Real options and strategic guidance in the development of new aircraft programs

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1. Abstract

Investment decisions in new aircraft development programs are difficult because of large capital expenditures, long lead times, and many technical and market uncertainties. A flexible strategy that takes advantage of the ability of managers to incorporate information as uncertainties are resolved is suggested as a means to manage risk. In this paper, the use of real options analysis to evaluate and guide new aircraft development programs is illustrated through a case study of a real-world aircraft program. The analysis provides clear evidence that investors can use the numerical results of the real options analysis to determine how much they should spend on an aircraft program, that managers can use the same results to restructure the program to improve the financial feasibility of the project, and that both investors and managers can use the output of derivative analyses to define minimum requirements (in terms of aircraft orders) to ensure program success. The analysis is based on a generalized real options methodology in which the value of completion and the strategy-enabling completion cost (commonly referred to as stock price and strike price in the real options literature, respectively) may be described by any probability distribution. Thus, with this methodology, it is not necessary to force the representation of the value of completion into known stochastic processes, such as the commonly-used geometric Brownian motion, or to assume that the cost of completion is fixed a-priori.

2. High risks and uncertain payoffs in new aircraft programs

The airline industry is a difficult environment in which to make investment decisions. Air travel demand is highly cyclical and it is subject to many technical and market uncertainties, including shocks such as the one induced by the events of September 11th, 2001. Planning in the face of such volatile traffic demand is a major challenge for all stakeholders, in particular airlines, aircraft manufacturers, and airports. The long lead times associated with delivery of new aircraft, construction of new runways, or new passenger buildings often result in these investments arriving at inopportune times: a premature investment may result in unused capacity that sits idle without generating any returns whereas a tardy investment may miss the potential market completely.

To understand the negative impact of a cyclical market on airline fleet planning, consider the orders and deliveries of Boeing 737 aircraft (all series) for United Airlines (UA) and American Airlines (AA) from 1980 to 2004 that are shown in Figure 1 along with the annual growth rate of US domestic market demand (measured in revenue-passenger miles, or RPMs[1]). United placed a large order for 101 airplanes in 1985 and a second order for 57 aircraft in 1989. Although United began receiving some of these aircraft in 1986, the majority of the aircraft were delivered during the four-year period between 1988 and 1992. At the time that the large order of 101 planes was placed in the mid 1980s, traffic was growing rapidly; however, by the time aircraft began to be delivered in large numbers in 1988, traffic growth was substantially less. In fact, in one year (1999) during the aforementioned four-year period in which UA received most of its new 737s, the year-over-year change in traffic was negative. A similar situation occurred with American Airlines in the second half of the 1990s and early 2000s.

[1] RPM is a standard measure of airline traffic. It represents one paying passenger flown one mile.

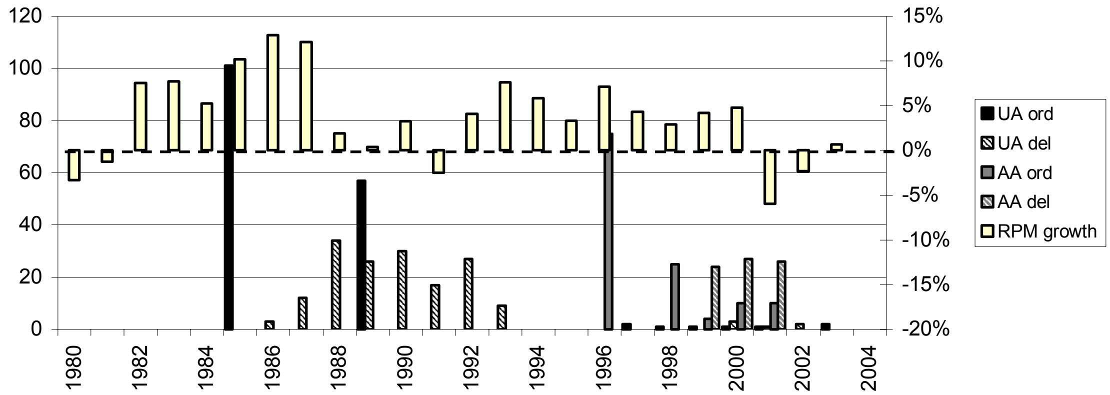

Figure 1: Orders and deliveries of Boeing 737 aircraft (all series) for United Airlines (UA) and American Airlines (AA) from 1980 to 2004. The blank bars represent traffic demand in the US domestic market in terms of RPM growth rate ***Source: ATA (2004) and Boeing (2004).***

Aircraft manufacturers, in their position as key suppliers to airlines, are directly affected by the demand uncertainties in the industry. The large capital expenditures that are required to launch a new aircraft, typically valued in the billions of dollars, the many years associated with these programs, and the fierce competition among the few remaining aircraft manufacturers mean that each new model presents a significant risk to the future of the company [Esty and Ghemawat, 2002]. Under these circumstances, flexible investment strategies that allow managers to better react to uncertainties can enhance the profitability and the likelihood of success of new projects.

In this paper, the use of real options analysis to evaluate and guide new aircraft development programs is illustrated through a case study of a real-world aircraft program where a major aircraft manufacturer provided the data. However, because of confidentiality concerns, the name of the company cannot be divulged, the magnitude of numerical results have been altered, and monetary values are given in terms of monetary units (MUs). Despite these modifications, the analysis provides clear evidence that investors can use the numerical results of the real options analysis to determine how much they should spend on an aircraft program, that managers can use the same results to restructure the program to improve the financial feasibility of the project, and that both investors and managers can use the output of derivative analyses to define minimum requirements (in terms of aircraft orders) to ensure program success.

The real options approach employed here is based on the generalized methodology developed by Miller and Clarke (2005), in which the value of completion and the strategy-enabling completion cost (commonly referred to as stock price and strike price in the real options literature, respectively) may be described by any probability distribution. The terminology used in this paper differs from the one commonly used in financial options. The terminology employed here is more intuitive to the physical meaning of the elements that constitute a real option and is similar to the one used by Clemons and Gu (2003). For example, instead of referring to the value of the underlying asset as the stock price, it is called “expected value of completion” or “value of completion.” The cost associated with exercising the option, i.e., the strike price in financial options, is called “strategy-enabling completion cost” or “completion cost.” Finally, the cost of acquiring the option in the first place is the “strategy-enabling partial investment” or “initial investment.”

3. Real options in new aircraft development programs

3.1 Description of a typical new aircraft program

A typical new aircraft development program consists of a number of phases in sequence, as shown in the highly simplified diagram in Figure 2. For the purposes of this study, it is assumed that the process starts with preliminary design, i.e., it is assumed that all preliminary work in terms of market research, preliminary trades studies, etc., has already been completed. Once preliminary design is finished, the next phase is product development. Product development is divided in three steps. The first step involves initial development of the aircraft. The second step consists of building a few aircraft for first test flights. The third step is flight certification. Once the aircraft has been certified, serial production of the baseline aircraft can begin. In the particular example considered here, it is assumed that after a year of serial production, the manufacturer has four alternatives to continue production: a) maintain production of the baseline aircraft, b) maintain production of the baseline aircraft and launch a derivative aircraft, c) sell the aircraft program, or d) abandon the program.

