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Methodologies and Techniques for Determining the Value of an Aircraft

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Abstract

Aircraft valuation and the estimation of an accurate aircraft price is undoubtedly a challenging task that has significant consequences for airlines. This paper presents an asset valuation model to show how a series of endogenous as well as exogenous factors can influence the value of an aircraft. Specifically, a discounted cash flow methodology is used to forecast the valuation of an old or new generation aircraft. Both total operating revenue and aircraft operating costs are taken into account to devise a reliable pre-tax profit measurement that is used as the basis of the discounted cash flow analysis. A sensitivity analysis based on Monte Carlo simulation is utilized to identify which factors have a more significant influence on the suggested aircraft value. Therefore, it addresses how value fluctuates in response to economic fluctuations. Indeed, the calculated value of an aircraft highly depends on the underlying assumptions used. The calculated value is compared with available data in a case study for verification.

Valuation is the process of determining the fair market value of an asset. In the commercial aircraft industry, valuation can be defined as the determination of the fair transaction value of an airplane. The fair market values for commercial aircraft generally have similar patterns following business cycles, supply, and demand. Aircraft manufacturers incur significant development and assembly costs to offer safe and reliable airplanes. The total cost of development and manufacture of the Boeing 787-9 Dreamliner, along with the deferred production cost and unamortized tooling, has been more than \$32 billion (*1*, *2*), and the total development cost for the Airbus 350 was around \$15 billion (*3*). The pricing of the various commercial airplanes is an essential part of the airline business. Airlines have to be constantly aware of aircraft values since aircraft represent the most important assets of their operation. Accordingly, the development of a reliable valuation model is crucial to assist manufacturers and airlines similarly in forecasting how the value of an aircraft can change when the factors that affect an aircraft fluctuate.

Examining an aircraft's physical and operating characteristics is crucial in aircraft valuation. In particular, components such as aircraft size (narrow-body versus wide-body), fuel efficiency, number of seats, age, and physical condition, as well as operating expenses that cover crew costs, maintenance, and depreciation, along with administrative and transport-related expenses, are all intrinsic factors that play a significant role in assessing an aircraft's value. On the revenue side, proceeds generated from passengers, cargo, and ancillary activities should be included in the analysis since they represent how an aircraft type contributes financially. It will be shown in this paper that revenue, and especially passenger yield, is one of the most critical factors affecting aircraft value.

Furthermore, external factors can also alter the aircraft's value. The advent of new technologies such as carbon fiber airframes or winglets (sharklets) to improve aerodynamics increases the value of modern airliners. More significantly, the success of manufacturers of aircraft and engines in improving fuel efficiency has made the older generation of airplanes less desirable. In some cases, such as the Boeing 747, low fuel efficiency is the reason for early retirement of the aircraft. Similarly, governmental regulations, for instance, environmental policies that address the mandates for reducing carbon emissions, affect the market value of airplanes (*4*, *5*).

It should not be neglected that macro-economic trends and business cycles, as well as isolated events, can have the most significant impact on aircraft values. A massive

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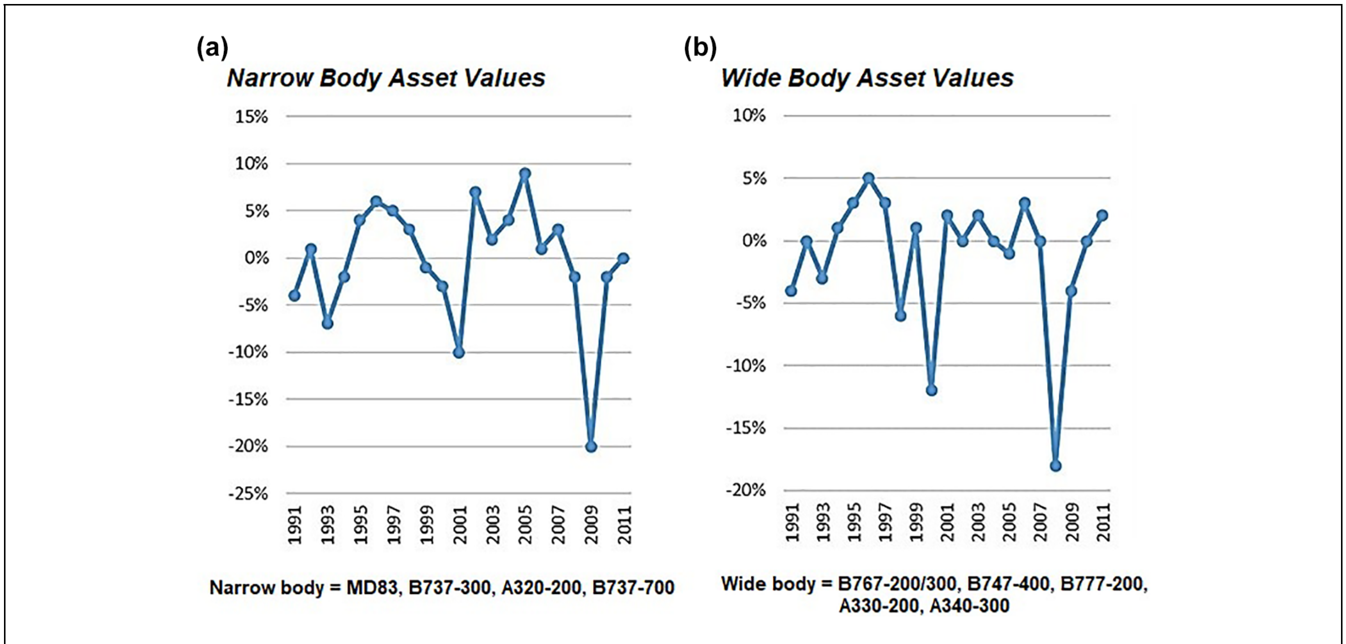

