A Risk Review of Urban Mobility Vehicle Concepts.

Applying the Evolutionary Lessons of the Past to the Future

Abstract

An examination of the certification and market risks for new aircraft projects aimed at the urban mobility sector

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About the Author

Richard Abbott has worked in aerospace development since 1992. He started his career as a stress engineer on military aircraft projects. For the last 17 years, he has worked with part 23 and 25 aircraft and part 27 rotorcraft companies developing new composite and metal, personal and business aircraft. He has worked in the UK, USA, Belgium, Canada and the Caribbean.

Richard currently holds the position of structures manager for Stratos Aircraft, acting structures, and mechanical systems manager for the Otto Aviation Celera 500 and acts as an adviser for DeLorean Aerospace as well as several other aircraft programs. Richard teaches several engineering courses including an engineering management course at the University College of the Cayman Islands and is the author of the textbook "Analysis and Design of Composite and Metallic Flight Vehicle Structures" and over 200 widely used spreadsheet-based engineering tools.

Author's Note

Engineers and entrepreneurs who have not worked in aircraft development and certification may not realize the impact that certification has on development cost and the eventual success of a project.

A trusted contact of mine suggested that I write a white paper on an assessment method for aircraft conceptual designs. I agreed as this would achieve several things:

- Confirm or contradict my positive gut feeling about the DeLorean Aerospace DR-7 aircraft concept. A project on which we are engaged.
- Provide a useful tool to make assessments of new aircraft designs
- Provide a tool to measure proposed modification of concepts to increase viability

At the very minimum, I would standardize my personal bias and keep my comparisons consistent.

This paper and resulting spreadsheet tool represent my attempt to codify a method, an honest attempt to minimize my personal bias and give a relative means of assessment of any urban mobility aircraft concept against of field of competitors', current in early 2018.

This paper includes references to regulations, external reports, and industry data. It also includes the opinion of the author based on his experience in aircraft development in certification. The author has discussed many of these issues with other similarly experienced engineers and industry leaders. If you disagree with the cited numbers, interpretations of the cited data or the author's opinion please email the author at rabbott@abbottaerospace.com.

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Introduction

At the start of any technological or market revolution, there is an evolutionary explosion of ideas and concepts. This can be conceptualized similarly to the Cambrian Explosion of 541 million years ago. Over time the many genetic variations are naturally selected until only the variations that naturally suit their environment or are able to adapt to their environment survive.

This effect can be observed to a lesser or greater extent when any technological breakthrough is developed in a relatively free market.

Phase 1:

Many organizations will evolve many different designs which will be tested in the market and regulatory environments. Over time different archetypes made by several manufacturers will survive the natural selection process.

Phase 2:

In the long term, these organizations will grow their market share, reduce in number through consolidation and will stabilize as two or more large organizations.

These two phases can be characterized as '*Conceptual Cull*' and '*Corporate Consolidation*'.

This white paper is concerned with the 'Conceptual Cull' phase.

This paper is not entirely scientific in nature. Where possible empirical assessments are made. These assessments are combined with the informed experience of the author and the reviewers in order to draw rational conclusions.

Technical Feasibility

This white paper is not intended to be a criticism of any single concept or any single company. This paper is not concerned with technical feasibility and for the purpose of this study, it is assumed that all of the designs reviewed are technically feasible.

In this context 'Technically Feasible' refers only to the ability (demonstrated or not demonstrated) to fly safety within a limited envelope.

There are other technical aspects that affect market success. These include:

- Reliability – inoperability due to component failure
- Likely life of the product
- Frequency, ease, and cost of scheduled maintenance

Of these technical aspects reliability and it's effect on utility, market perception and the frequency, ease and cost of scheduled maintenance have been considered. These two aspects of operation are related to the mechanical complexity of the aircraft product.

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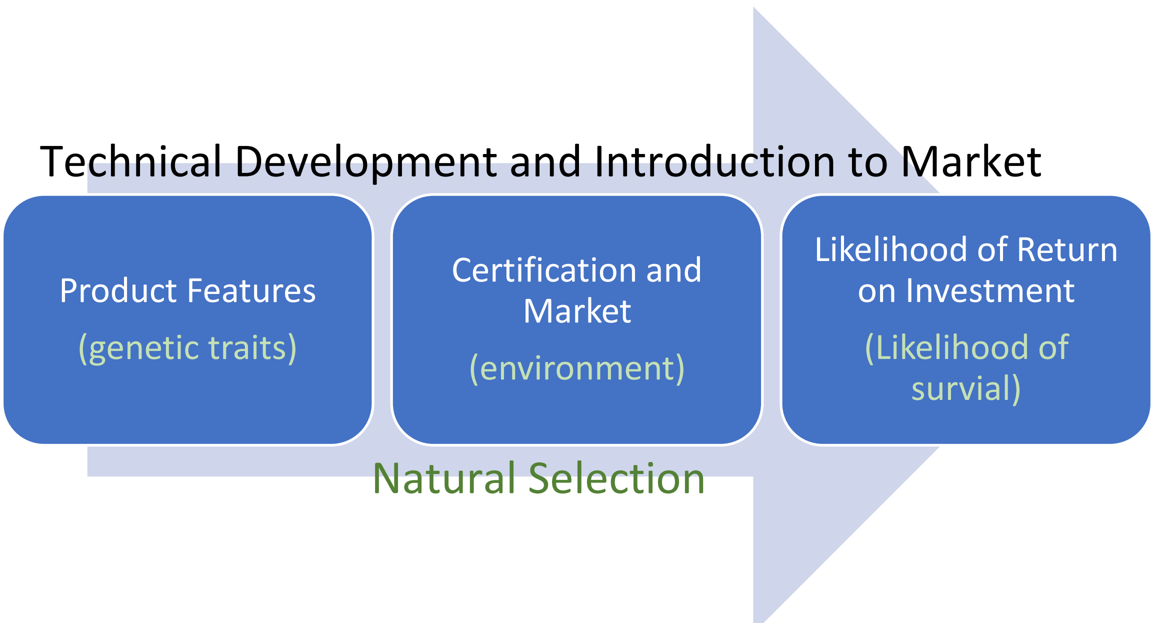
The paper examines the likelihood of success in the combined market and regulatory environments (the environment).

For the purpose of this study 'success' is defined as achieving a level of profit relative to the investment required to bring to market, such that the investors are likely to recoup the funds invested.

This is a value judgment based on a semi-empirical weighted factors approach informed by the author's direct experience.

In general, the product features (the organism) are assessed against certification risk, where certification risk is directly analogous to development cost, and likely market acceptance.



The basis for the various assessments made is explained in the next section.

Certification

The certification environment acts as a gateway to the market environment. In this paper, it is assumed that it is possible to certify all the products considered. The cost of certification is affected by the features of the product.

The features of the product are assessed with regard to the impact on the cost of and time to certification

This numerical assessment results in the *Certification Quotient*

The recent rewrite of the part 23 standards was done, in part, to simplify the introduction of new technologies into the part 23 aircraft sector. It remains to be seen if the new part 23 standards will achieve this goal. Any regulatory changes in the short term are likely to cause disruption and delay, this translates as an additional cost to the aircraft developer. In the medium to long-term the new standards may have a positive impact.