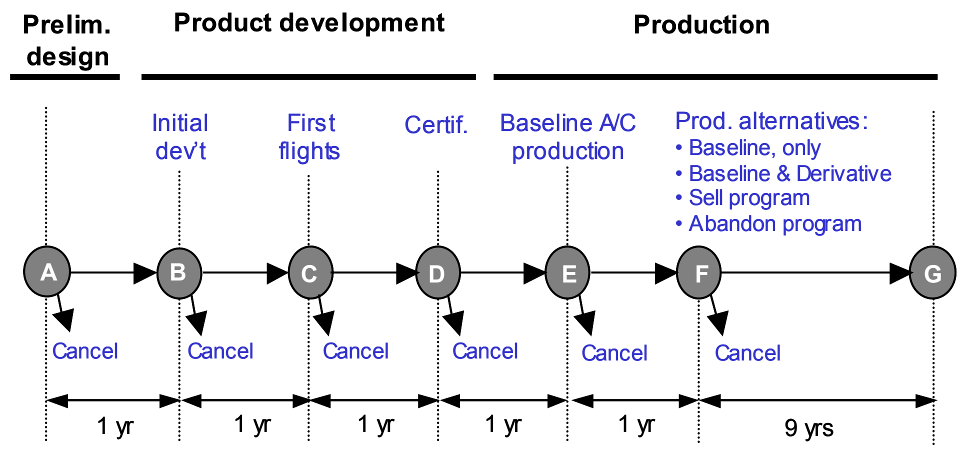

Figure 2: Main steps in a new aircraft development process.

There are many real options in this process. For example, at the end of each phase, project managers have the option to continue or stop development. Thus, as market and technical uncertainties become clearer, managers can assess the progress of the program, revise their expectations for success, and decide to continue or not.

For the purposes of this analysis, it is assumed that investors are standing at Step A and are considering whether to and, if so, how much to invest in preliminary design. At the end of this phase, they will have the real option to continue with the aircraft development process by starting development. Similarly, the option to start development will lead to other real options. They can be identified by the step in which they are exercised:

B. Real option to start development: By engaging in initial development, the investor will have the option of building a few test aircraft to enter first flight tests in Step C.

C. Real option to do first test flights: The first flights of the test aircraft will provide information about product performance and it will open the option to certify the airplane in Step D.

D. Real option to certify the aircraft: By certifying the airplane, the investor will have the ability to start production of the baseline aircraft in Step E.

E. Real option to start production: The beginning of serial production of the baseline airplane creates the option to follow one of four different production alternatives in Step F.

F. Real option to pursue one of the following mutually exclusive alternatives:

1) Production of the baseline aircraft, only: the manufacturer dedicates all its resources to producing and selling the baseline aircraft.
2) Production of the baseline and a derivative aircraft: the manufacturer has the option of launching a derivative in addition to producing the baseline aircraft.
3) Sale of the aircraft program: the manufacturer can sell the aircraft program to an interested buyer.
4) Abandon the program: the manufacturer can abandon the program and recuperate its salvage value, if any.

Notice that options B through E are compound options. This means that the value of each option is dependent on the value of subsequent options. For example, the value of the real option to certify the aircraft depends on the value of the real options to produce and to continue a production alternative. Consequently, in order to find the value of options earlier in the process, it is necessary to start the valuation exercise at the end of the program and proceed backwards.

3.2 Cash flow in the new aircraft development program

Before explaining the structure of each option in detail, it is helpful to explain the assumed cash flow for the example analyzed here. The development costs of the aircraft program can be divided in Engineering Cost and Production Facilities. Engineering Cost includes resources spent in the final design, wind-tunnel testing, blueprints, etc. and corresponds to 80% of development costs. Production Facilities covers hangars, tooling, etc. and comprises the remaining 20% of development costs.

Major investments are expected to occur in Steps B, C and D (see Figure 3). The expenditure necessary for initial development in Step B is 30% of Engineering Cost. The cost to prepare for and conduct the test flights in Step C includes 40% of Engineering Cost, Production Facilities, and the production cost of 5 aircraft. In Step D, the remaining 30% of Engineering Cost is disbursed to complete certification. Expenditures in Step F depend on which production alternative is chosen: if a derivative aircraft is launched, an investment equal to 20% of the development cost of the derivative is necessary; otherwise, there are no expenses. Revenues are realized in Step E if production of the baseline aircraft starts. Revenues between Step F and Step G depend on which production alternative is chosen.

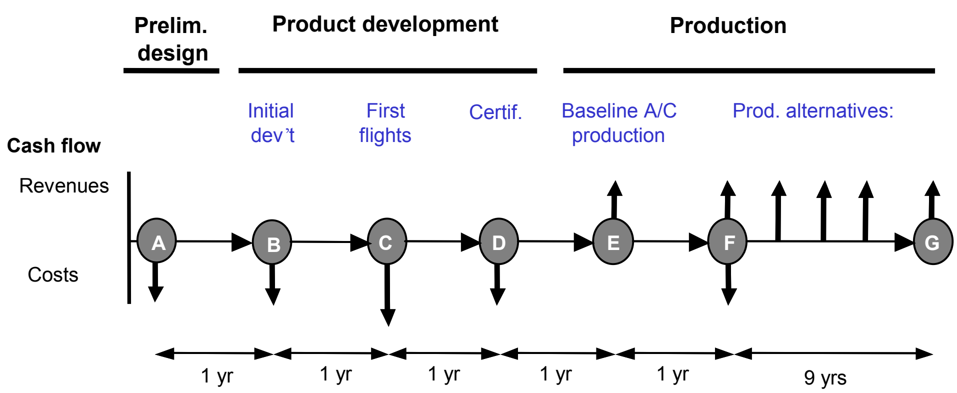

Figure 3: Sketch of expected cash flow in the new aircraft development program.

Finding the amount of the expenditure in Step A is one of the objectives in using the real options analysis methodology. This expenditure should be less than the value of the real option to start development in Step B.

3.3 Taxonomy of the real options in the new aircraft development program

The structure of each of the real options identified above is presented below starting with the last real option in the aircraft development process. To simplify the analysis, it was assumed that all options are European-like, i.e., they can only be exercised at one point in time.

F. Real option to continue a production alternative:

- Value of completion of continuing production, $V_{continue\ production}$: since the four production alternatives considered here are mutually exclusive, the value of completion of this real option is the maximum of the value of completion from of each of the alternatives in each simulation run. The value of completion for each alternative is explained below:

- Value of completion of producing the baseline aircraft, $V_{baseline\ aircraft}$: income from baseline aircraft sales.
- Value of completion of producing the baseline and a derivative aircraft, $V_{baseline\ \&\ derivative\ aircraft}$: sum of income from baseline aircraft sales plus the net value of the option to launch the derivative, i.e., the value of the option to launch the derivative minus the cost of obtaining this option.
- Value of completion of selling the aircraft program, $V_{sell\ aircraft\ program}$: It is assumed that after one year of baseline aircraft production, the aircraft program can be sold. The value of the sold program is estimated at 70% of development costs.
- Value of completion of abandoning the program, $V_{abandon\ program}$: The investor decides to abandon the aircraft development project and obtain a salvage value equal to 15% of development costs.

- Completion cost of continuing production, $C_{continue\ production}$: The completion cost of this real option is zero. If production of the baseline aircraft continues, the completion cost is zero because the production facilities are already in place and no more investments are necessary. Similarly, it is assumed that there are no expenditures associated with the exercise of the alternatives to sell or abandon the program. If the alternative to produce the baseline aircraft and launch the derivative is chosen, $C_{continue\ production}$ is also zero because the cost of exercising this option is already included in the value of completion of this production alternative.
- Maturity of the option to continue production, $M_{continue\ production}$: This real option has a maturity of one year. It is alive between Steps E and F in Figure 2.