Figure 1. Year-on-year percentage change in market value, 1991–2011: (*a*) narrow-body aircraft, (*b*) wide-body aircraft (7).

shock for the airline industry was the terrorist attack of September 11, 2001 (*6*). The attacks created a ripple effect in the industry, followed by several bankruptcies and furloughs, which shrank the U.S. commercial aircraft fleet by around 700 units between 2001 and 2009. Airlines had to store and scrap their fleets or look for conversion options. Similarly, the financial crisis of 2008–2009 led to the most significant drop in year over year market values of both narrow-body and wide-body assets (*7*). Figure 1 presents the year-to-year percentage change in the market value of wide- and narrow-body aircraft. The effects of the 9/11 attacks and the financial crisis are visible. More recently, safety concerns arising from incidents involving the Boeing 737-MAX led to a notable reduction of the market value of the aircraft (*8*).

The diversity of factors affecting the values of aircraft and their fluctuation complicates the aircraft valuation modeling. In practice, there is no consensus on one unique approach for aircraft valuation; various models are proposed for this task. However, each approach has its own strengths and weaknesses and may result in a different assessment. Some of the existing methodologies are briefly reviewed in the literature review, which is the next section.

This paper proposes a modified discounted cash flow (DCF) analysis based on financial theory to determine aircraft value. This methodology can assist both manufacturers and airlines in their decision-making processes. Manufacturers can price their products correctly, while airlines can make more sound fleet replacement and retirement decisions. After presenting the methodology, its performance is demonstrated by assessing the value of multiple aircraft from Boeing and Airbus using the proposed method and the results are compared against the list price.

Literature Review

Despite its significance, the subject of valuing commercial aircraft has not been extensively researched by academia in the recent past. As mentioned in the introduction, a modified DCF model is proposed in this paper. This approach is based on the financial theory that the value of an investment can be estimated from the future cash flows that the investment is expected to generate (*9*). However, several other research papers and articles have attempted to approach aircraft valuation under different methodologies. The most relevant literature is briefly reviewed in this section.

One of the valuation methods that has been studied extensively in the literature is real options analysis. Under this approach, it is assumed that companies react to changes and take actions to steer a project toward profitability. Thus, the actual value of a project can be estimated by accounting for the managerial inputs and reactions to potential future scenarios. Stonier (*10*) discussed option values for commercial aircraft and utilized the binomial-tree pricing model to obtain a set of potential net present values (NPVs) under Monte Carlo simulations. Gibson and Morrell (*11*) proposed the adoption of a weighted average cost of capital (WACC) and NPV technique. The model is adjusted to offer the potential for flexibility beyond its classic interpretation. The proposed adjusted present value (APV) concept provides insight into lease versus purchase decisions as well as an equity NPV that demonstrates the overall returns from an aircraft from the shareholder perspective. They argued that the APV approach is advantageous since it measures the cost of flexibility. Sala et al. (*12*) applied real options analysis in studying the impact of environmental regulation like carbon emissions on the value of an aircraft.

Justin et al. (*13*) utilized a network approach to the valuation of aircraft for fleet planning and strategic decision making. In particular, they extended the DCF model by using real options analysis, which dictates that the concept of the time value of money should be recognized. However, managers should react if uncertainty is unfolding and actively steer projects into profitability. Justin et al. (*13*) and also Justin (*14*) proposed game theory to complement the real options analysis approach. They developed an aircraft and engine value calculator that quickly evaluates the intrinsic value of an aircraft—or fleet of aircraft—by including both revenues and costs. The outcome is the value of an aircraft over a whole network of routes, taking into consideration future wear-and-tear and the increased maintenance and operating costs. More recently, Justin and Mavris (*15*) presented a customer-centric methodology to value the combined aircraft and engine by detailed consideration of cost and revenue elements. They also suggested an approach inspired by real options analysis for valuing maintenance contracts.

