GRA, Incorporated

An Economic Analysis of Maximum Take-off Weight (MTOW) Reductions under an ICAO CO_2 Standard

May 7, 2013

Authors:
Richard Golaszewski
William Spitz, Ph.D.
Benjamin Litvinas

GRA, Incorporated
115 West Avenue
Jenkintown, PA 19046

Publication Data

Richard Golaszewski, William Spitz, Ph.D., and Benjamin Litvinas
An Economic Analysis of Maximum Take-off Weight (MTOW) Reductions under an ICAO CO_2 Standard

Prepared by:
GRA, Incorporated
Jenkintown, PA, USA
March 2013

Prepared for:
International Council on Clean Transportation
Washington, DC, USA

Preface

This report has been prepared for the International Council on Clean Transportation (ICCT) by GRA, Incorporated to examine the potential influence of an ICAO CO_2 standard on the maximum certificated take-off weight (MTOW) of new delivery transport aircraft. Airframe manufacturers could elect to certify some in-production aircraft types to ICAO's future carbon dioxide (CO_2) standard by limiting the upper range of maximum take-off weights at which they are delivered. This would limit payload carrying capability to specific weights over various lengths of flight (payload-range constraint). The purpose of GRA's analysis is to examine the impact of various levels of restriction on the economic value of these aircraft. GRA prepared all the analyses; ICCT provided input data from the PIANO-X model to establish payload-range performance under the baseline and under the various levels of MTOW restriction for the aircraft models we examined. In addition, our work benefitted materially from the review and critique of our analyses by staff at ICCT, including Daniel Rutherford, Anastasia Kharina and Mazyar Zenali. Responsibility for any errors remains with the GRA project team.

Richard Golaszewski
William Spitz, Ph.D.
Benjamin Litvinas

Table of Contents

List of Figures

APPENDIX A: Results for 90 Percent MTOW Case

Executive Summary

As part of efforts to address the impact of aircraft emissions on the global climate, the International Civil Aviation Organization (ICAO) is currently developing the world's first carbon dioxide (CO_2) emission standard for aircraft. While that standard aims to promote the development and deployment of fuel efficiency technologies on new aircraft, the metric developed for the standard may also allow for compliance via non-technology means, notably through reductions in maximum aircraft certificated take-off weight (MTOW).

Airframe manufacturers may certify some in-production aircraft types to ICAO's CO_2 standard by limiting the upper range of maximum take-off weights at which they will be delivered, which would influence their payload carrying capability over various lengths of flight (payload- range). Because aircraft are typically designed to operate on a variety of different missions in terms of payload and range, a cap on MTOW would affect only a percentage of existing flights by an operator. This research analyzes how the economic value of existing aircraft types marketed with lower MTOWs might be affected in order to better understand the incentives provided for manufacturers to either continue production of existing aircraft types or develop new aircraft types with lower levels of emissions.

The value of an aircraft can be assessed by determining the net present value (NPV) of the income stream it can produce over its economic life. Reducing MTOW effectively limits an aircraft's payload-range capability below what is technically feasible. The estimate of the impact on aircraft value requires an analysis of the changes in aircraft revenues and costs resulting from a reduction of MTOW. This can be estimated by comparing an aircraft operating at different MTOW limits over representative mission lengths in relation to the baseline MTOW at which the aircraft is currently certified. This study examines a range of percentage reductions in MTOW (from two percent to ten percent) for selected aircraft so that the aircraft can still operate on existing missions but with reduced passenger and cargo carrying capability. The baseline aircraft types analyzed include:

- Wide-body Airliner—Boeing 777-300ER (B77W): 365 seats; 775,000 lb. MTOW
- Narrow-body Airliner—Airbus A320-200: 150 seats; 172,900 lb. MTOW
- Regional Jet—Embraer E190: 98 seats; 114,200 lb. MTOW
- Corporate Business Jet—Gulfstream G450: 12 seats; 74,444 lb. MTOW

For the three commercial aircraft types considered (B777, A320 and E190), the analysis assumed fixed mission requirements, where the effects of an

MTOW constraint were felt solely through reductions in payload (passengers and cargo) and fuel. In contrast, the business jet analysis assumed a fixed payload, and the effects of an MTOW constraint were manifest in the costs of a required fuel stop for constrained flights. Three specific sources of revenue impacts from an MTOW constraint were identified for the commercial aircraft:

