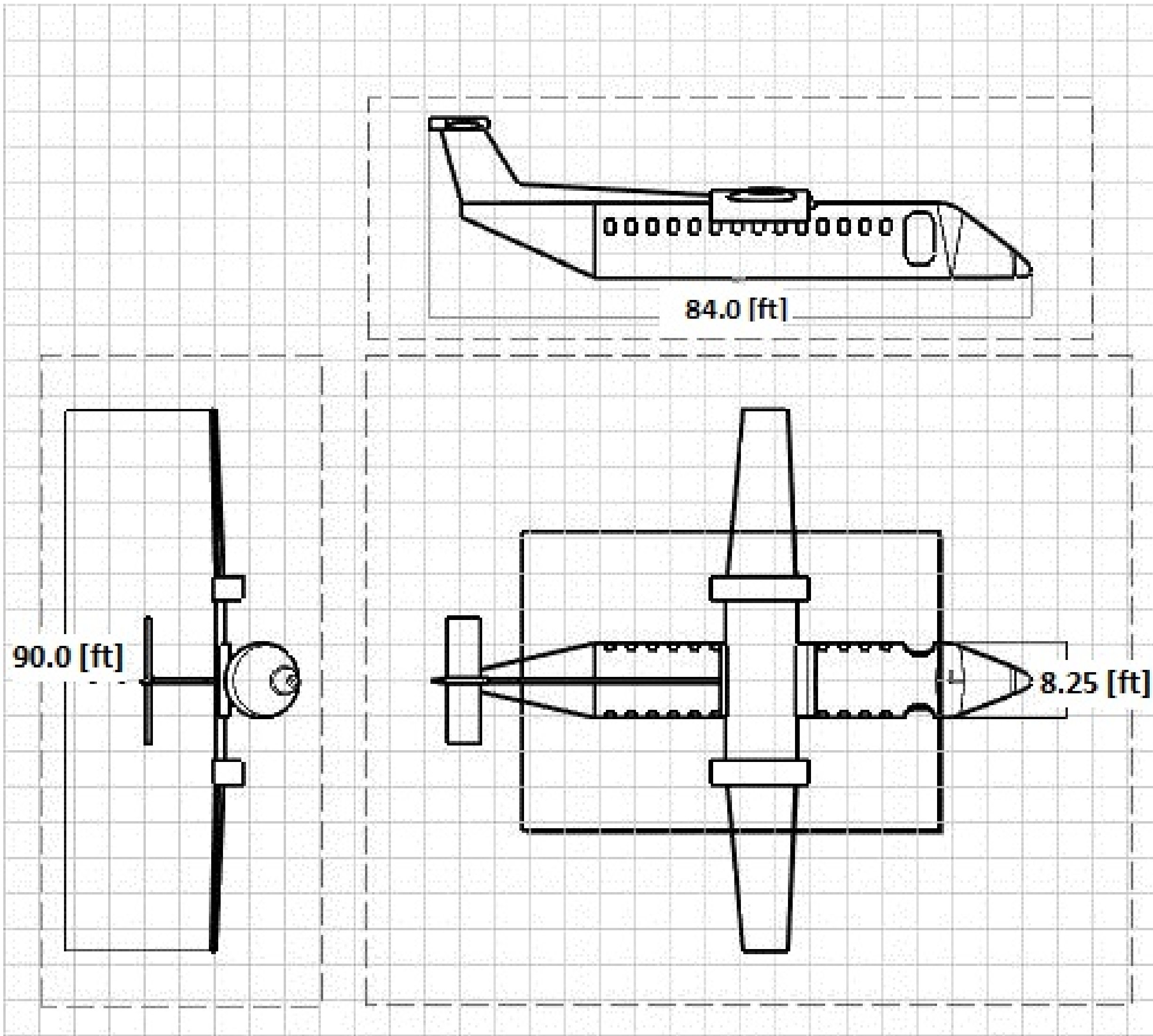

Figure A.3 - Q400S Proposal 3-View

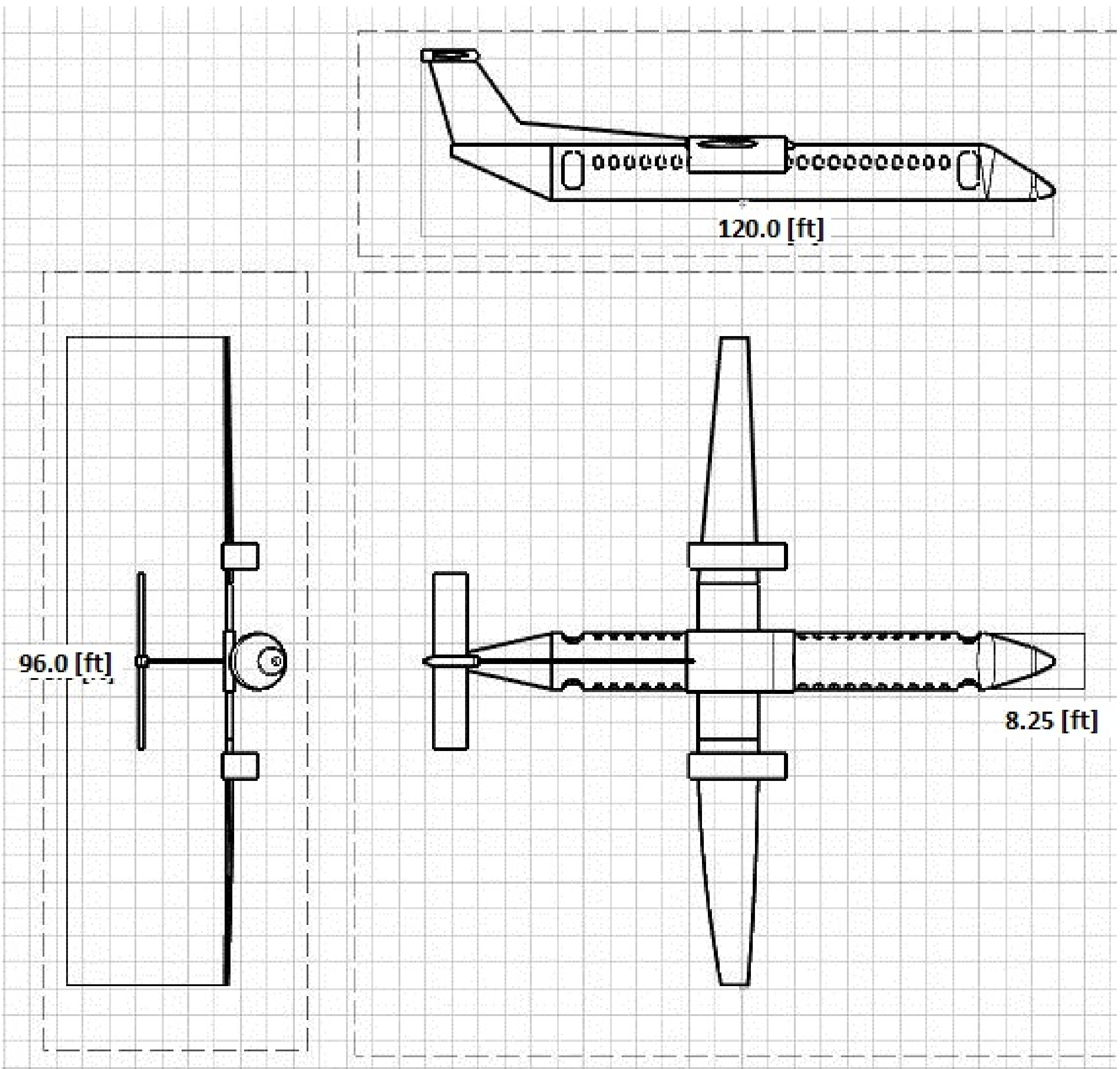

Figure A.4 - Q400X Proposal 3-View

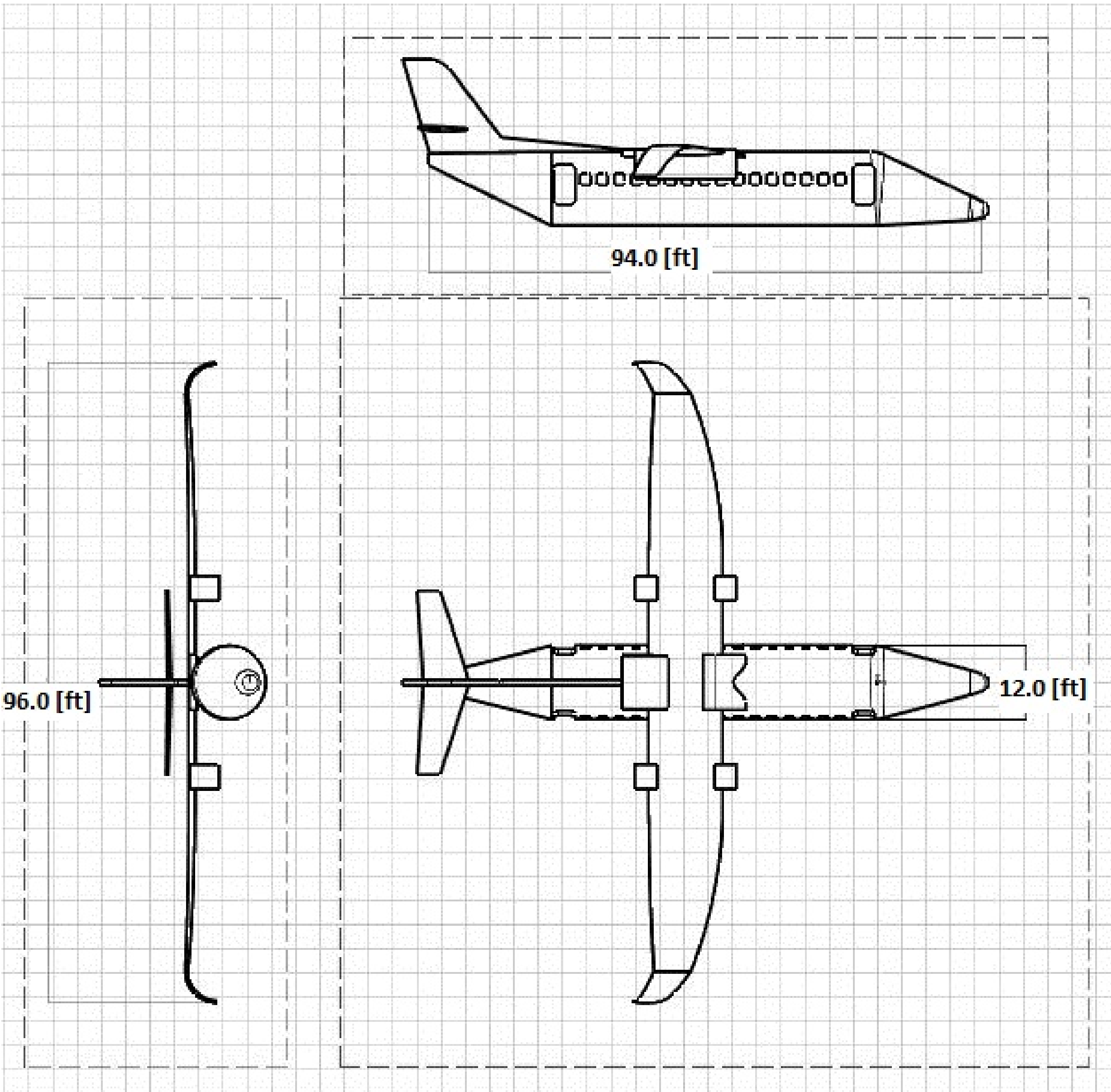

Figure A.5 - QX Proposal 3 View

Table A.1 - BOMBARDIER 2011 MARKET FORECAST (Bombardier Aerospace, 2011)

FLEET GROWTH FORCAST				
SEGMENTS	**FLEET 2010**	**DELIVERIES**	**RETIREMENTS**	**FLEET 2030**