E. Real option to start production:

- Value of completion of starting production, $V_{start\ production}$: The value of completion of starting production is the maximum between income from the first year of baseline aircraft sales plus the discounted value of the payoff of the real option to continue production and zero. The payoff of the option to continue production is discounted from Step F to Step E.

- Completion cost of starting production, $C_{start\ production}$: The completion cost to start production is zero, because it is assumed that serial production of the baseline aircraft can use the same facilities built for constructing the test aircraft. Therefore, no extra expenditures to enter production are required.
- Maturity of the option to start production, $M_{start\ production}$: This real option has a maturity of one year. It is alive between Steps D and E in Figure 2.

C. Real option to certify the aircraft:

- Value of completion of certification, $V_{certification}$: The value of completion of certifying the aircraft is the maximum between the discounted value of the payoff of the real option to start production and zero. The payoff of the option to start production is discounted from Step E to Step D.
- Completion cost of certification, $C_{certification}$: The completion cost to enter the certification phase is estimated to be 30% of Engineering Cost.
- Maturity of the option to do certification, $M_{certification}$: This real option has a maturity of one year. It is alive between Steps C and D in Figure 2.

C. Real option to do first test flights:

- Value of completion of doing first test flights, $V_{1st\ flights}$: The value of completion of doing first test flights is the maximum between the payoff of the real option to certify and zero. The payoff of the option to certify is discounted from Step D to Step C.
- Completion cost of doing first test flights, $C_{1st\ flight}$: The completion cost to do the first test flights is substantial. It includes 40% of Engineering Cost, Production Facilities estimated to be 20% of Development cost, and the cost of building five baseline aircraft.
- Maturity of the option to do first test flights, $M_{1st\ flight}$: This real option has a maturity of one year. It is alive between Steps B and C in Figure 2.

B. Real option to start development:

- Value of completion of starting development, $V_{start\ development}$: The value of completion of starting development is the maximum between the payoff of the real option to do first flights and zero. The payoff of the option to do first flights is discounted from Step C to Step B.
- Completion cost of starting development, $C_{start\ development}$: The completion cost to start development is 30% of Engineering Cost.
- Maturity of the option to start development, $M_{start\ development}$: this real option has a maturity of one year. It is alive between Steps B and A in Figure 2.

4. Generalized real options methodology

The evaluation of the real options in the aircraft development program requires a methodology that can take as inputs any probability distribution of the value of completion and the completion cost because of the following two reasons. First, the probability distribution that describes the possible future values of completion of these real options may be the result of a stochastic process that cannot be expressed analytically. Second, the completion cost of the options is not necessarily a fixed number and, like the value of completion, may be the result of a stochastic process with no analytical representation. Thus, instead of sacrificing accuracy by approximating the value of completion and the completion cost so that they would fit within a conventional real options solution technique, a generalized real options methodology was used. The basics of this methodology are explained below.

4.1 Certainty equivalents (CEQs) and the risk-free discount rate

In order to simplify the calculation of the value of the real options with the generalized methodology used in this paper, it is helpful to express the value of completion and the completion cost in terms of their certainty equivalents [Myers, 2004]. The certainty equivalent (CEQ) is the certain cash flow that a risk-averse investor would be willing to exchange for the risky cash flow. It can be computed with CAPM, for example [Brealey and Myers, 1996; Trigeorgis, 1996]. Because these cash flows are certain, the risk-free discount rate is the appropriate discount rate to find their present value. Thus, in the generalized methodology the risk-free rate is used because all values are given in terms of their certainty equivalents.

4.2 Derivation of the generalized real options methodology

The derivation of the generalized real options methodology begins with the assumptions and logic outlined by McDonald and Siegel (1985)[2]. First, the value of a European call option at time T, $O|_{t=T}$, is defined as the expected value of the cash flow, given that the option is only exercised if profits are equal or greater to zero:

$$O_{t=T} = E[\max(V_T - C_T, 0)] \qquad \text{(Eq. 1)}$$

where V_T and C_T are the value of completion and the completion cost at maturity, T, respectively. The value of this option today, O, is found by discounting the value of the option at time T to the present with a suitable discount rate, r:

$$O = e^{-rT} E[\max(V_T - C_T, 0)] \qquad \text{(Eq. 2)}$$

Assuming that the value of completion at time T can be described with a probability density function, $f_v(v_T)$, and using the definition of expected value for continuous random variables, Equation 2 becomes:

$$O = e^{-rT} \int_{v=C_T}^{\infty} (v_T - C_T) \cdot f_v(v_T) dv_T \qquad \text{(Eq. 3)}$$

Notice that the lower limit of the integral must be the completion cost, C_T, in order for $(v_T - C_T) \geq 0$. Rearranging terms, Equation 3 can be written as:

$$O = e^{-rT} \left(\int_{v=C_T}^{\infty} v_T f(v_T) dv_T - C_T \int_{v=C_T}^{\infty} f(v_T) dv_T \right) \qquad \text{(Eq. 4)}$$

Finally, substitute $f_v(v_T)$ and C_T for their certainty equivalent at time T, $f_v(v)$ and C, respectively. In addition, replace the discount rate, r, with the risk-free discount rate, r_f, since all terms are certainty equivalent:

[2] For an alternative derivation using ideas from Hull (2000) and Chriss (1997), see Miller and Clarke (2005).

$$O = e^{-r_f T}\left(\int_{v=C}^{\infty} v \cdot f_v(v)dv - C \cdot \int_{v=C}^{\infty} f_v(v)dv \right) \qquad \text{(Eq. 5)}$$

It is important to note that McDonald and Siegel (1985) do not reach Equation 5. Rather, they continue the derivation from Equation 4 assuming that the value of completion follows a random walk and eventually come to an expression that, depending on their assumptions on risk, is identical to Black and Scholes's (1973) formula for European call options, or Merton's (1979) European call option formula on stocks that pay a proportional dividend.

For the generalized real options methodology, however, there is no need to specify the shape of $f_v(v)$ nor is it necessary to assume a fixed completion cost. Continuing from Equation 5, let $f_c(c)$ be the probability distributions of the certainty equivalent of the completion cost at maturity time T, and assume that this distribution can be of any shape. With a random completion cost, c, the value of the option is now dependent on c. Thus, substituting c for C in Equation 5 yields:

$$O(c) = e^{-r_f T}\left(\int_{v=c}^{\infty} v \cdot f_v(v)dv - c \cdot \int_{v=c}^{\infty} f_v(v)dv \right) \qquad \text{(Eq. 6)}$$

The expected value of the option, w, can be determined by applying the definition of expected value for continuous random variables to Equation 6:

$$w = E[O(c)] = \int_{c=-\infty}^{c=\infty} O(c) \cdot f_c(c)dc = e^{-r_f T}\left(\int_{c=0}^{\infty} f_c(c) \int_{v=c}^{\infty} v \cdot f_v(v)dvdc - \int_{c=0}^{\infty} c \cdot f_c(c) \cdot \int_{v=c}^{\infty} f_v(v)dvdc \right)$$

(Eq. 7)