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Most of the aircraft examined for this study will have some component of part 23 certification. The potential impact of the new part 23 regulations on the certification quotient has not been included in this assessment. It has been assumed that the ease of certification under part 23 is equal to that under the previous part 23 standards.

LSA Certification may also be applicable.

Market

The market is where the products are tested against each other and against the discriminatory purchasing power of the public.

The desirability of the product is affected by the features and the performance of the product. The potential effect of perceived value is ignored, and the market is assumed to be entirely pragmatic.

The size of the market is unknown. The market is a projected to be a combination of commercial operators (air taxi or on demand autonomous use) and private owners and it is assumed that the same features will appeal to both commercial and personal owners and operators equally.

This numerical assessment results in the calculated *Market Quotient*

Certification and Market Combination

The certification process has a significant effect on the cost of development and therefore the price of the product. It is assumed that the investors in each of the products want to recoup their investment and the larger the investment required the higher the price of the product in the market. The higher the price of the product the less likely it is to succeed.

The cost component is balanced by the desirability of the product in the marketplace. The more desirable the product is the more likely it is to succeed.

The combination of the *Certification Quotient* and the *Market Quotient* is called the *Survival Quotient.*

A score of zero for either of the *Market Quotient* or *Certification Quotient* does not indicate a zero chance of success. The results are normalized between 1 and zero. A score of 1 indicates the highest relative chance of success and a score of zero indicates the lowest relative chance of success.

Survival Quotients are calculated for all the aircraft products listed in Appendix A. The *Survival Quotients* are a relative measure of viability and do not represent an absolute likelihood of success.

Survival Quotients are calculated as a negative or positive value that represents the distance and direction the point is from a line on the Urban Mobility Environment graph. The line represents the condition of the certification and market environments.

During the development of the assessment method, two reference configurations were used to check relative scores. The characteristics of a fixed-wing part 23 light aircraft and a part 27 light helicopter are simple to define. The results of these comparisons are included in Appendix B of this paper.

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Note on the Market Environment.

It should be noted that there are existing products in the market who are already established and competing for the same resources. The most obvious of these is the helicopter. Helicopters have been used for decades for 'urban mobility' in the business and executive segments.

It would be foolish to believe that helicopter manufacturers already in the market are not ready and able to compete for the presumed expansion in the market for urban mobility aircraft.

The effects of the existing products in the market environment and their competition for the same resources are not included in this study. They are assumed to have an equal effect on the new products and so do not affect the relative chance of success of the projects surveyed.

Result

The 5 concepts in the VTOL category with the highest overall survival quotient will be published at the end of the white paper

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Candidate Products

To qualify for this study, the concept must fulfill the following criteria

1) Originate with a startup company, if it is later bought out by an established OEM this project is still a valid candidate
2) Be represented as an urban mobility design, or a design that can meet those needs. Some new fixed-wing concepts are included and these are highlighted in the results
3) Have either a completely electric drive system or a hybrid drive system
4) Be of a non-typical aircraft/rotorcraft configuration

All the candidate concepts are listed in Appendix A.

The concepts reviewed at the time of writing are correct and complete to the best of the author's knowledge.

As the aim is not to criticize individual concepts or projects. The individual concept designs are not identified in the results plot or the accompanying spreadsheet data.

I have not considered the DR-7 as candidate concept. Because of my association with that project I do not want this paper to promote that concept. If the user is interested in how the DR-7 compares with the field of concepts they can enter the DR-7 project parameters into the spreadsheet tool.

Assessment of Concepts

The range of vehicle configurations and technical features of the vehicles are diverse. It is impossible to label each vehicle as an individual type.

Therefore, the candidate concepts are classified according to defining characteristics. These characteristics are:

1) VTOL or non-VTOL – Yes/No

Can the vehicle take off and land vertically? – Neutral for Certification, Positive for Market Acceptance. ***VTOL = 1 or 0***

2) Road-ability – Yes/No

Can the vehicle be driven on the public highway? Negative for Certification Cost, Positive for Market Acceptance. ***ROAD = 1 or 0***

3) Motor and Propeller/Fan Articulation – Yes/No

Does the motor and propeller articulate relative to the rest of the vehicle's fixed structure? – negative for certification, neutral for the market. ***MOTART = 1 or 0***

4) Complete Wing Articulation – Yes/No

Are the motors and propellers fixed to the wing(s) and do the wing(s) articulate relative to the vehicle's fixed structure? – negative for certification, neutral for the market, ***WINGART = 1 or 0***

5) The number of motors and propellers/fans – Numeric

How many motors and propellers are used? (assuming one propeller per motor) – the greater number the greater the safety but the lower the reliability – negative for certification, neutral for the market, if the number of propellers exceeds 10 then set equal to 10. ***NUMPROP = n***

6) Lift Generated by Wing in Forward Flight – Yes/No

Does the vehicle depend on airflow over a lifting surface relative to the vehicle forward movement in forward flight or is lift in forward flight provided by rotors? – using a wing for forward flight increases speed and range, positive for the market. ***WINGLIFT = 1 or 0***

7) Metric for Unusual Configuration – Numeric, out of 10

A mark out of 10 given on a scale from conventional (0) to exotic (10) based on the authors value judgment – In general the more unusual a configuration the greater the certification cost and the less market acceptance there will be. ***UNUSUAL = n***

8) Metric for Mechanical Complexity – Numeric, out of 10

A mark out of 10 given on a scale from complex (0) to simple (10) based on the authors value judgment of the number of articulating components – In general the greater the mechanical complexity the greater the certification cost and the higher the cost of operation leading to negative market acceptance. ***MECH = n***

9) Metric for Aerodynamic Stability – Numeric, out of 10

A mark out of 10 from aerodynamically unstable (all flight characteristics software controlled) (0) to aerodynamically stable (no characteristics software controlled) (10) – the less aerodynamically stable the aircraft the greater the certification cost. ***AERO = n***

10) Aesthetics – Numeric, out of 10

Is the aircraft particularly attractive or unattractive, marked out of 10, for particularly unattractive aircraft (0), aesthetically neutral (5), exceptionally visually attractive (10). ***AESTH = n***

11) Ability to carry more than one person – Yes/No

Self-Explanatory. ***PERSON = 1 or 0***

In general, the greater the certification cost, a higher market acceptance is required to create the sales to repay the development investment.

These assessments can be crudely classified as shown in the following table:

Certification Cost Quotient	Market Acceptance Quotient	Overall Evolutionary Success Quotient
Low	Low	Poor
High	Low	Moderate
Low	Low	Moderate
High	High	Good

The actual assessments are made on a continuous scale. These classifications are shown on the graph of results.