20- TO 59-SEAT	3,600	300	2,500	1,400
60- TO 99-SEAT	2,200	5,800	1,200	6,800
100- TO 149-SEAT	5,200	7,000	3,000	9,200
TOTAL AIRCRAFT	11,000	13,100	6,700	17,400

Table A.2 - ATR 20-YEAR MARKET FORECAST (ATR, 2010)

FLEET FORCAST FOR 2030			
SEGMENTS	TURBOPROP	REGIONAL JETS	TOTAL
30- TO 60-SEAT	550	300	850
61- TO 90-SEAT	1250	1100	2350
91- TO 120-SEAT	1150	3050	4200
TOTAL AIRCRAFT	2950	4450	7400

Table A.3 - Aircraft Proposal's Technical Attributes*

Aircraft	Q400	Q400S	Q400X	QX
MTOW [lb]	64500	52070	72810	67660
# OF CREW	4	3	4	4
# of Passengers	70	58	90	78
RANGE [NM]	1200	1600	1300	1600
CRUISE SPEED [kts]	360	360	360	360
SPAN [ft]	93	90	96	96
AREA [ft^2]	679	650	740	680
AR	12.7	12.5	12.5	13.6
W_C [lb]	800	600	800	800
W_P [lb]	18300	14500	23300	20300
W_E [lb]	37866	28640	39320	35860
W_f [lb]	10345	8330	10190	11500