Similarly, the variance of the option value can be found by applying the definition of variance for continuous random variables to Equation 6:

$$Var(O(c)) = E\left[O(c)^2\right] - \left(E[O(c)]\right)^2$$

$$= e^{-2r_fT}\left[\int_{c=-\infty}^{c=\infty}\left[\left(\int_{v=c}^{\infty} v\cdot f_v(v)dv\right)^2 - 2\cdot c\cdot \int_{v=c}^{\infty} v\cdot f_v(v)dv\cdot \int_{v=c}^{\infty} f_v(v)dv + c^2\cdot\left(\int_{v=c}^{\infty} f_v(v)dv\right)^2\right]\cdot f_c(c)dc\right.$$

$$-\left(\int_{c=0}^{\infty} f_c(c)\int_{v=c}^{\infty} v\cdot f_v(v)dvdc\right)^2 + 2\cdot\left(\int_{c=0}^{\infty} f_c(c)\int_{v=c}^{\infty} v\cdot f_v(v)dvdc\right)\left(\int_{c=0}^{\infty} c\cdot f_c(c)\cdot\int_{v=c}^{\infty} f_v(v)dvdc\right)$$

$$\left.-\left(\int_{c=0}^{\infty} c\cdot f_c(c)\cdot\int_{v=c}^{\infty} f_v(v)dvdc\right)^2\right] \qquad \text{(Eq. 8)}$$

Equations 7 and 8 give the expected value and the variance, respectively, of a European call option on an asset with a random value of completion and a random completion cost. These formulae can be used to evaluate European-like real options on any projects for which a probability distribution for the value of completion and the completion cost can be determined. These distributions can be completely arbitrary as the formulae do not constrain them to any particular stochastic process.

An important assumption in the derivation of Equations 7 and 8 is that the value of completion and the completion cost are independent. This can be a reasonable assumption for real projects where, for example, the couplings between revenues and costs are non-existent or very weak. In the case where these couplings may be significant, the distributions for value of completion and the completion cost price would have to be conditional on each other.

5. Evaluation of a new aircraft program with a generalized real options methodology

To evaluate the real options in the new aircraft development program with the generalized methodology, it is necessary to determine the probability distribution of the value of completion, V, and of the completion cost, C. Once these distributions are known, they can be substituted in equations 7 and 8 to calculate the expected value and variance, respectively, of the real option.

For the particular example considered here, the probability distribution of the value of completion can be calculated with a combination of system dynamics and Monte Carlo simulation, where the system dynamics model is run many times with different values for the exogenous variables which are drawn from probability distributions specified for each one of them (see Figure 4). The probability distribution of the completion cost can be calculated directly from data provided by the aircraft manufacturer. The procedure to determine both quantities is explained next.

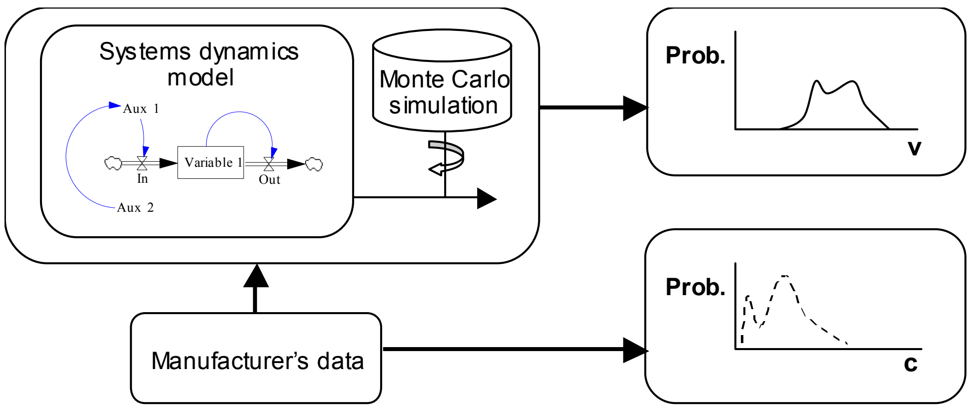

Figure 4: Schematic of the process to obtain the probability distributions of the value of completion, V, and of the completion cost, C, for the real options in the new aircraft development program.

5.1 System dynamics model of the new aircraft program

A system dynamics model to obtain the numerical values to evaluate the real options in the new aircraft development program was developed with input from the aircraft manufacturer (see Figure 5). The variables in bold in are exogenous and their values are determined by probability distributions in the Monte Carlo simulation (see below).

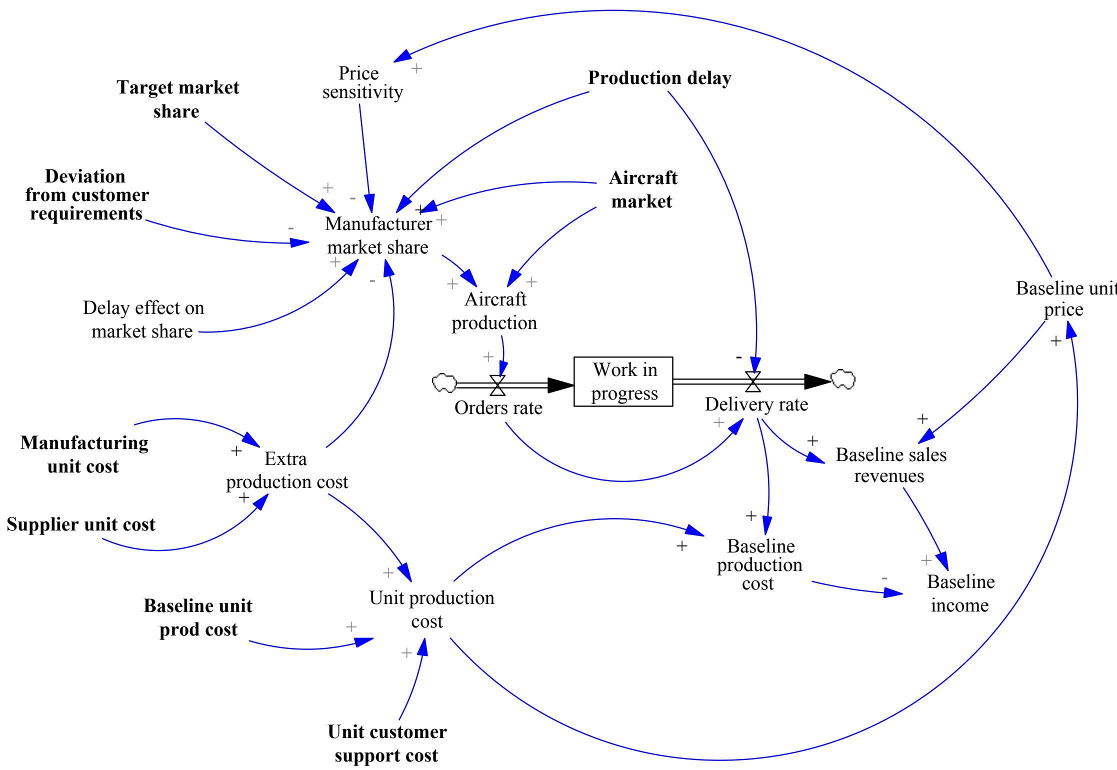

Figure 5: System dynamics model to determine the value of completion of the real options in the new aircraft development program.

There are three main variables in this model: Manufacturer Market Share, Unit Production Cost and Baseline Unit Price (for more details, see Miller and Clarke (2004)). Manufacturer Market Share is key in this model because it determines aircraft production, which in turn affects the number of aircraft orders (Order rate) and aircraft deliveries (Delivery rate) per year. Unit Production Cost is the cost of producing each individual aircraft. It is the sum of Baseline Unit Production Cost, Unit Customer Support Cost, and Extra Production Cost.. Based on information from the manufacturer, Unit Price is determined so that a certain margin over Baseline Unit Production Cost is achieved. In the base case, this margin is assumed to be 12%. If there is any Extra Production Cost, it is added to the Unit Price, which in turn affects Price Sensitivity and Manufacturer Market Share.