Hu and Zhang (*16*) utilized real options analysis with two options: the shutdown-restart option and the aircraft delivery deferral option. They claimed that results obtained by this approach are closer to actual values than the static NPV method. Hu et al. (*17*) further utilized real options analysis to justify the underlying reasons behind the different approaches to using regional jets in three different countries (U.S., Brazil, and China) and demonstrated how regional options affect the value of an aircraft. More recently, Chen (*18*) proposed a theoretical value evaluation model for commercial aircraft from the perspective of Chinese airlines using real options analysis.

On the other hand, Ackert (*19*) took a rather qualitative and empirical view on how aircraft values can fluctuate. Specifically, he identified several aircraft value retention factors that are either market or performance driven. For example, Ackert argued that the orders for a particular aircraft type, surpluses, or shortages in its segment, and the general financing environment could all affect an airplane's residual value. Similarly, aircraft specifications, aircraft economics, and overall aircraft family characteristics also play a crucial role in appraising an aircraft. This study was an expansion of the earlier work in which Ackert (*20*) examined the relationship between an aircraft's value and its maintenance status. Ackert (*20*) developed future base value forecast cycles to predict the value that the asset should achieve with reference to the normal depreciation of the underlying asset.

Bruno et al. (*21*) introduced a hybrid novel model for aircraft evaluation rather than valuation, based on the investigation of airlines' needs. In an effort to overcome the weaknesses of the previous NPV/APV, Monte Carlo simulation, and real option analysis models, they proposed a model that combines two main approaches to address evaluation problems: the analytic hierarchy process and the fuzzy set theory. The model includes four criteria (economic performance, technical performance, aircraft interior quality, and environmental impact) and eight sub-criteria (aircraft price, operative cost, cruise speed, autonomy, seat comfort, cabin luggage compartment size, noise, and environmental pollution). This hybrid approach may be used as an evaluation system and as a strategic tool. Bruno et al. (*21*) argued that airlines and manufacturers could use the model, both ex-ante and ex-post, to identify their requirements.

The diversity of the methods proposed for aircraft valuation is because of the complexity of the process. Some approaches, such as Ackert (*19*) and Bruno et al.(*21*), may rely on data that are not publicly available to the interested parties. On the other hand, the real options analysis method seems to be mostly utilized in academic studies. Gibson and Morell (*22*) presented the results of their survey of the airline industry in relation to valuation methods used and preferred in practice. Their study reveals that airlines indicated a strong preference for NPV and a weaker preference for accounting-based ARR. Concerning the advanced techniques, the airlines' responses showed a very weak preference for both real options analysis and APV, even less than the general business community. The common criticisms levied against real options analysis is that it is difficult to explain, theoretical rather than practical, and obtaining the required data is challenging. Similar observations have been reported by other surveys (*22*−*25*).

The objective of this study is to offer a method that can utilize public information and provide a quick assessment of the value of one given aircraft at a time. Sophisticated analytical methods, when applied correctly, may offer a more accurate valuation of assets. However, surveys of the practitioners in the aviation industry consistently show that sophisticated methods tend to be avoided in favor of simpler methods. In this study, an approach is present based on a modified discount cash flow model, which distinguishes this study from some of the existing literature that employed complex analysis to achieve a similar goal. Using four popular aircraft models as case studies, it is demonstrated that a relatively straightforward approach can be employed to estimate the value of aircraft using only publicly available data. In addition, to identify the key factors affecting the value of an aircraft, a Monte Carlo based simulation was conducted for sensitivity analysis.

Asset Valuation Model

The general concept of estimating the value of an investment from the future cash flows that the investment will generate serves as the theory for this paper's analysis. A DCF model is utilized to provide a present value calculation of expected future cash flows. Projecting future cash flows is an intricate process and necessitates a series of hypotheses.