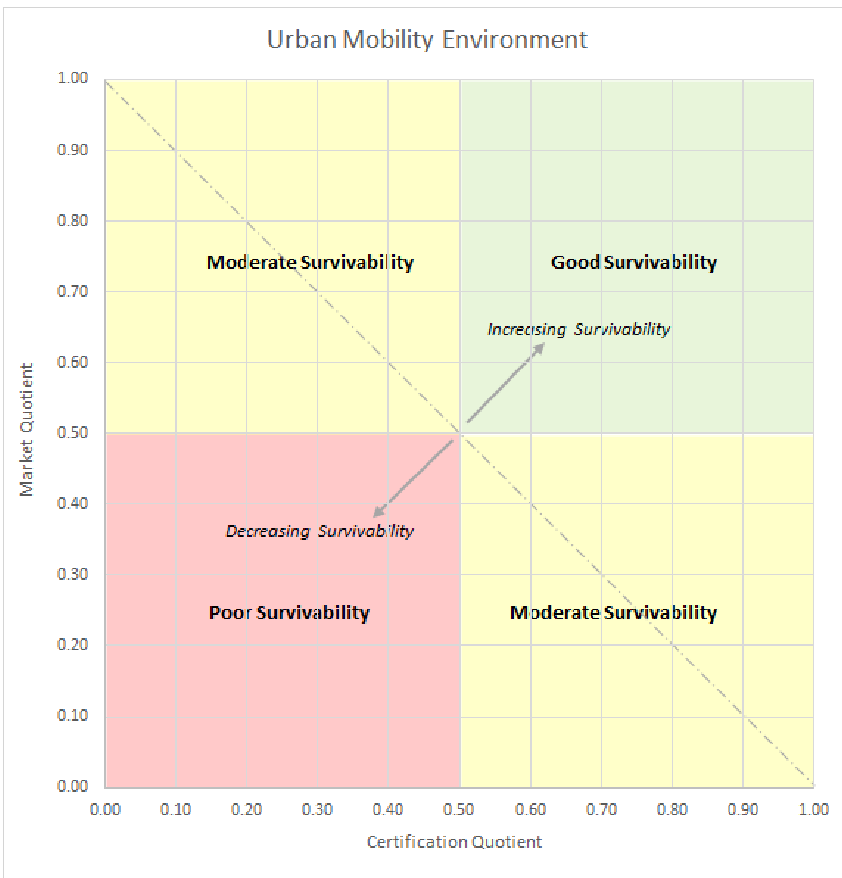

Figure 1 Urban Mobility Environment Classifications

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Risks and Features

Market and Commercial Risks

The market risk is related to the price of the product and the likelihood that the market will accept the product.

The size of the market is important to conceptualize. From (2016 General Aviation Statistical Databook & 2017 Industry Outlook, 2016) the total number of certified general aviation aircraft delivered in 2016 was 1525. These aircraft sales generated $10.577Bn.

The best-selling part 23 aircraft is the Cirrus SR22/SR22T. These two aircraft sold a total of 282 units in 2016, SR22 List Price is $540,000USD, SR22T List Price is $640,000USD

The best-selling part 27 helicopter is the Robinson R44, this aircraft sold 152 units in 2016, List price $340,000USD to $470,000

The aircraft market is generally conservative when considering new concepts or proven concepts with significant visual differences to existing aircraft.

It is acknowledged that the projected ‘urban mobility’ market extends beyond the existing general aviation aircraft market. However, it remains to be seen how accepting the urban commuter/traveler is when considering the choice between a short distance journey in an unusual flying vehicle or the same journey in a conventional ground vehicle – *conceptual acceptance*

This decision will affect the private owner markets and the non-owner taxi markets.

It is almost certain that there will also be a significant cost differential between the urban air taxi and urban ground taxi markets. It is unclear what level of premium the consumer will be prepared to pay for the benefits of using an air taxi – *commercial acceptance*

How the conceptual acceptance and commercial acceptance interact and determine actual demand is impossible to predict in absolute terms. In the urban mobility market a significant determining factor for success is the value placed on time, or convenience. The end point of the trend towards increasing value placed on convenience was distilled by the Dead Kennedys into the phrase “Give me convenience or Give me Death”.

The use of this phrase may appear hyperbolic, however the perceived risk in the mind of the consumer of an unproven flying taxi over a traditional ground taxi places them in the position of making this subconscious or conscious value judgment.

Over the medium to long-term, assuming urban mobility air vehicles are brought to market and become established with a good safety record, this perceived risk will reduce.

This white paper is concerned with a return on investment in the short to medium term (10-15 years from the time of initial investment). If it takes decades for a large market to grant commercial and conceptual acceptance to the product the product will have a low survivability quotient.

The various parameters are given the following basic weightings:

$$175 \cdot VTOL + 10 \cdot ROAD - 10 \cdot WINGART + 15 \cdot WINGFLT - 10 \cdot UNUSUAL - 15 \cdot MECH + 20 \cdot AESTH + 50 \cdot PERSON$$

These weightings are applied relative to each other. Note that where an aircraft parameter receives no weighting in the above expression that parameter is assumed to have no effect on market acceptance.

Explanation of the factors in the context of the market.

VTOL	The capability of the aircraft to take off and land vertically is assessed to be very important to the customer. E.g. VTOL is 10 times more important than the aircraft use a wing for forward flight.
ROAD	It is assessed that the ability of the aircraft to be driven on the road as a car is not important to the market
WINGART	An articulating wing introduces a highly loaded bearing system. This will increase cost and weight and this will create a vehicle with lower performance at a higher price negatively affecting the market quotient.
WINGFLT	For most customers using a wing for forward flight is relatively important as in most cases a winged aircraft is faster and has a longer range than a rotorcraft. This is not true of all the fixed-wing aircraft surveyed because of the drag of lift rotor systems, however, it is taken to be generally true.
UNUSUAL	If the craft is unusual or exotic this is assessed to have a small negative effect on the market quotient.
MECH	The more mechanically complex a craft is the more expensive it will be to purchase and operate, this has a negative effect on the market quotient.
AESTH	The more beautiful the aircraft is the greater chance it has of being accepted by the market.
PERSON	There is a much larger market for vehicles that can carry a passenger. This feature has a significant effect on the market quotient.

Table 1 Basic Market Weighting Values

The factors applied in the spreadsheet are the author's assessment. Users of the spreadsheet are encouraged to modify the factors if they feel that they have a better understanding of the market

The basic weightings are modified by the Market Environment setting. This parameter accounts for the general state of the market and is an attempt to adjust for general market attitudes. The market parameter has a value between 0 and 100. In general, a more accepting market will be less critical of negative features and a harsh market will be more critical of negative features.