The growth rate of the Aircraft Market is modeled as a mean-reverting stochastic process that captures the cyclical growth rate in the air transportation industry. The model was calibrated using the method outlined in Dixit and Pindyck (1994) with historical airline industry capacity[3] data in the United States domestic market between 1979 and 2001 contained in the Form 41 database [USDOT, 1979-2001].

Baseline Sales Revenue is obtained by multiplying Delivery Rate times Unit price. Baseline Production Cost is similarly the product of Delivery Rate times Unit Production Cost. Baseline Income is the difference between Baseline Sales Revenue and Baseline Production Cost. Baseline Income is used to determine the value of completion. The certainty equivalent of the value of completion is calculated according to the method in Brealey and Myers (1996) assuming a risk-adjusted discount rate of 18% and a risk-free rate of 5%. These discount rates were chosen based on the data given by the aircraft manufacturer.

5.2 Monte Carlo simulation to calculate the value of completion for the real options in the aircraft development program

With a Monte Carlo simulation, the system dynamics model is run repeatedly with different values for the exogenous variables, which are drawn from probability distributions specified for each one of them. In this way, many values of the output variable Baseline Income are calculated, and a probability distribution for the value of completion can be obtained. The exogenous variables selected for this study and their associated probability distributions are shown in Table 1. These values are based on data provided by the aircraft manufacturer. They illustrate a representative new aircraft development program at this manufacturer but note that these numbers are not necessarily representative of other programs in the industry. The purpose of this example is to illustrate the use of the generalized real options methodology to evaluate investments under uncertainty in aircraft development programs. Thus, the emphasis of the example is on the framework, which could be used to analyze other aircraft programs if the data was available.

[3] Measured in terms of available-seat-miles (ASM).

Table 1: Variables selected for the Monte Carlo simulation of several real options in the new aircraft development program and their associated probability distributions.

Variable	Probability distribution						
	Unit	Value	P(value)	Value	P(value)	Value	P(value)
Aircraft Market	Aircraft/year	500	0.6	750	0.2	1000	0.2
Deviation from Customer Requirement	%	5	0.6	4	0.2	1	0.2
Production Delay	Year	1	0.6	0.75	0.2	0.5	0.2
Target Market Share	%	20	0.5	30	0.3	40	0.2
Unit Customer Support Cost	% of Unit price	5	0.5	4	0.4	3	0.1
Unit Manufacturing Cost	MU Million/year	10	0.5	5	0.3	0	0.2
Unit Supplier Cost	MU Million/year	10	0.5	5	0.3	0	0.2

5.3 Calculation of the completion cost for the real options in the aircraft development program

According to the data provided by the aircraft manufacturer, it is assumed that the completion cost of several of the real options in the new aircraft development program are given in terms of a percentage of Engineering Cost, which is estimated at 80% of Development Cost. Development Cost is given by a probability distribution supplied by the manufacturer (see Table 2). Again, the certainty equivalent of the completion cost was calculated according to the method in Brealey and Myers (1996) assuming a risk-adjusted discount rate of 18% and a risk-free rate of 5%.

Table 2: Probability distribution of Derivative Development Cost based on the data provided by the aircraft manufacturer.

Variable	Probability distribution						
	Unit	Value	P(value)	Value	P(value)	Value	P(value)
Development Cost	MU Million	15,000	0.6	19,000	0.2	12,000	0.2

6. Numerical results

Numerical results for the different real options in the new aircraft development program are presented below. In Figure 6, the expected value of the real options in the aircraft development program, the expected value of an inflexible strategy at each decision point, and the value of flexibility are shown. In Table 3, the expected value and the standard deviation of the same quantities are tabulated. The reference inflexible strategy is defined as one in which the real option is always exercised at maturity, regardless of the relative values of the value of completion and completion cost. This represents following the original investment plan without incorporating any new information into the decision-making process. The value of flexibility is defined as the difference between the expected value of the real option and the expected value of the inflexible strategy. This definition of the value of flexibility can be found elsewhere, e.g., in Tufano and Moel (1997), Clemons and Gu (2003), and Greden et al. (2005). All values have been discounted to Step A in the aircraft development process.

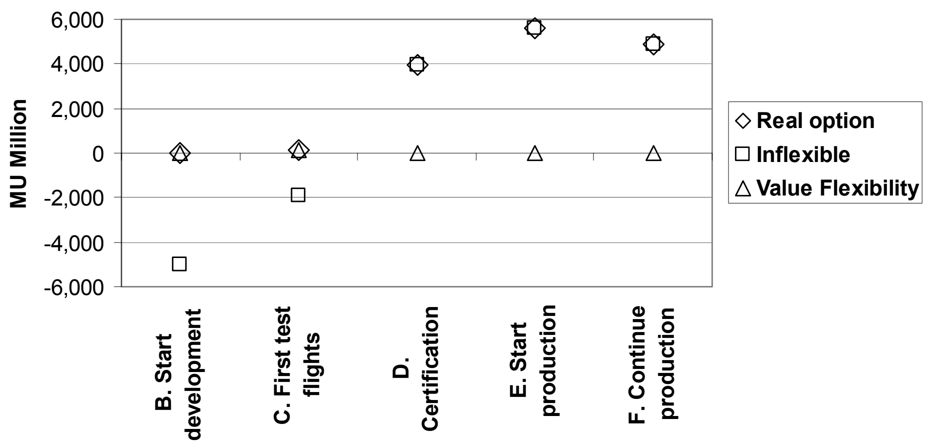

Figure 6: Summary of the numerical results of the expected value of the real options in the new aircraft development process.

Table 3: Summary of the numerical results of the real options in the new aircraft development process assuming a time-varying market.

		Real option				
		B. Start development	**C. 1st test flights**	**D. Certification**	**E. Start production**	**F. Cont. production**
Real option strategy	Expected Value	14.5	104.4	3,957.0	5,575.0	4,874.0
	Std. Deviation	4.9	45.3	239.0	0.0	0.0
Inflexible strategy	Expected Value	-5,016.0	-1,893.0	3,956.0	5,575.0	4,874.0
	Std. Deviation	466.0	743.0	239.0	0.0	0.0
Value of flexibility	Expected Value	5,030.5	1,997.4	1.0	0.0	0.0
	Std. Deviation	466.0	744.4	338.3	0.0	0.0

There are a number of observations from the above results that are worth highlighting. First, the expected value of the strategies with or without the real option tends to increase as the process moves forward. For example, the expected value at Step B (start development) is MU 14.5 million for the strategy with the real option and –MU 5,016.0 for the inflexible strategy, while the expected value at Step E (continue production) is MU 4,874.0 million for both strategies. Typical aircraft development programs are structured such that large expenditures occur in earlier rather than in later stages.[4] At the same time, manufacturers generally do not receive significant revenues until they deliver the finished aircraft. In some cases, manufacturers may receive advance payments for firm orders and aircraft order options, but these tend to be small compared to the full price of the aircraft. In fact, the manufacturer that provided the data for the analysis presented here suggested the assumption that no revenues are received until the aircraft are delivered. Thus, the further the manufacturer moves along the process, past expenditures become sunk costs, less investments remain outstanding, and the time to receive revenues approaches. Therefore, from the viewpoint of an investor standing at point A, the expected value of the project with either strategy is higher towards the end of the process.