First, the cash inflows are taken into account. Total revenue is calculated by adding the revenue generated from passengers and cargo. As presented in Equation 1, passenger revenue is derived from multiplying passenger yield with revenue passenger miles (RPM). Similarly, cargo revenue is calculated by multiplying cargo yield with revenue ton miles (RTM). Several assumptions are made to match each aircraft type with the more appropriate yield. For Airbus 320-200ceo, JetBlue's passenger yield is selected since the carrier is the largest operator of the type in the U.S.A. For Boeing 737-800, the yield from the whole fleet type is considered more suitable since the type is prevalent among U.S. airliners. In the case of Airbus 330-200 and Boeing 787-9, passenger yield as presented by the MIT airline data project was used (*26*). This choice is because the active fleet sizes of these models are still limited, and their respective fleet yields might not be representative of the actual aircraft value. Cargo yield is determined by dividing the total operating revenue by RTM. It is observed that the narrow-bodies have a lower cargo yield than wide-bodies because they have less available cargo space while they may incur extra costs since cargo often has to be loaded manually. A possible variable that can be considered for further research is ancillary revenue yield since ancillary products have risen dramatically over the recent past. This would allow appraisers to understand what portion of the passenger yield reflects ancillary revenue. The cash inflows can be generated as follows.

$$TR = \mathrm{RPM} \times \tau_{\mathrm{Pax}} + \mathrm{RTM} \times \tau_{\mathrm{Cargo}} \quad (1)$$

where

TR = total revenue ($)

RPM = revenue passenger mile

RTM = revenue ton mile

τ_{Pax} = passenger yield, revenue per RPM

τ_{Cargo} = cargo yield, revenue per RTM

Next, it is necessary to consider the corresponding cash outflows. Total costs include several components from operating to administrative expenses. Operating expenses include flight crew expenses, fuel cost, maintenance, depreciation, and amortization costs. Administrative expenses carry marketing, sales, and general administration costs. There are also indirect costs, such as transport-related expenses. These costs are allocated on an available seat mile (ASM) basis. This means costs are distributed throughout the airline product, namely their flights throughout the system. Without neglecting the cost of capital, total costs can be defined as:

$$TC = \mathrm{ASM} \times [\theta \times \omega + \lambda + \mu + \psi] + \gamma \quad (2)$$

where

TC = total costs

ASM = available seat mile

θ = fuel cost per gallon

ω = gallons of fuel consumed per ASM

λ = flight crew costs per ASM

μ = maintenance costs per ASM

ψ = capital cost per ASM

γ = administration costs

Finally, the subtraction of cash inflows from cash outflows generates the net cash flow, which presents the profit a carrier can generate from operating a single aircraft every year. This value will naturally diminish as the aircraft ages. Discounting future net cash flows is the key to determining the current value of the aircraft. Adding all discounted cash flows represents the value of the asset. The DCF model, therefore, can be summarized using the following equation.

$$\text{Aircraft Value} = \sum_{t=1}^{n} \frac{TR_t - TC_t}{(1+k)^t} \quad (3)$$

where

k = cost of capital (required rate of return)

t = year

n = expected aircraft lifespan

The calculation of the cost of capital, k, is discussed in the next section.

Cost of Capital

A suitable discount rate has to be established to discount future net cash flows. Implementing a proper discount rate is crucial in obtaining an accurate result. The discount rate needs to represent both the time value of money and the risk over time. Often, in practice, firms develop a discount rate that is used across various projects for decision making. However, the variation in risk and volatility of different factors such as cost and revenue may support using multiple discount rates. Applying dual or multiple discount rates is more sophisticated and offers advantages over a single discount rate. However, the success of the method relies on the correct selection of the discount rates, as misusing the rates may diminish any advantages that multiple rates may offer. The discount rate is a subjective concept that is often challenging to assess. Indeed, it is even more challenging to estimate multiple rates correctly. Moreover, the choice of using different discount rates may introduce managerial biases as the selection of the discount rates may be affected by the optimism or pessimism of the managers about individual projects (*27*). In this study, the objective is to provide a relatively straightforward and practical approach to aircraft valuation. Various surveys have demonstrated that practitioners, especially in airlines, prefer less sophisticated approaches that are easy to apply and easy to explain (*22*−*25*).

In this paper, WACC is used to align the model to current market rates and risk that the airline industry is facing. This approach is the method most widely used in the industry (*24*). From a financial standpoint, the WACC is defined as follows:

$$WACC = w_d k_d (1-T) + w_e k_e \quad (4)$$

where

w_d = proportion (weight) of debt
w_e = proportion (weight) of equity
k_d = cost of debt
k_e = cost of equity
T = corporate tax rate

Based on IATA's end of year report (*28*) on the economic performance of the airline industry, the WACC for 2016 that is employed in this research is approximately 6.5%. Table 1 presents the key financial indicators for the airline industry. Figure 2 shows both the actual WACC as well as forward-looking forecasts for 2018, whereas the graph depicts the trend of the WACC in relation to the return on invested capital (ROIC) for airlines (*28*). As can be observed in Figure 2, after 2014, the ROIC finally became higher than the WACC.