*Technical parameters calculated utilizing methods outlined in D. Raymer’s Aircraft Design: A Conceptual Approach (2006)

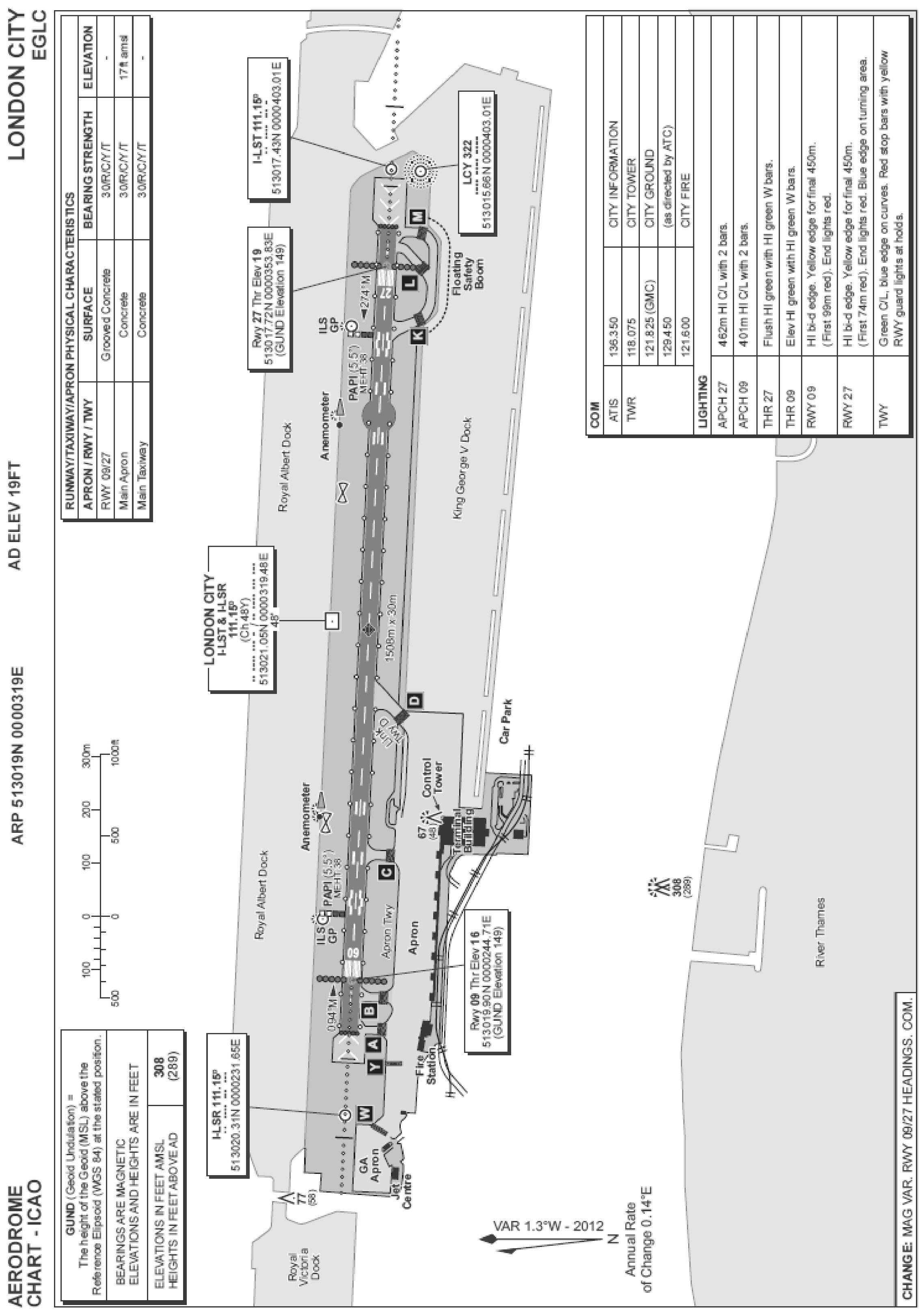

Figure A.6 - London City Airport ICAO Information (Civil Aviation Authority, 2011)