- Loss in passenger revenue
- Loss in cargo revenue
- Savings in fuel costs

Two specific sources of cost impacts from an MTOW constraint were identified for the additional fuel stop with the G450 business jet:

- Increased aircraft operating costs for the need to make an additional landing, refueling stop and return to flight
- The value of the time lost by the passengers in the additional time needed to complete the flight to the destination

For all four aircraft types, three different MTOW restrictions were considered: 98%, 95% and 90% (reductions of 2%, 5% and 10% in total MTOW, respectively.) ICCT provided technical inputs for aircraft fuel consumption, payload-range and other parameters under both the baseline and the three restriction scenarios using PIANO-X, an aircraft performance analysis tool.[1] The analysis considered a range of weight allowances for the commercial aircraft. Two baseline scenario cases were developed: a low takeoff weight (TOW) case using the PIANO default OEW (operating empty weight), a 100-nm diversion range, plus a 30-minute hold; and a high TOW case using the PIANO OEW plus an additional two percent allowance in weight, a 100-nm diversion, and a 45-minute hold requirement. Throughout the document, these are referred to as the "Low TOW" and "High TOW" cases.

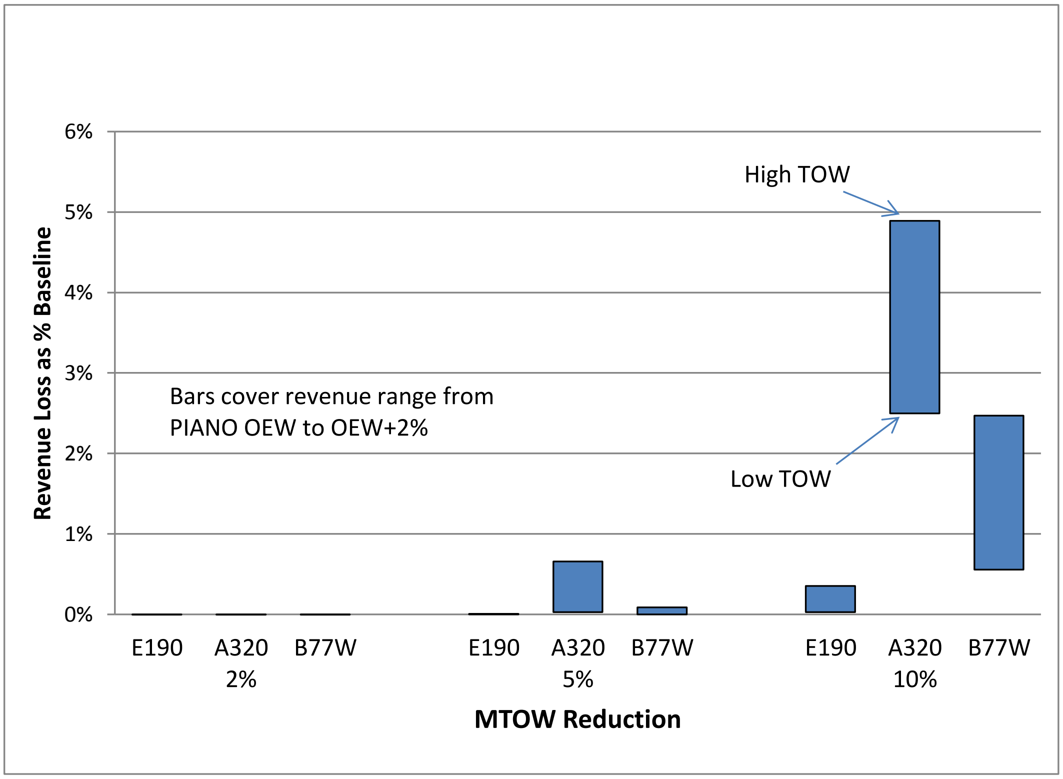
The key results are reported below in terms of the annual change in revenues plus fuel savings per aircraft. These are extended to assess changes in overall aircraft value (measured as willingness to pay) as described in the report itself. In addition the report also presents the results of various sensitivity analyses that were performed.

The primary results for the three commercial aircraft types are shown in Figure ES-1.