The second observation pertains to the value of flexibility, i.e., the value of the strategy with a real option compared to the value of an inflexible strategy. Given the assumptions in the structure of the project and in the numerical data used in this analysis, the value of flexibility initially increases and then decreases as the process moves forward. Again, this behavior can be explained with the assumed schedule of expenditures shown in Figure 3. As the process moves from B to C, the investment costs are greater and, thus, the value of being able to close down increases. Remember that the completion cost at C is the single largest in the entire process, because it includes 40% of Engineering Cost, the production facilities for the baseline aircraft, and production cost for five test units. The ability of avoiding this expenditure if conditions are not favorable is very valuable and, therefore, the value of flexibility at this point is the largest. As the process moves forward, however, less expenditure remain outstanding and, thus, options further in the process tend to be "in the money" and, consequently, will be exercised with great certainty. Thus, the value of waiting to invest decreases past Step C.

[4] These are characteristics of aircraft development programs in general, not only the one considered here. See, for example, Jenkinson et al. (1999) and Schaufele (2000).

Another aspect worth highlighting in the context of the value of flexibility is that, in many other examples of real options, the value of flexibility tends to increase, not decrease, throughout the life of the option. A fundamental feature of real options is the phasing of investments until more information is available. Thus, in general, the holder of the option pays a small price at the beginning of the investment to purchase the option and the large expenditure, i.e., the completion cost, comes at a later time when, ideally, a significant portion of the uncertainties have been resolved. In the particular case of aircraft manufacturing, however, this does not seem to be the case. As mentioned above, in typical aircraft development programs much of the expenditures occur in the early stages of the process and they dwindle as the project advances. Therefore, the value of the ability of waiting to invest decreases because less expenditures remain outstanding.

The third observation regarding the results in Table 3 is that the importance of real options can be seen in the earlier stages of the program. For example, the real option to do first flight tests (option C) has an expected value of MU 104.4 million while an inflexible strategy at this point would result in an expected value of –MU 1,893.0 million. Thus, the ability that the option gives the investor to cancel the investment at the maturity of this option if conditions are not favorable is very valuable. Similarly, the value of flexibility provided by the real option to start development (option B) is significant: the expected value of the real option is MU 14.5 million while the expected value of an inflexible strategy is –MU 5,016.0 million.

This observation highlights an important characteristic of options: options are most valuable in uncertain situations. For the particular assumptions in the aircraft development program used here, the option is deep "in the money" in the later stages of the process and, thus, it will be exercised with great certainty. The value of flexibility is low in that case. In earlier stages, however, there is great uncertainty about the fate of the program. The project is "at the money" and it is uncertain whether its financial performance will be positive or negative. It is here that options are valuable, because they can make the difference in the financial viability of the project.

There is at least one implication of this observation for policymaking. The results in Table 3 suggest that the new aircraft program is very risky in earlier stages but, after a certain point (Step C in this example), the project becomes profitable. This suggests that if there are reasons other than profit maximization for having such an aircraft program, e.g., national security, job creation, or maintenance of a high tech capability, outside intervention in the early stages of the project may be justified to guarantee its viability until it reaches a point of self-sufficiency.

The last observation regarding the numerical results in Table 3 is that the value of the real option to start development is also the maximum amount that the investor should spend during the preliminary design phase. Thus, the aircraft manufacturer should pay no more than an expected MU 14.5 million with a standard deviation of MU 4.9 million for the first phase of the project.

Finally, it should be noted that the numerical results may not be representative of project returns of other new aircraft programs. The values in the data provided by the aircraft manufacturer are based on its own experience but they are not necessarily representative of other programs in the industry; however, the emphasis of this paper is to demonstrate an evaluation methodology that can be used with different data sets and not necessarily on obtaining specific numerical results.

7. Exploiting flexibility to increase project value

The flexibility provided by the real options to cancel the program when it is not profitable to continue has been proven to increase the expected value of the investment over a strategy that proceeds with initial plans regardless of how uncertainties are resolved; however, the value of a program even with this flexibility is low. There are other ways in which managerial flexibility can be exploited to increase project value. One strategy consists of postponing investment decisions until more information is available. A second strategy corresponds to re-structuring capital expenditures so that major investments occur later in the program as opposed to in earlier stages, as it is typically the case in traditional aircraft projects. The effects of these strategies on the expected value of the program are investigated below.

7.1 The value of postponing investments

There are advantages related to the ability of postponing investments such as the possibility of gathering more information to reduce market and technical uncertainty, and guarantee on-time deliveries; however, postponing an investment also increases the risk of loosing market share to competitors that may act earlier. To explore the value of postponing capital investments in this new aircraft example, it was assumed that the decision to do initial test flights (Step C in Figure 2), which is the single-largest expenditure in the aircraft development program, can be postponed by a year. The effects of postponing the investment at Step C were incorporated into the analysis by assuming that waiting to invest would affect the following three variables: Deviation from Customer Requirements (reduction), Production Delay (reduction), and Manufacturer's Market share (reduction).

The impact of postponing the investment at Step C by one year on the overall value of the real option to do preliminary design is significant: the value of the option increases 31% from MU 14.5 million in the baseline scenario to MU 19.0 million assuming the investment is postponed. This indicates that according to the specific assumptions and numerical values used here, the benefits of waiting to invest in terms of reducing delivery delays and deviation from customer requirements are larger than the potential losses in market share. The insight for the aircraft manufacturer is that delaying the investment in Step C for a year may lead to a higher expected payoffs if there is reason to believe that the extra time can lead to a product with better performance and on-time delivery schedule.

7.2 The value of re-structuring capital expenditures

As discussed above, new aircraft programs are typically very capital intensive in the early stages of the project. This has at least two important implications for project managers. First, it means that large investments are spent on products with a high degree of technical and market uncertainty and, thus, a high probability of negative expected payoffs. Second, large expenditures early in the project reduce the ability of managers to influence the project, because once the project advances beyond a certain stage, the manufacturer should always continue with the project.

To analyze the value of re-structuring the investment schedule, it is assumed that the delivery of the production facilities for the new aircraft is shifted from Step C to Step E (start of production) and that the test aircraft can be produced using existing assembly lines. The unit cost of the test aircraft is increased 25% over the unit cost of the production aircraft to take into account extra costs associated with building the test aircraft using facilities designed for another product.

With the re-structuring of the investment schedule, the expected value of the option to start development is MU 22.1 million, a 52% increase from the expected payoff of MU 14.5 million of the flexible strategy with the original capital expenditures. An analysis of the numerical results indicates that even with the new investment schedule, the option to start production at Step E is always exercised. Thus, in this particular case, and with the specific assumption and numerical values used here, the benefits of re-structuring capital expenditures come from more heavily discounted expenditures as opposed to the ability of managers to cancel the project.

7.3 Summary of expected project payoffs with alternative investment strategies

The ideas of postponing the investment at Step C and re-structuring the capital expenditures are not mutually exclusive. In fact, combining the positive effects of both increases the expected payoff of the project. Calculations show that a strategy that combines both alternatives results in an expected value of the option to start development of MU 28.2 million, a 93% increase over the original flexible investment strategy (see Table 4). Notice also that the payoff from the combined strategy is higher than the expected payoff that would result from implementing either alternative separately.

Table 4: Summary of the expected payoff of the new aircraft program given different alternative investment strategies. All values in MU million.