Table 1. Key Financial Indicators for The Airline Industry

Worldwide airline industry	2016	2017	2018
ROIC, % invested capital	10.30	9.60	9.40
ROIC−WACC, % invested capital	3.70	2.40	2.0
Investor value, $ billion	19.2	13.2	11.5
EBIT margin, % revenue	9.20	8.30	8.10
Net post-tax profit, $ billion	35.3	34.50	38.4
% revenues	5.00	4.60	4.70
$ per passenger	9.26	8.45	8.9
Free cash flow, % invested capital	1.10	1.00	1.20
Adjusted net debt/EBITDAR	3.70	3.51	3.47

Note: ROIC = return on invested capital; WACC = weighted average cost of capital; EBIT = earnings before interest and taxes, depreciation and amortization; EBITDAR = earnings before interest, taxes, depreciation and amortization.

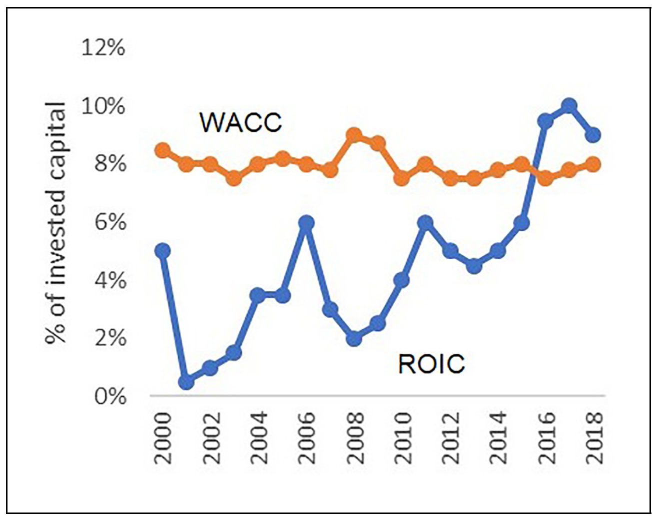

Figure 2. Weighted average cost of capital (WACC) and return on invested capital (ROIC).

Data Collection and Aircraft Selection

The primary source of aircraft data used for this paper is Form 41 financial data, which is publicly accessible from the Bureau of Transportation Statistics. This research has solely focused on the major U.S. legacy and low-cost carriers. The data were examined on a yearly basis observing a 10-year period from 2006 to 2016. The aircraft data were collected at the fleet level, and further computations were necessary to extrapolate the accurate numbers for an individual airplane. As a rule, the total assigned days for the fleet type were found from Form 41 to calculate the average number of aircraft in service. Then, all revenue and cost elements were divided by the aircraft in service to transition from the fleet to single aircraft data. The revenue and cost elements were disaggregated to provide a thorough sensitivity analysis to evaluate the overall responses of the calculated aircraft value to these elements. On the revenue side, the relevant passenger and cargo yields along with the RPM and RTM were collected. On the cost side, fuel and labor, as well as maintenance and administrative and transport-related expenses, were examined to cover the operating expenses. Total block hours, as well as gallons of fuel consumed, were also taken into account to assist in the calculations for aircraft utilization and fuel costs. A

Table 2. Model Factors and Their Respective Calculations

Factor	Calculation
Total block hours	Average daily utilization × 365.25
Gallons consumed	Gallons per block hour × total block hours
Passenger revenue	Revenue passenger miles × overall passenger yield
Cargo revenue	Revenue ton miles × overall cargo yield
Aircraft fuel	Gallons consumed × fuel cost ($/gallon)
Servicing, sales, and general expense	Allocated based on available seat miles

detailed overview of the different elements and the respective calculations can be seen in Table 2.

Two aircraft types from the two leading aircraft manufacturers, Airbus and Boeing, were selected to develop the valuation model. The Airbus 320 and the Boeing 737 are the most popular airliners. Four industry favorite narrow-body and wide-body jets were selected to highlight the differences in value for single-aisle and twin-aisle aircraft. On the one hand, data for the Airbus 320-200ceo and 330-200 were obtained since these two types represent the top sellers for Airbus on the short-haul and long-haul market segments, respectively. On the other hand, data for the Boeing 737-800 and 787-9 were selected, considering that these aircraft are two of the most popular Boeing commercial airplanes. The aircraft selection also accounts for the comparative aspect of the models since the Airbus 320-200ceo competes closely against the Boeing 737-800.