---

[1] http://www.lissys.demon.co.uk/PianoX.html

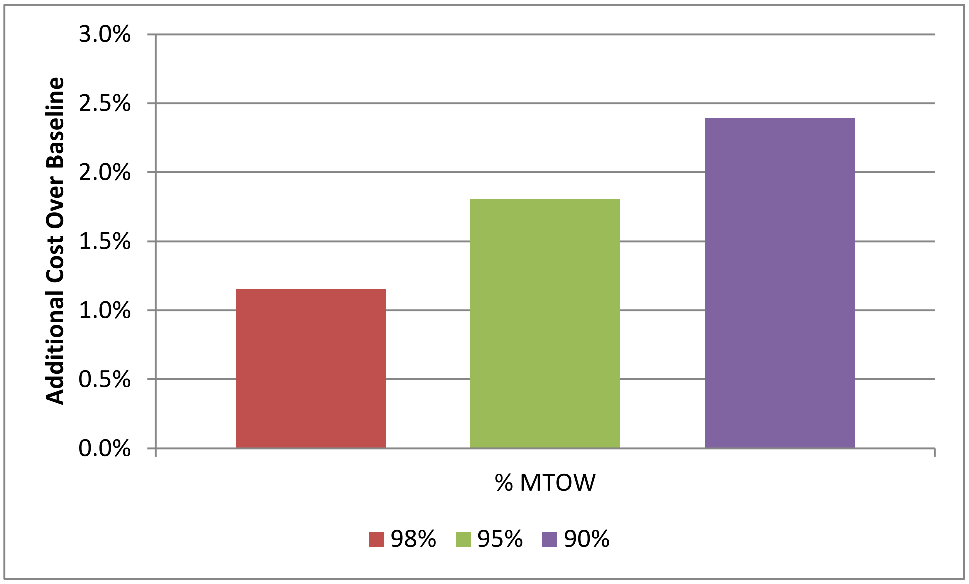
Figure ES-1: Annual Revenue Loss for Commercial Aircraft



As can be seen, the 98% MTOW scenario (equal to a 2% reduction) has no effect on operators. This is indicative of the fact that most operations are carried out well below the maximum payload-performance capabilities of each aircraft type. Movement to a 95% MTOW restriction begins to modestly affect operations. The results for both the E190 and B77W are very small at this restriction level, while the A320 impacts are larger, though still very modest (well under one percent of baseline revenues). At 90%, the impacts begin to become much more significant, in the 0.5-2.5 percent range for the B77W and from 2.5-5.0 percent for the A320.

The MTOW limitations for the G450X do not have a large impact. In part this is due to the fact that most flights with this aircraft are at distances well below maximum range and the MTOW constraints affect a very small number of flights. Figure ES-2 shows the percentage change in cost for the G450X. These changes range from about 1.2% for the 98% MTOW restriction to 2.4% for the 90% MTOW restriction. These do not differ between the low TOW and high TOW cases.

Figure ES-2: Change in G450X Costs at Different MTOW Restrictions



An Economic Analysis of MTOW Reductions under an ICAO CO_2 Standard

Introduction

As part of efforts to address the impact of aircraft emissions on the global climate, the International Civil Aviation Organization (ICAO) is currently developing the world's first carbon dioxide (CO_2) emission standard for aircraft. While that standard aims to promote the development and deployment of fuel efficiency technologies on new aircraft, the metric developed for the standard may also allow for compliance via non-technology means, notably through reductions in maximum aircraft certificated take-off weight (MTOW).

Under the standard, larger margins will be provided to lower "paper" MTOW variants of a given aircraft type—for this reason, there has been discussion about whether some airframe manufacturers may choose to certify some in-production aircraft types to ICAO's future CO_2 standard by limiting the upper range of maximum take-off weights at which they are delivered rather than through incremental investments in technology. Because aircraft are typically designed to perform a variety of different missions in terms of payload and range, a cap on MTOW would affect only a small share of existing flights by an operator. This research aims to understand how the economic value of existing aircraft types marketed with lower MTOWs potentially could be affected, and what incentives this could provide for manufacturers to either continue production of existing types or to develop new aircraft types with lower levels of emissions.