Strategy	Real Options strategy with original investment schedule	Real Options with 1yr postponement at C	Real Options with restructuring of production facilities to Step E	Real options with 1yr postponement at C and restructuring of production facilities to Step E	Inflexible strategy
Exp. Value	14.5	19.0	22.1	28.2	-5,016.0
Std. Dev.	4.9	6.8	7.0	9.1	466.0

The expected payoffs of each alternatively in isolation, i.e. only postponing investments at C or only re-structuring capital expenditures, are very similar to each other. The expected payoff of postponing is MU 19.0 million whereas for re-structuring it is MU 22.1 million. These values are still higher than the expected payoff of the real options strategy with the original investment schedule of MU 14.5 million, therefore, pursuing either one would be in the interest of the aircraft manufacturer. Finally, notice the expected payoff of any of the strategies with real options is higher than the expected payoff of the inflexible strategy of –MU 5,016.0 million. This indicates that the aircraft manufacturer should always follow a strategy that allows managers to modify the project as uncertainties are resolved versus following an investment plan fixed from the beginning of the project.

7.4 Insights for strategic decision-making

Knowing how much to spend in preliminary design is useful information for management to make its budgeting plan, but it does not provide strategic guidance on how to proceed as uncertainties get resolved. Further analysis of the numerical data from the real options valuation is necessary to uncover insights that are useful for strategic decision-making.

An important metric of progress in aircraft programs is the number of aircraft orders. Often, the decision by the board of directors to proceed with further development and/or production is heavily based on the number of firm orders at the time when the decision is to be made. Thus, it may be argued that for a decision support tool to be both useful and readily accepted, it must provide the user with some correlation between the current state (e.g., in terms of firm aircraft orders) and the likelihood of program success or alternatively, the expected profit.

To illustrate how the methodology that has been presented may be used to guide decision-making within this context, assume that the aircraft program is at Step C and management is deciding how to proceed next. The project has already advanced past preliminary design and the first phase of development. According to the strategies discussed in the previous section, there are several alternatives available:

1) Proceed with the original investment schedule with real options.
2) Postpone first test flights by a year.
3) Re-structure capital investments so that production facilities for the new aircraft are delivered in Step E.
4) Postpone first test flights by a year and re-structure capital investments so that production facilities for the new aircraft are delivered in Step E.

In addition to these four strategies, the inflexible strategy is also considered, i.e., the one in which capital expenditures occur as planned from the beginning of the project without the ability to react as uncertainties are resolved.

Using the numerical results from the system dynamics and Monte Carlo simulation and the real options analysis, it is possible to calculate the probability of positive program payoff from Step C on as a function of aircraft orders at that point (see Figure 7). In other words, the information in Figure 7 indicates the probability that the aircraft program from Step C until the end of the project will result in a positive expected payoff, given the number of orders at that point, expectations about further orders as a function of firm orders in hand, and given an investment strategy.

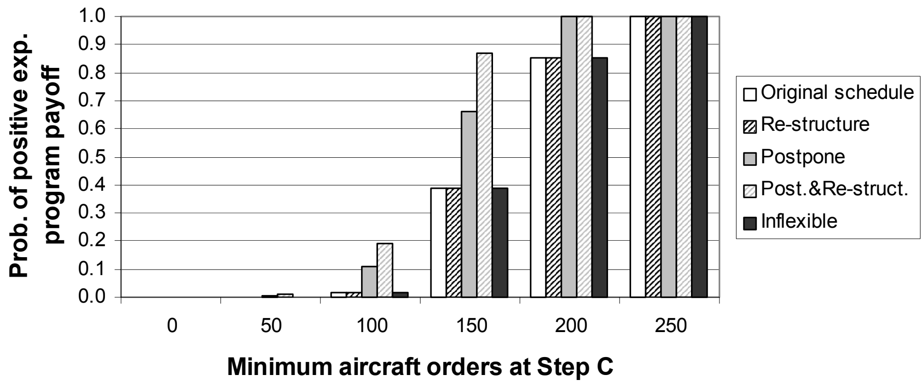

Figure 7: Probability of positive expected program payoff as a function of minimum aircraft orders and investment strategy at Step C.

The data in Figure 7 can be relevant for strategic decision-making. For example, it indicates that the program will always have a positive expected payoff if there are at least 250 aircraft orders at Step C, regardless of the strategy followed. On the other extreme, the data shows a practically zero probability of program success if aircraft orders are less than 50. As the minimum number of orders increases, so does the probability of program success for all investment strategies. The strategies to postpone first test flights and the strategy that combines postponement of first test flights and restructuring of capital investment lead to the highest probability of program success for a given number of aircraft orders, with the latter strategy offering a considerable advantage where there are only 150 orders.

Based on the information provided in Figure 7, and assuming that investors are willing to accept a minimum probability of success of 80%, the following guidelines for strategic decision-making can be established (see Table 5):

Table 5: Guidelines for strategic decision-making to maximize the probability of project success as a function of aircraft orders at Step C and assuming a minimum allowable probability of success of 80%.

Minimum aircraft orders at Step C	Suggested strategy	Probability of success
0	Cancel project	N/A
50	Cancel project	N/A
100	Cancel project	N/A
150	Postpone & Restructure	87%
	Postpone, only	66%
200	Postpone & Restructure	100%
	Postpone, only	100%
250	Any	100%

Besides knowing the probability of program success, managers might also be interested in the average value of the project as a function of aircraft orders. The average value of the aircraft program for a given number of orders and investment strategy is shown in Figure 8. This information indicates the average value of the project that can be expected from following a specified investment strategy for a given number of aircraft orders at Step C.

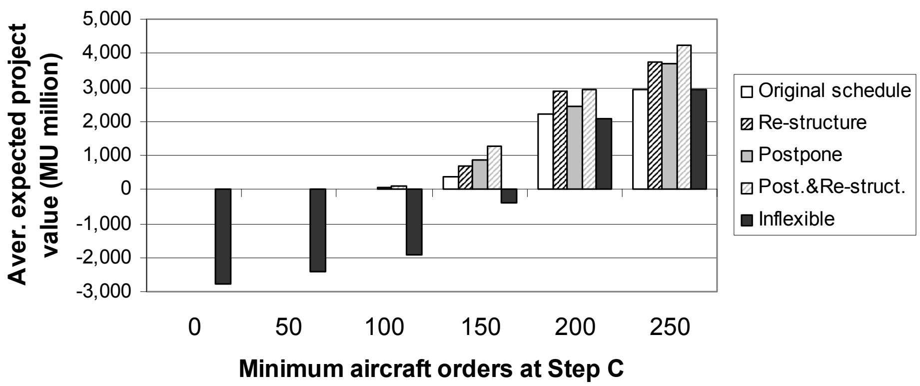

Figure 8: Average expected program value as a function of minimum aircraft orders at Step C.

As expected, the average value of the project increases with the number orders for a given investment strategy. The maximum average project value of MU 4,224.0 million corresponds to a situation in which 250 minimum orders have been received at Step C and a postponement and restructuring strategy has been followed. Notice that even the inflexible strategy achieves positive average project values for minimum orders above 200 aircraft.

Guidelines for strategic decision-making can also be made based on the average project values in Figure 8 (see Table 6):

Table 6: Guidelines for strategic decision-making based on maximizing average project value as a function of aircraft orders at Step C. Average project value given in MU million.