Airbus delivered its first Airbus 320 to Air France in 1988. As of January 2019, a total of 8,605 Airbus 320 aircraft have been delivered to the customers. The Airbus 320neo (new engine option) was introduced by Airbus in 2012. The Airbus 320neo replaces the original Airbus 320, which is referred to as Airbus 320ceo (current engine option) (*29*). In the U.S.A., the Airbus 320-200ceo is in service with JetBlue (130), United (103), Delta (65), Spirit (64), and Allegiant Air (64) being the main Airbus 320 operators (*30*). The Airbus 330-200 launched in 1998 and is one of the two top sellers of the Airbus 330 variants (along with Airbus 330-300). There are 607 units of Airbus 330-200s currently in service (*30*). The three top U.S. airlines operating the type are Hawaiian (24), American (15), and Delta (11). As of April 2020, the number of aircraft manufactured by Airbus was reported as 12,762 aircraft.

The Boeing 737 has a long history starting with Boeing 737-100, which was first introduced in 1965. Boeing launched the Boeing 737 Next Generation (600/-700/-800/-900) series in 1993. There are about 4,914 737-800s in service globally. In the U.S.A., American (304), Southwest (207), and United (141) are the top three operators of the Boeing 737-800 (*31*). Last but not least, the 787-9 is one of the newest Boeing models, introduced in 2014. As of May 2020, 300 airplanes are in service and in the U.S.A., only United (30) and American (20) operate the type (*31*).

Model Applications and Sensitivity Analysis

Aircraft values are calculated based on the proposed approach. Using 2016 as the benchmark year, the net future cash flows for the next 30 years are forecast. This mainly aids in providing a long-term valuation trend that can assist manufacturers and airlines in assessing an accurate retirement age for their aircraft. Table 3 shows how the various examined revenue and cost elements are expected to change in the future. The table presents the year-to-year change in percentages and the forecast value for 2045 based on the corresponding values of the factors in 2016. These elements are also used as inputs to observe how different forecast growth rates can affect aircraft value.

Table 4 illustrates the calculated aircraft values based on the methodology presented for the four selected aircraft types. As discussed earlier, the ideal benchmark for verification of the proposed method is to compare the calculated values against transactional prices as the closest estimator of the fair market value of an aircraft. In the aviation industry, however, transactional prices are proprietary and highly confidential. Therefore, other accessible benchmarks were sought for comparison. The list price of Airbus and Boeing and the estimated value of a new aircraft provided by *The Airline Monitor* (*AM*) were utilized. *AM* (*32*) states that the presented estimates are the average of three sources. While the details of *AM*'s approach are propriety, to the best of the authors' knowledge, these estimates combine expert opinion and actual transactional data. These values can provide insights for aviation financial analysts and aid them in their decision making, such as whether it is beneficial to purchase an aircraft or to evaluate which inputs are most influential if an aircraft needs to be refurbished or retired.

As can be observed in Table 4, all the aircraft types have lower calculated values than the published list prices. The Airbus 320-200ceo's calculated value is 11% lower than the list price of $101 million. The Airbus 330-200 and Boeing 737-800 show about 20% difference, while Boeing 787-9 displays the lowest difference between list price and calculated value. This variation can be explained by manufacturers generally pricing their products higher than the actual value of the aircraft to realize profits. Indeed, every deal between a manufacturer and a carrier depends on several factors, such as the number of aircraft ordered, the existing seller-buyer relationship,

Table 3. Forecasting Factors for Narrow-Body and Wide-Body Aircraft, 2016 as the Base Year

Factor	% annual change	Airbus 320-200ceo		Boeing 737-800		Airbus 330-200		Boeing 787-9	
		2016	2045	2016	2045	2016	2045	2016	2045
Daily utilization (hours)	0.10	10.96	11.29	10.46	10.77	12.31	12.67	13.34	13.74
Gallons per block hour	−0.05	798.69	787.19	798.06	786.57	1,739.05	1,714.01	1,696.58	1,672.15
Fuel cost ($ per gallon)	2.0	1.39	2.48	1.48	2.63	1.39	2.48	1.43	2.54
Revenue passenger miles (millions)	0.05	204.75	207.74	207.97	211.01	462.30	469.05	525.99	533.67
Passenger yield (¢)	1.5	15.12	23.28	14.78	22.76	13.55	18.08	13.55	18.08
Revenue ton miles (millions)	0.01	20.57	20.63	21.11	21.17	56.24	56.40	74.76	74.98
Cargo yield (¢)	1.5	21.00	32.34	21.50	33.11	77.48	103.40	60.42	80.64
Direct maintenance per aircraft ($)	3.75	2,838,727	8,256,172	2,857,480	8,310,711	na	na	na	na
	7.0	na	na	na	na	6,347,201	45,155,623	3,275,337	23,301,590

Note: na = not applicable. All other cost factors have annual percentage change of 2.0 percent.

and market conditions, among others. A common understanding is that, in practice, the actual purchase price after a negotiation is (much) lower than the list price.