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The weightings for the individual parameters are affected by the market setting as shown in the table below

	Market Setting		
	Accepting (0)	**Nominal (50)**	**Harsh (100)**
VTOL	+175	+175	+175
ROAD	+10	+10	+10
WINGART	-2	-10	-22
WINGFLT	+15	+15	+15
UNUSUAL	-2	-10	-22
MECH	-3	-15	-33
AESTH	+20	+20	+20
PERSON	+50	+50	+50

Table 2 Effect of Market Parameter on Basic Market Weighting Values

The market parameter also affects the angle of the line that is used to calculate the survivability quotient in the following way:

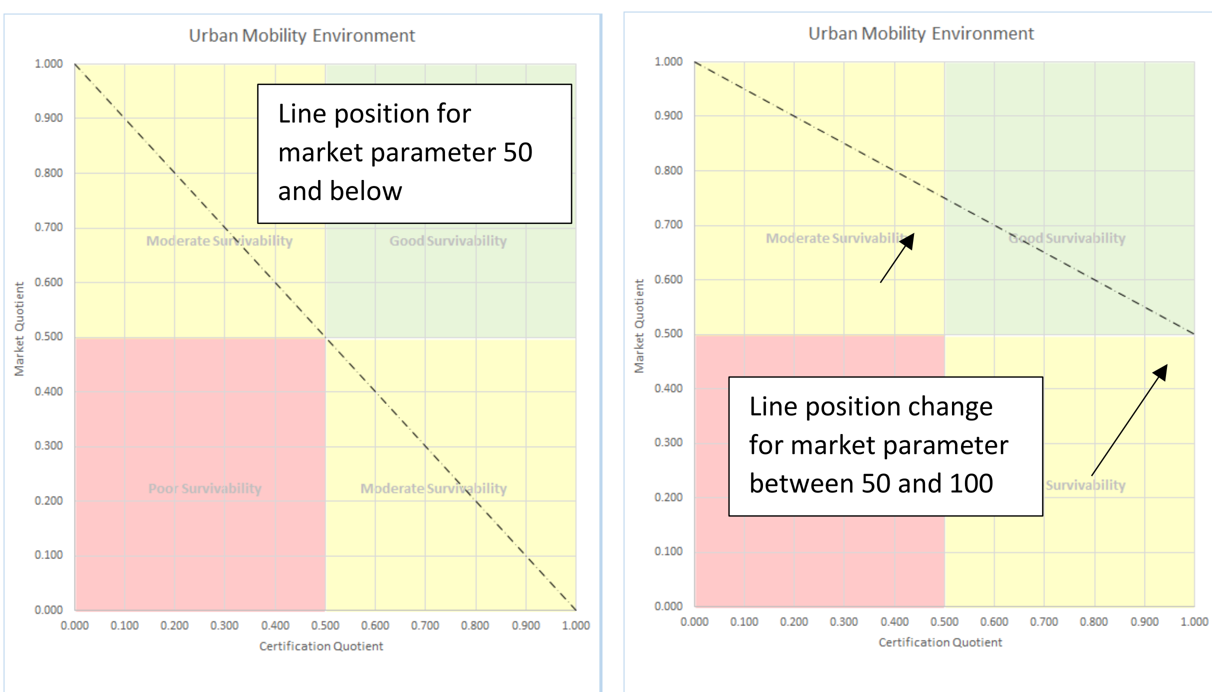


Figure 2 Effect of Market Parameter on Survivability Quotient

The market parameter is normalized between zero and one between the maximum and minimum calculated market quotients.

Certification Risks

It is assumed that the candidate concepts will be certified under part 23 or part 27 or a combination of part 23 and part 27.

Historically the certification agency in the US (and other certification authorities) have been conservative when it comes to new companies, new aircraft designs, and new technical innovations. For many of the urban mobility aircraft concepts, these three factors are negatively combined. The level of conservatism at the certification agency applied to the applicant results in additional significant certification costs the applicant must bear.

There are moves to simplify the certification process for features such as fly by wire, however, the benefits of these discussions have so far failed to materialize. It is also not clear how the standards can be made less onerous while maintaining a similar level of safety.

It may be that commercial pressure caused by the level of investment in this sector will trigger a simplification of the regulations and a cheaper and quicker route through to the market. Echoing the concern in the previous paragraph, this relaxing of standards may result in a reduction in reliability of the vehicles certified under these hypothetical new regulations. Aircraft developers should be very cautious about pressuring governments to relax the standards based on a commercial imperative. The market response to a reduction in reliability and the potentially catastrophic consequences of a reduction in reliability could harm individual developers or the whole urban mobility sector.

How does the cost of certification standards and activities impact the overall cost of an aircraft development program? This is a question that has arisen on many aircraft programs. A good way to visualize this is to compare the development cost of a kit aircraft with the cost of a certified equivalent aircraft. In general, the adherence to certification standards and the process of demonstrating compliance will increase compliance costs by at least one order of magnitude.

The impact of certification on cost is very high in proportion to other development costs.

The basic calculation for the certification quotient is as follows

$$40 \cdot VTOL + 40 \cdot ROAD + 50 \cdot MOTART + 75 \cdot WINGART + 8 \cdot NUMPROP - 50 \cdot WINGFLT + 20 \cdot UNUSUAL + 20 \cdot MECH + 50 \cdot AERO + 10 \cdot PERSON$$

These weightings are applied relative to each other.

Explanation of the factors in the context of the market.

VTOL	VTOL Certification has a negative effect on the overall certification quotient.
ROAD	Adding certification to roadworthy standards will increase the overall cost of certification and has a negative effect on the overall certification quotient.
MOTART	A moving motor mount creates significant additional certification costs and has a negative effect on the overall certification quotient.
WINGART	An articulating wing creates significant Stability and Control problems in certification and has a negative effect on the overall certification quotient.
NUMPROP	The more propellers/motors there are the more complex systems are required - has a negative effect on the overall certification quotient.
WINGFLT	An aircraft that uses a wing for lift has potentially less critical failure modes has a positive effect on the overall certification quotient.
UNUSUAL	The more unusual or exotic an aircraft is the more effort is required to demonstrate compliance, this has a negative effect on the overall certification quotient.
MECH	An increase in mechanical complexity translates to an increase in certification effort and cost and has a negative effect on the overall certification quotient.
AERO	A lack of aerodynamic stability will cause significant certification costs in stability augmentation system or full fly by wire, this has a significant negative effect on the overall certification quotient.
PERSON	A single person craft will cost less to certify than an aircraft carrying passengers as it may fall under LSA rules. This has a positive effect on the overall certification quotient.

Table 3 Basic Certification Weighting Values

As with the marketing factors, the certification factors applied in the spreadsheet are the author's assessment. Users of the spreadsheet are encouraged to modify the factors if they feel that they have a better understanding of the certification process

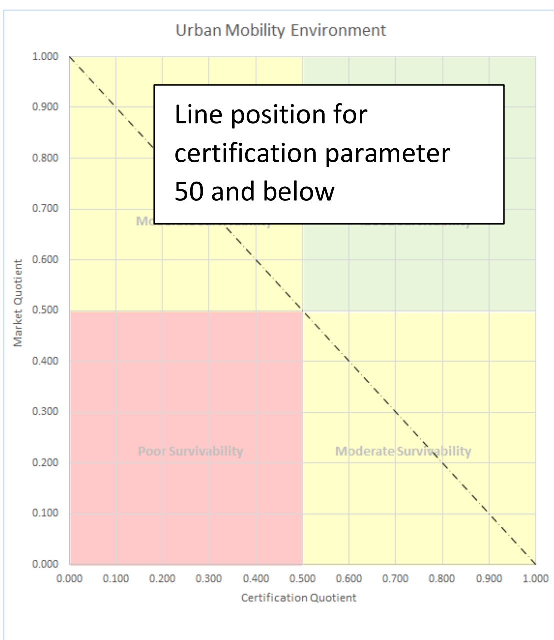
The basic weightings are modified by the Certification Environment setting. This parameter accounts for the general state of the certification authorities and their attitude towards the urban mobility segment. The certification parameter has a value between 0 and 100. In general, a more lenient attitude from the certification agency will be less critical of unique and complex features and a harsh attitude from the certification agency will demand a greater number of and more expensive demonstrations of compliance.