Minimum aircraft orders at Step C	Suggested strategy	Average project value
0	Cancel project	0.0
50	Postpone & Restructure	5.4
100	Postpone & Restructure	118.3
150	Postpone & Restructure	1,267.5
200	Postpone & Restructure	2,948.5
250	Postpone & Restructure	4,224.0

The strategy to postpone and restructure achieves the maximum average project value when there are more than 50 aircraft orders. For the case when there are 200 minimum aircraft orders, this is still the preferred strategy, although by a small margin because the average expected value of restructuring is MU 2,897.0 million, very close to the MU 2,948.5 million of postponing and restructuring.

The guidelines based on average project value in Table 5 can be combined with those drafted using the probability of project success shown in Table 6 to give managers more elements of judgment when making decisions to proceed with the project. Assuming that managers still require a minimum probability of project success of 80% and that they want to maximize average project value, the suggested strategy based on both metrics is shown in Table 7. According to these results, managers would cancel the project if aircraft orders at Step C are less than 150 units. If the number of orders is higher than 150 aircraft, the preferred strategy would be to postpone the investment at Step C for a year and build the production facilities at Step E.

Table 7: Guidelines for strategic decision-making based on the probability of success and average project value as a function of aircraft orders at Step C.

Min. aircraft orders at Step C	Suggested strategy based on probability of success	Suggested strategy based on average project value	Suggested strategy based on both metrics
0	Cancel project	Cancel project	**Cancel project**
50	Cancel project	Postpone & Restructure	**Cancel project**
100	Cancel project	Postpone & Restructure	**Cancel project**
150	Postpone & Restructure Postpone, only	Postpone & Restructure	**Postpone & Restruct.**
200	Postpone & Restructure Restructure, only	Postpone & Restructure	**Postpone & Restruct.**
250	Any	Postpone & Restructure	**Postpone & Restruct.**

8. Challenging the assumption of zero cancellation costs

A typical assumption in real options analysis is the absence of penalties for canceling an investment. In reality, however, canceling a program may come at a cost to the investor. For example, in the new aircraft program, the manufacturer may be contractually liable to pay compensation costs to customers and/or to suppliers. The assumption of zero terminating costs can be relaxed by establishing a penalty in the case where the aircraft manufacturer decides to cancel the project. In this case, the managerial decision becomes a choice between keeping the project alive or paying a cancellation cost if the project is terminated. In the example investigated here, the ability to cancel the program is relevant only at Step B (Start development) and Step C (First test flights), because if the program has advanced beyond Step C, it is always "in the money" and, thus, it is carried to completion in all occasions.

The baseline case for the sensitivity analysis is the strategy that postpones the exercise of the option to do first test flights at Step C by one year. The expected value of the option to start development with this strategy is MU 19.0 million. The sensitivity of the expected value of the real option to start development to cancellation costs at Step B is shown in Figure 9. Cancellation costs are normalized by total development costs, i.e., they are given in terms of percentage of total development costs.

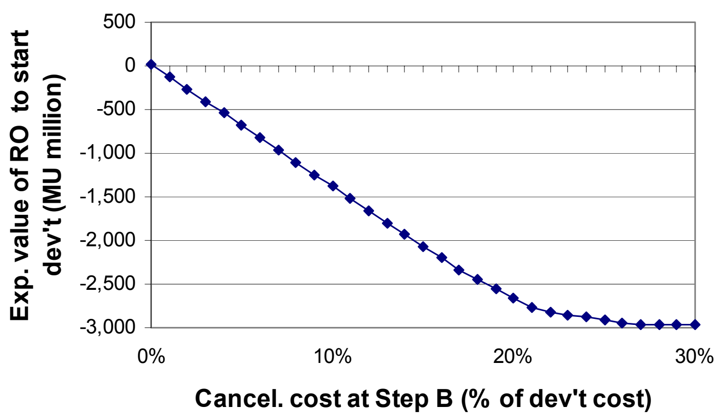

Figure 9: Expected value of the real option to start development as a function of cancellation costs at Step B. Cancellation costs are specified as a percentage of total development cost.

The result in Figure 9 shows that the expected value of the real option to start development is very sensitive to cancellation costs at Step B. With a cancellation cost of just 0.15% of development cost, the expected value of the real option is zero, compared to MU 19.0 million with no cancellation costs.

Similarly, the cancellation costs at Step C have a significant impact on the value of the real option to do first test flights. The expected value of this real option becomes negative if cancellation costs at Step C are more than 1.35% of development costs (see Figure 10).

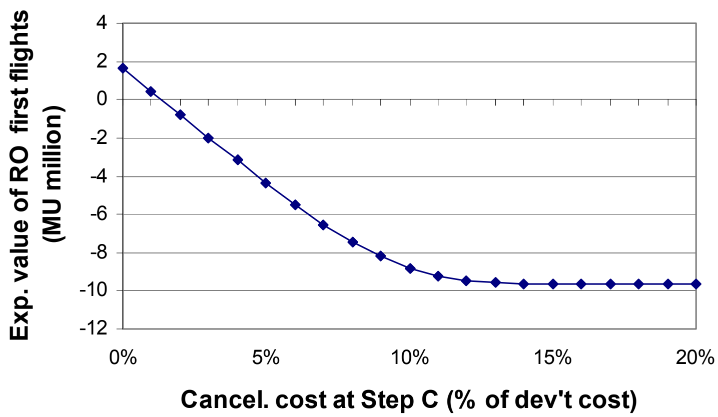

Figure 10: Sensitivity of the expected value of the option to do first test flights (Step C) to cancellation costs at Step C. Cancellation costs are specified as a percentage of average development cost.

If there are non-zero cancellation costs, the manufacturer must ensure that termination costs at Steps B and C are kept below 0.15% and 1.35% of total development costs, respectively. Otherwise, the expected value of the options to start development and do first test flights would be negative.

9. Conclusions

A new aircraft development program is a process with many embedded real options. Many of these options arise from the phased-structure of these projects. Thus, project managers may have the ability to cancel or postpone investments. Furthermore, once the production stage is reached, the aircraft manufacturer has a series of options available to continue the project, ranging from continuing with the baseline aircraft, launching a derivative model, selling the program, or abandoning the program.

A generalized real options methodology has been used to evaluate the real options in the new aircraft program. This methodology does not restrict the probability distribution of value of completion or of the completion cost to any stochastic process. Thus, there is no need to sacrifice accuracy by approximating the value of completion or the completion cost so that they would fit within a conventional real options solution technique, such as those based on modeling the value of completion as a geometric Brownian motion.

As the numerical results show, a real options approach can increase the value of the project significantly over an inflexible strategy in which it is assumed that the program is always completed as scheduled from the beginning. Real options have been found to be more valuable in earlier stages of the project, which is where the largest expenditure occur. As the process advances, less capital outlays remain outstanding and, thus, the option is always in the money.

Apart from the real options to stop the project after each phase, there are other options available to managers. For example, investment decisions can be postponed until more information is available, and capital expenditures can be re-structured so that major investments occur later in the program as opposed to in earlier stages, as it is typically the case in traditional aircraft projects. Simulation results show that these options can increase the value of the project.

The data from the system dynamics and Monte Carlo simulation can be further analyzed to provide strategic guidance to managers. These guidelines indicate the appropriate course of action according to the minimum number of aircraft orders, a common decision variable in aircraft programs.

Finally, sensitivities to the assumption of non-zero cancellation costs were analyzed. Results show that the expected value of the real options are very sensitive to cancellation costs. Thus, managers should pay close attention to these variables when evaluating new aircraft development programs.

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