Comparing the results with the *AM* estimated values provides additional support for the validity of the proposed approach. The calculated values seem to be much closer to the *AM* estimates, compared with the list prices. Moreover, it is observed that, in contrast to list prices, when *AM*'s values are used as the benchmark, the calculated value overestimates the aircraft value for Airbus 32-200. As before, the Boeing 787-9 has the lowest variation.

Another perspective that may provide support for the validity of the proposed methodology is to consider the trend of similarity and dissimilarity between the values for different aircraft models rather than the actual prices. It can be observed that the data sources used in this study imply a similarity between the value of the A320-200 and B737-800. For instance, the percentage difference between the estimates provided by the *AM* for these two models is about 9% (that is, the absolute difference between the values divided by their arithmetic mean). The percentage difference between the calculated values for these two models using the proposed methodology is about 13%. As for the wide-body models, the percentage difference calculated from the *AM* estimates is 31%, compared with 35% based on the calculated values. In other words, the calculated values present the same trend of differences between the aircraft values for different manufacturers as suggested by the benchmarking source.

Indeed, the inputs for the proposed methodology were subjected to several assumptions. Another significant advantage of the model pertains to the possibility of sensitivity analysis of the inputs. A Monte Carlo simulation was run to analyze which inputs are more influential for each aircraft type. The discount rate, passenger yield, fuel costs, maintenance costs, and block hours were analyzed under different scenarios.

From an economic point of view, if costs are expected to grow, then the value of the aircraft naturally decreases. In contrast, if passenger yield is expected to grow, then the value of the aircraft will increase. The calculated values of the assets were used as the outputs in a simulation to measure the extent of deviations when inputs are decreasing or increasing. Past data were used to estimate the range of fluctuation in various factors. Indeed, users may employ other values that serve their specific purpose for sensitivity analysis. Some of these factors may fluctuate differently for various companies, and by selecting the appropriate ranges, decision-makers could run what-if scenarios suitable for their situation.

The simulation in this study experimented with the following variation range for each of the factors: discount rate (4.5%−8.5%); fuel cost (1.0%−5.0%); maintenance expenses (1.0%−8.0% for narrow-body and

Table 4. Calculated Aircraft Values Compared with Airbus and Boeing 2018 List Prices and 2018 Data from *The Airline Monitor* (*AM*)

Aircraft type	A320-200ceo	A330-200	B737-800	B787-9
Calculated value ($ million)	89.9	191.5	79.0	271.9
Published list price	101.0	238.5	102.2	281.6
% difference between calculated and list price	11.0	20.2	22.7	3.4
Estimated value (*AM*)	85.9	204.2	93.8	280.0
% difference between calculated and the *AM* value	4.6	6.2	15.8%	2.9