The weightings for the individual parameters are affected by the certification setting as shown in the table below:

	Certification Setting		
	Lenient (0)	**Nominal (50)**	**Harsh (100)**
VTOL	6.66	40	73.3
ROAD	40	40	40
MOTART	9.16	50	100.8
WINGART	10	75	110
NUMPROP	1.47	8	16.13
WINGFLT	-50	-50	-50
UNUSUAL	3.33	20	36.7
MECH	20	20	20
AERO	1.39	50	168
PERSON	1.67	10	18.3

Table 4 Effect of Certification Parameter on Basic Certification Weighting Values

The certification parameter also affects the angle of the line that is used to calculate the survivability quotient in the following way:



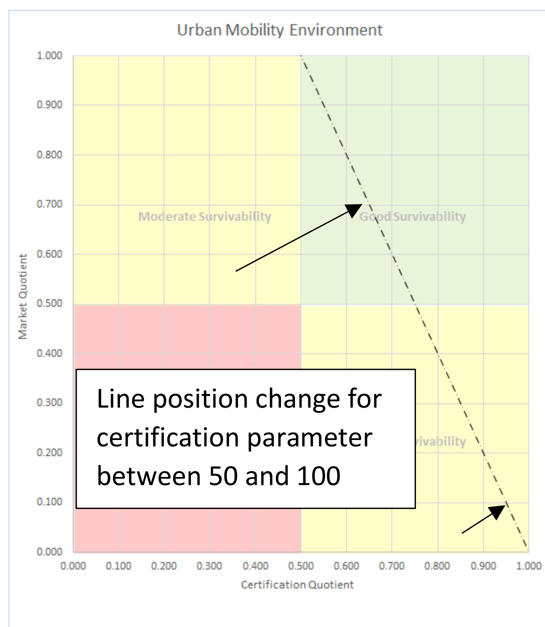


Figure 3 Effect of Certification Parameter on Survivability Quotient

The certification parameter is normalized between zero and one between the maximum and minimum calculated certification quotients.

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Survivability Quotient

Each design concept is plotted within the Urban Mobility Environment space.

The survivability quotient is created by calculating the perpendicular distance from the separator dashed line to the point that represents the design concept.

Points upwards and right of the line have positive quotients, points below and to the left of the line have negative quotients.

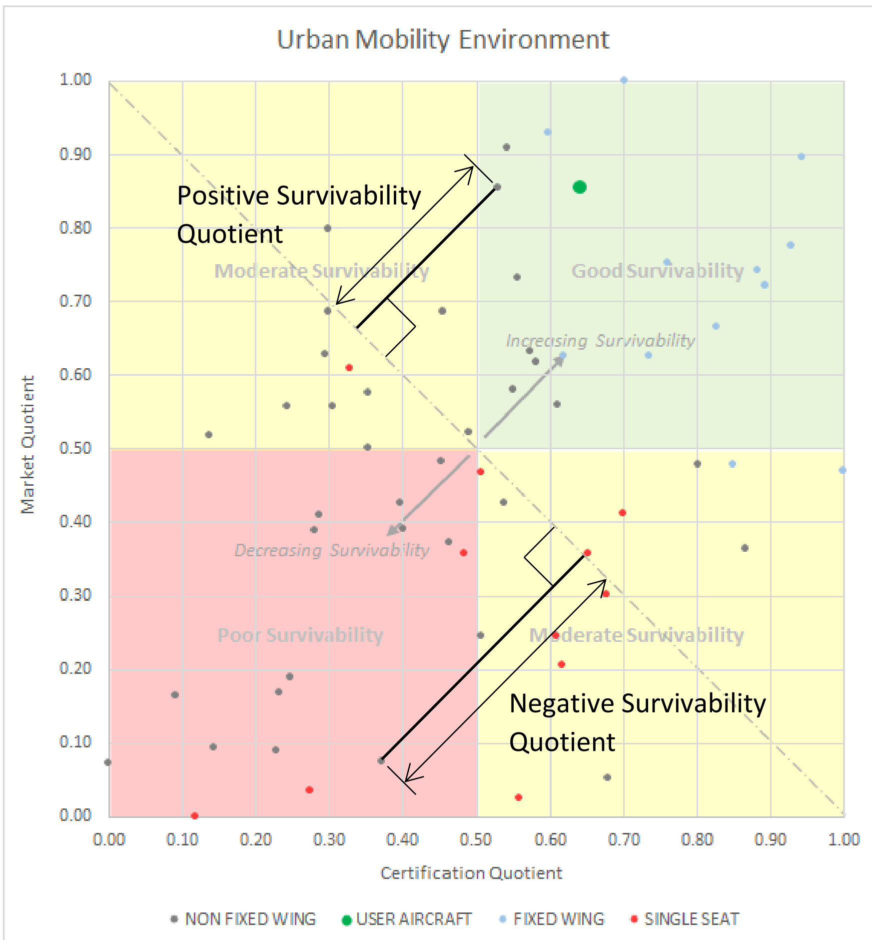

Figure 4 Calculation of Survivability Quotient

The user can input the parameters of a sample project in the associated spreadsheet. The project position appears on the plot as a larger green dot.

The user project is also compared to the different surveyed projects by the graphs to the right of the Urban Mobility Environment graph.