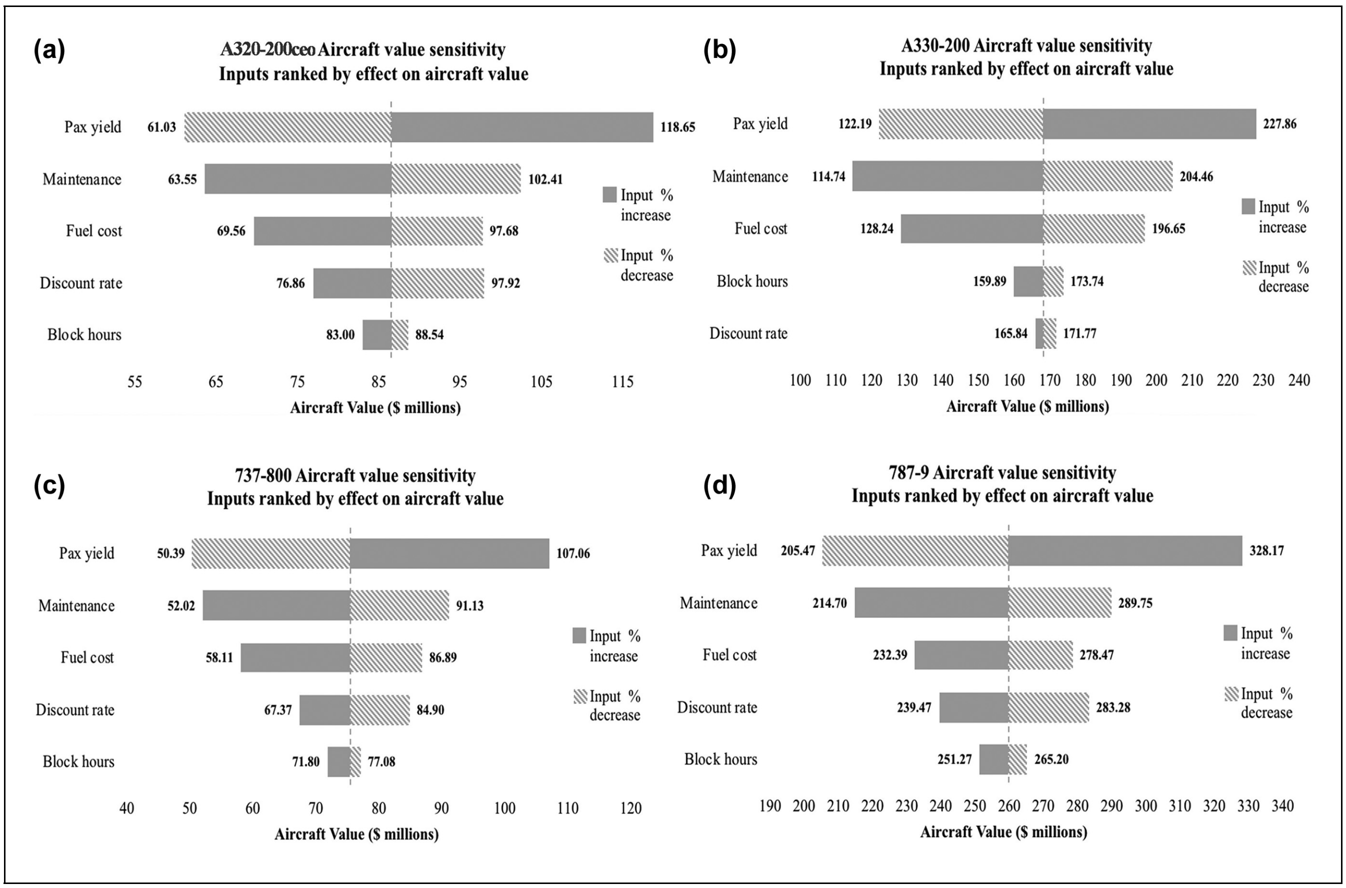

Figure 3. Sensitivity analysis for (*a*) Airbus 320-200ceo, (*b*) Airbus 320-200, (*c*) Boeing 737-800 and (*d*) Boeing 787-9.

6.0%−10.0% for wide-body); passenger yield (1.0%−2.5% for narrow-body and 0.5%−2.0% for wide-body); block hours (0%−0.75%). The charts presented in Figure 3 show how inputs are ranked by their effect on aircraft value.

It is observed that passenger yield is the driving factor in all aircraft types. The revenue generated from operations will eventually decide whether the aircraft is profitable or not. Maintenance and fuel costs are also two factors that can have a significant impact on aircraft profitability. The discount rate and block hours, on the other hand, seem to be less significant, ranking fourth and fifth, respectively. The only exception in the ranking order is the Airbus 330-200, where the discount rate ranks last. This can largely be explained by the valuation trend of the Airbus 330-200, where it is shown that the recommended age of the airplane is in its twelfth year of operation. Thus, the discount rate becomes less important compared with the other aircraft types that have longer useful lives.

Conclusion

This research provided a modified DCF approach for estimating aircraft values over an extended period in the future. A series of revenue and cost drivers were included in the research to forecast net cash flows. In turn, net cash flows were discounted by the WACC to provide an estimate of the net present value of a given aircraft.

To assess the validity of the method, the actual list prices of the chosen Airbus and Boeing aircraft types were used to compare against the value measures provided by the model. In addition, the estimated values and their relative trends were compared with estimates provided by AM. A sensitivity analysis was conducted to observe how inputs ranked by their effect on aircraft value. Calculated aircraft values were weighed against different discount rates, passenger yields, fuel, and maintenance costs along with block hours. Passenger yield stood out as having the greatest influence on aircraft value with maintenance and fuel costs ranking second or third in order of importance.

This paper presents an extensive examination of aircraft valuation. The proposed DCF methodology can assist practitioners in determining the profitability potential of an aircraft type. Moreover, it is beneficial in complementing the purchase or lease decisions of airlines as well as providing them with the appropriate retirement age.

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Author Contributions

The authors confirm contribution to the paper as follows. Study conception and design: B. Vasigh, F. Azadian, K. Moghaddam; data collection: B. Vasigh, F. Azadian; analysis and interpretation of results: B. Vasigh, F. Azadian, K. Moghaddam; draft manuscript preparation: B. Vasigh, F. Azadian. All authors reviewed the results and approved the final version of the manuscript.

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