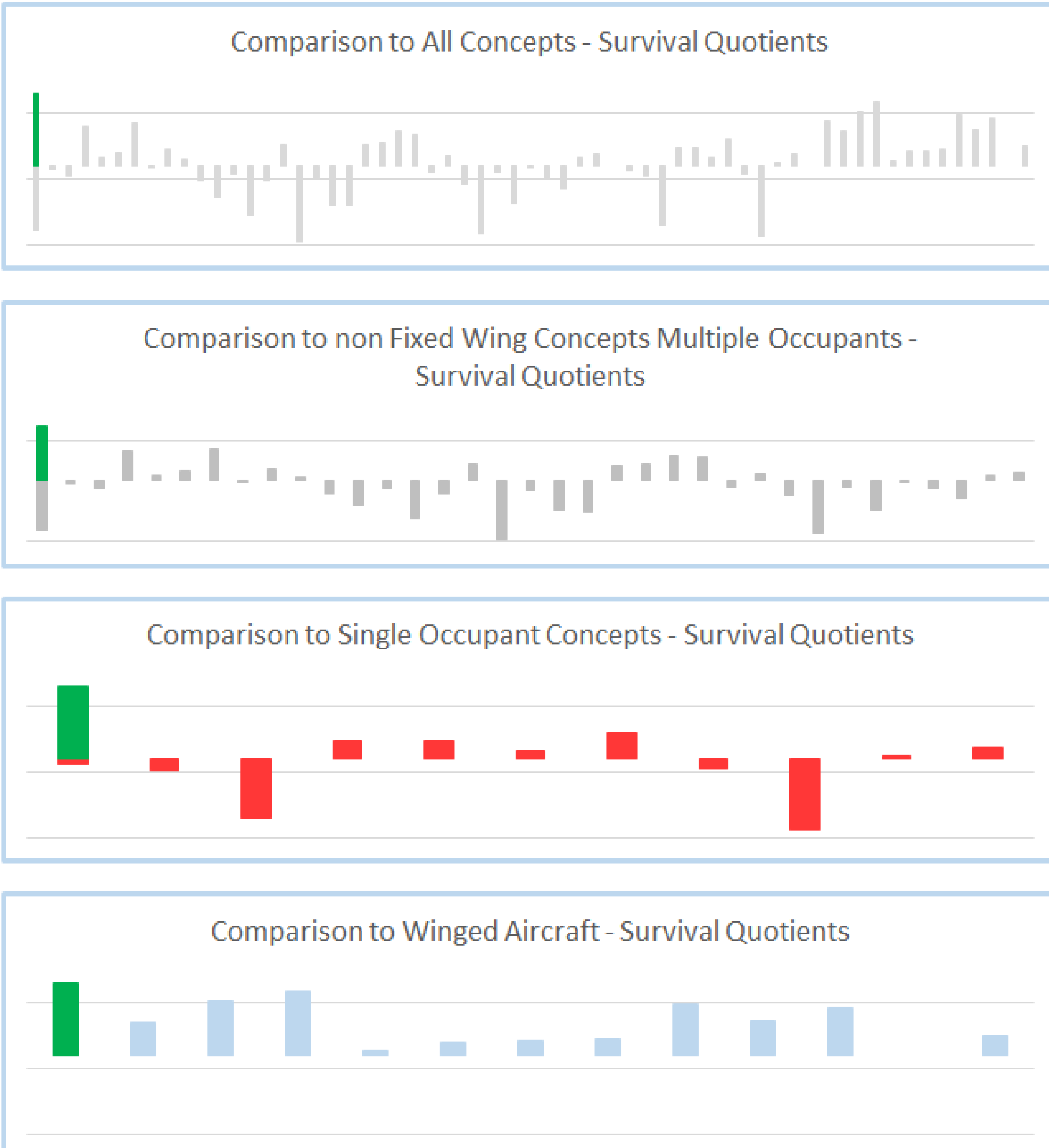

Figure 5 Comparison of Survivability Quotient (example)

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Summary & Conclusion

A method has been created that may predict the relative chance of success of a design concept.

Undoubtedly bias remains in the author's assessment of the market and certification risks. However, the bias regarding the risks of certification and chance of market success has been applied consistently and within the limitation of the author's bias the results are 'fair'.

There are value judgments that are unavoidable in the attribution of some input parameters, the weighting of these parameters and the additional parameters from the market and certification parameters.

From the literature survey, discussions and authors knowledge there are several key attributes that are very desirable.

VTOL capability:

The ability to operate without a runway, or without a body of water for an amphibious aircraft

Range:

The range is important not only in terms of the distance of a single trip, but the interval or number of trips before recharging or refueling is required.

There are several key attributes that introduce a high level of risk to these aircraft programs

Lack of natural aerodynamic stability:

This aspect of design is the single greatest certification risk. There are moves to introduce a less onerous route through certification for fly by wire systems. However, the revised standards or regulations are not introduced yet and at the time of writing ASTM WK61549 is under development and no schedule has been set for introduction. In the judgment of the author, almost all the multi-rotor (greater than 2 lift rotors) systems will require some element of fly by wire or software control to maintain stability.

In addition, any aircraft that does not have aerodynamic stability (i.e. glide or auto-rotate) will require a secondary recovery system to cope with power/engine failure. This will most likely be a ballistic recovery system. These systems are well established in the General Aviation sector. They do introduce additional weight that subtracts from the aircraft payload and introduces a servicing cost for the ballistic device.

Ballistic recovery systems require a clear region, aft of the direction of travel of the vehicle in order correctly deploy. It can be seen on some multi-rotor aircraft concepts that consideration may not have been given to this required design element.

Considering the evolutionary model of an explosion of a variety of life forms being reduced over time by inability to adapt to the environment; how can this model be applied?

An evolutionary conclusion is that the certification environment is currently hostile to most of the design concepts reviewed. It is probable that the certification environment will become less hostile. It

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is not known when the change in the regulations will occur. An ability to adapt to the certification environment will be a critical survival trait.

Incurring avoidable cost in the certification environment will make the design less likely to survive in the market. The resources consumed in the certification environment must be extracted from the market environment in the form of elevated price.

There are several examples of aircraft designs that served a market need but failed because the cost incurred in the development and certification phase was too great to be recouped from the market. The principal examples are Eclipse Aircraft (now One Aviation) and Sino Swearingen (Briefly Emivest and now CyberJet).

Excessive development cost and delay will cause additional chronic problems when the aircraft is first introduced to the market. It is normal to take orders for aircraft in advance of certification, these orders are taken at the projected initial market price. The price of the aircraft invariably increases with the level of investment and time it takes to get to market. This combination of factors forces the company to sell the first production run of the aircraft at a loss while fulfilling the earliest orders.

The initial interaction with the market consumes additional resources rather than generating resources required to satisfy the existing resource deficit. This is a problem few programs survive.

If the designs reviewed for this study are to survive they will have to adapt to the existing regulatory environment. Alternatively, they must ensure that they have the resources to survive for an indefinite period until the regulations change – a form of hibernation.

On the positive side, there is a strong will and a significant amount of investment in the field. If the regulations can be revised to provide adequate safety in a timely manner at a significantly reduced cost the future of transportation could be radically different to the present.

Recommendations to Urban Mobility Aircraft Developers – How to Survive

It is essential to reduce certification risk and therefore reduce the overall development cost and time to market. It is recommended that Urban Mobility Aircraft developers formulate a compliance plan based on the existing LSA, part 23 standards and part 27 regulations.

Identify the high risk (and therefore high cost) aspects of the program and hold a series of design reviews to assess whether key functionality can be retained while modifying the design to better show compliance under the existing standards/regulations.

Waiting for updated standards, which will potentially reduce certification risk, ties your project schedule to reliance on an external factor that you have little to no control over. Your schedule will move inexorably to the right and you will be unable to make progress.

Regarding updated or new standards:

The certification agency is charged with interpreting a new set of standards while ensuring the safety of the public. Making a finding of compliance against a new set of standards/regulations is likely to be a time-consuming process. The certification agency is cautious and has a duty to ensure safety, without regard for the developer's schedule or budget.

When new standards are formulated and published there may be several applicants who are vying for the attention and time of the certification agency. Certification agency resource limitations could cause additional delay.

It is a valuable risk reduction measure to minimize reliance on standards or regulations yet to be published.

It is also wise not to overestimate the ease of certification that new standards may bring.

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Ranking The Top 5 Projects

The spreadsheet tool has been used to rank the top 5 VTOL urban mobility concepts. This ranking only judges the design concept in the context of the market and the certification environment. This ranking does not judge the capability of the organization to successfully execute the development program.

These rankings are created using 'neutral' certification and market weightings (both set to 50 in the spreadsheet). To avoid the appearance of comparative bias the DeLorean DR-7 has been excluded from this evaluation. The DeLorean DR-7 concept is evaluated in the next section.

The top 5 VTOL projects are:

1	Uber Elevate	https://www.uber.com/info/elevate/
2	Aurora/Boeing eVTOL	http://www.aurora.aero/
3	Passenger Drone	http://passengerdrone.com/
4	PAV-X	http://www.pav-x.com/#
5	AirspaceX Mobi-One	http://airspacex.com/

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The DeLorean DR-7

I act as an advisor on the DR-7 project. To avoid the appearance of overt bias or favorable comparison I am not carrying out comparison with other projects. Instead I have written a short section on how the analysis of the DR-7 concept (using the spreadsheet) compares to my original assessment of the project.

I got involved with the DR-7 project because my initial assessment was that it was likely to be successful. The latest design concept minimizes certification risk and has attractive aesthetics.

To confirm or contradict my initial assessment I parametrized the project in the same way as all of the other candidate projects and input the data into the spreadsheet.

Figure 6 The DeLorean DR-7 Vehicle Concept

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The spreadsheet output for the DR-7 concept is shown below:

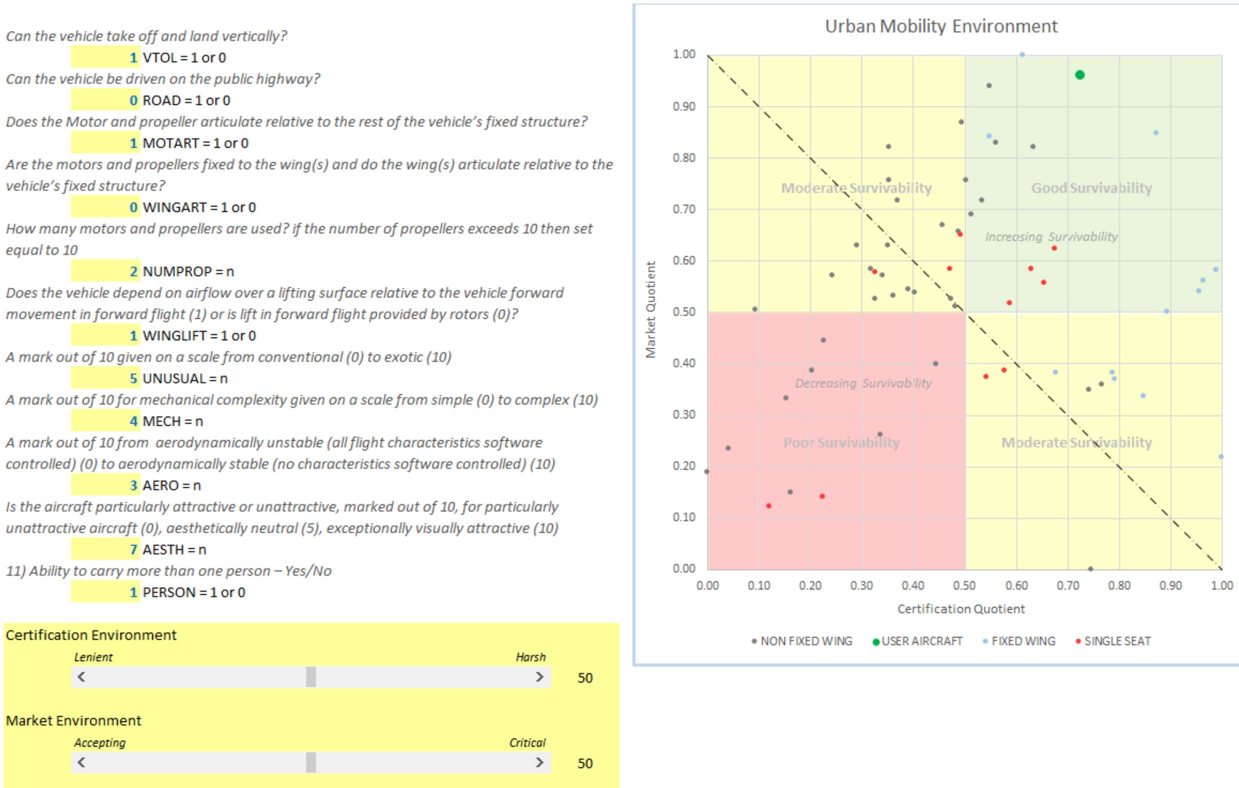

Figure 7 Examination of the DR-7 Concept

The green 'dot' on the graph shows that the DR-7 has a favorable survivability quotient compared to the field of other VTOL concepts.

This score is significantly influenced by the small number of rotors and the use of wings for lift in forward flight signifying a level of natural aerodynamic stability that minimizes certification risk

The score is also influenced by the aesthetics of the aircraft which has a major influence on market acceptance.

The spreadsheet tool does reinforce my initial assessment of the DR-7 project. Have I parameterized and codified my bias? Or have I produced a way to make a fair assessment?

APPENDIX A – Review of Existing Concepts

	Manufacturer	Model
1	Airbus	OX
2	Airbus	Vahana
3	Aurora/Boeing	LightningStrike X-Plane
4	Aurora/Boeing	eVTOL
5	Ehang	184
6	Lilium	Eagle
7	Lilium	Jet
8	Uber	Elevate
9	Volocopter	
10	Terrafugia	Transition
11	Terrafugia	TF-X
12	Joby	
13	Verdego	
14	Urban Aeronautics	Cormorant
15	Evation	Alice
16	AeroMobil	
17	Vimana	AAV
18	Zee Aero	
19	XTI	TriFan 600
20	Kitty Hawk	
21	AirspaceX	Mobi-One
22	Avianovations	Hepard
23	Bartini	
24	Cartivator (Toyota)	Skydrive
25	Dekatone	
26	HoverSurf	Formula
27	HoverSurf	Scorpion 3
28	JetPack Aviation	
29	Kalashnikov	
30	Passenger Drone	
31	PAV-X	

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32	VRCO	NeoXCraft
33	Workhorse	SureFly
34	Autonomous Flight	Y6S
35	Carter	Cartercopter
36	Digi Robotics	Drofire/Droxi
37	EVA	X01
38	FlexCraft	
39	HopFlyt	Venturi
40	JAXA	Hornisse
41	Skylys	
42	Martin	JetPack
43	Alauda	Airspeeder
44	Davinci	ZeroG
45	Flike	
46	Flyt	FlytCycle
47	GravityX	
48	Malloy	
49	Neva	AirQuadOne
50	Airis	Airisone
51	Ampaire	
52	Sabrewing	
53	Talos	
54	Faradair	Beha
55	Onera	Ampere
56	Solar Flight	6-Seat
57	Synergy	V31
58	PAL-V	

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Appendix B – Reference Cases

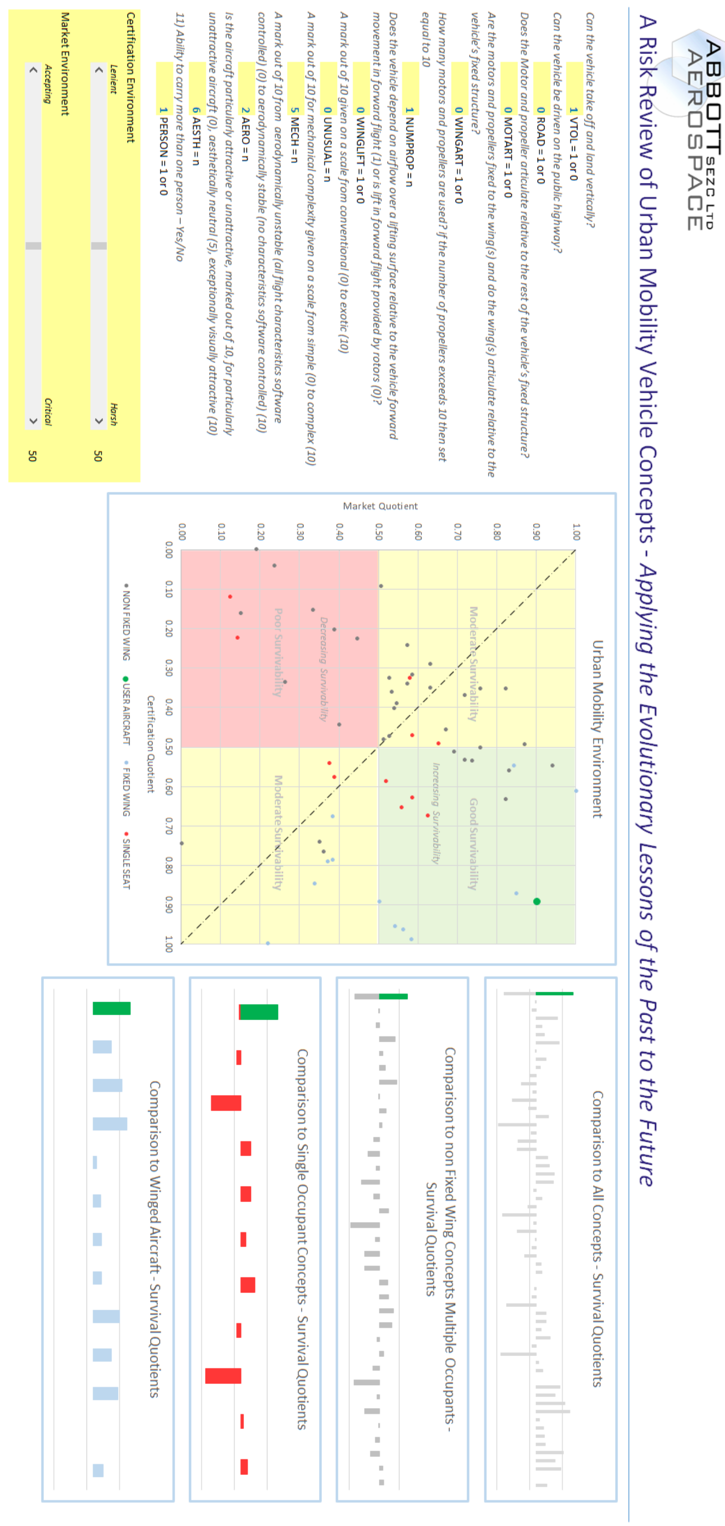

Figure 8 Reference Case – Part 27 Helicopter

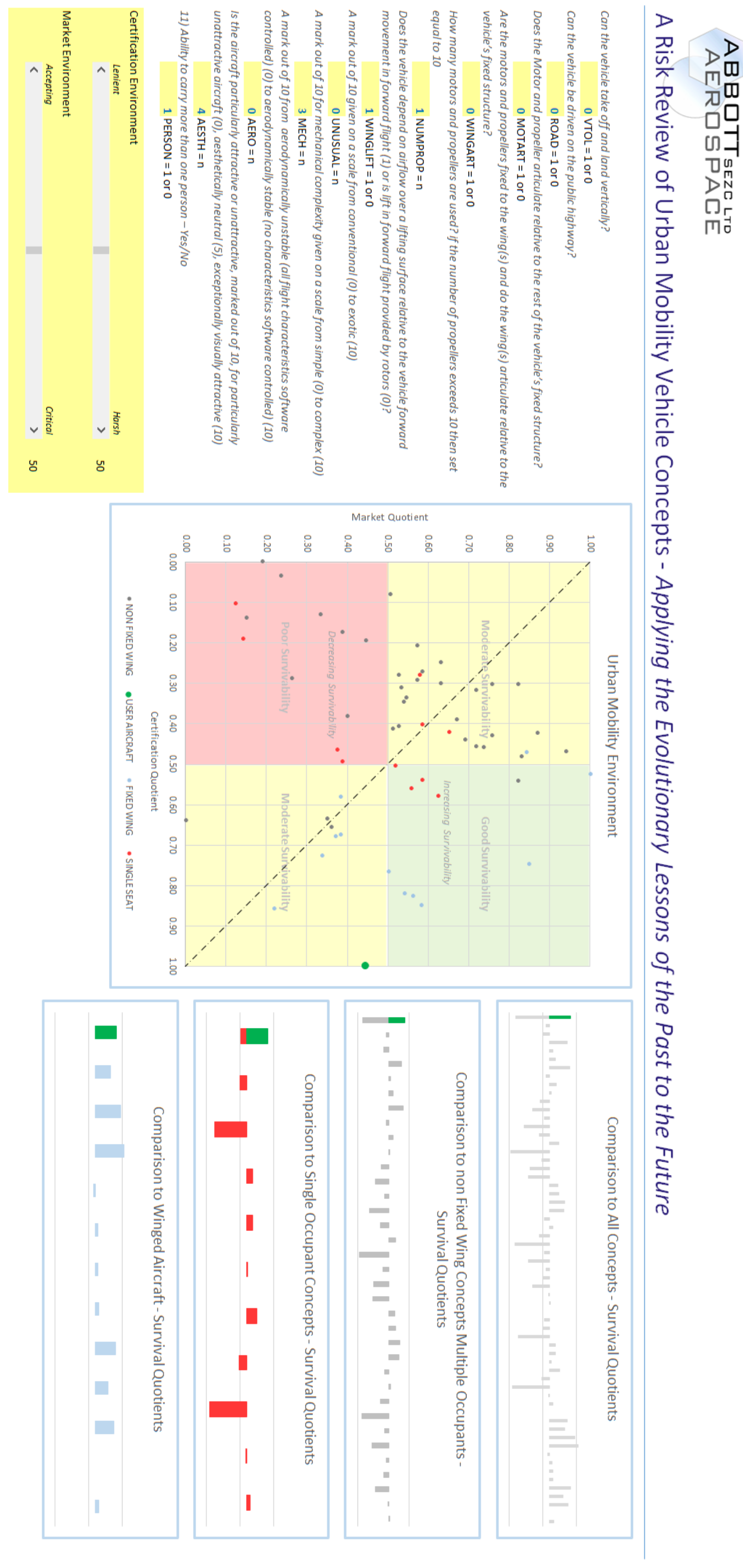

Figure 9 Reference Case – Part 23 Single Engine Aircraft

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