Prior research has shown that the value of an aircraft can be assessed by determining the net present value (NPV) of the income stream it can produce over its economic life.[2] A cap on MTOW effectively reduces an aircraft's payload-range capability below what is technically feasible. The estimate of the impact on aircraft value requires an analysis of the changes in aircraft revenues and costs resulting from a stated cap on MTOW. This can be estimated by comparing the same aircraft operating at different MTOW limits over representative mission lengths and with different passenger and cargo loads for an aircraft operator. The overall goal of this research is to develop

[2] Golaszewski, Richard, and Fred J. Klein (1998). "Airline and Manufacturer Issues in Marketing Large Commercial Transport Aircraft." In *Handbook of Airline Marketing*, edited by Gail Butler and Martin Keller, 189-206. Washington, DC: Aviation Week Group.

estimates of the decrease in specific aircraft values to the operator of each of the specified aircraft; this research is not designed to estimate overall industry impacts. In the report we focus on annual revenue and cost changes for the ease of exposition; however, we do report the NPVs at various discount rates.

In effect, capping MTOW for new deliveries of in-production aircraft will reduce performance capabilities relative to identical aircraft that were delivered prior to imposition of the cap. This analysis does not assess the impact on the values of aircraft of the same type that were already in the fleet when the cap was imposed, or on the incentives to retain these pre-cap aircraft.

Analysis Approach

This research project examined several aircraft types, including a business jet, a regional jet, a narrow-body airliner and a wide-body airliner. In this paper, we develop and use data on typical aircraft missions for prospective aircraft, based on analysis of the Official Airline Guide (OAG), FAA's Enhanced Traffic Management System (ETMS) flight data, and other databases to develop mission parameters for these aircraft. We selected four representative aircraft/engine combinations for in-depth analysis. The aircraft were chosen in consultation with ICCT, and are the maximum certified MTOW variants for each type being analyzed by ICAO under the standard. We then examined a range of percentage reductions in MTOW (two percent to ten percent) for each of these aircraft so that the aircraft can still operate on existing missions but with reduced passenger and cargo carrying capability. The baseline aircraft types analyzed include:

- Wide-body—Boeing 777-300ER (B77W): 365 seats; 775,000 lb. MTOW
- Narrow-body—Airbus A320-200: 150 seats; 172,900 lb. MTOW
- Regional Jet—Embraer E190: 98 seats; 114,200 lb. MTOW
- Corporate Jet—Gulfstream G450: 12 seats; 74,444 MTOW

Most of the data used in the study are from publicly available sources; ICCT provided technical inputs for baseline aircraft fuel consumption, payload-range and other parameters using PIANO-X, an aircraft performance analysis tool developed by Lyssis, Ltd. (UK).[3] ICCT provided similar information for these aircraft with an MTOW limitation.[4] We assumed a useful life of 25 years for each aircraft and computed the change in value during this period.

---

[3] http://www.lissys.demon.co.uk/PianoX.html

[4] GRA also examined manufacturer data for these aircraft in terms of published payload-range performance and took into account differences between the published manufacturers' operating weights and those weights for an aircraft typically configured for scheduled service with all operator-furnished equipment.

The estimates are based on the current performance of newly delivered aircraft with specified MTOW limits in comparison to identical aircraft without such limits. The baseline assumptions are for sea level operations on a standard day with zero wind and no constraints imposed by runway length.

Development of Models to Estimate Aircraft Revenues and Costs

GRA developed two modeling approaches (including data sources) that are suitable for estimating operating revenues and costs in terms of an aircraft's payload-range capabilities. For the three commercial aircraft types considered, the analysis assumed fixed mission activities where the effects of an MTOW constraint would be observed solely through reductions in payload (passengers and cargo) and fuel. The analysis assumes that the operator continues the mission and simply offloads cargo, passengers and fuel sufficient to be able to operate the reduced MTOW. This permits a value to be established for the impact of the constraint. In contrast, the business jet analysis assumed a fixed payload, and the effects of an MTOW constraint were manifest through a required fuel stop for constrained flights.

The economic models for each commercial aircraft are sensitive to numbers of passengers and quantities of cargo carried, stage length, fuel cost, and unit passenger and cargo revenue.

Estimation of unit revenues involved the development of yield curves (revenue passenger-mile or freight ton-mile) that vary by market distance and types of traffic flown. These were based on U.S. DOT ticket sample data and other sources.

For commercial aircraft, three specific sources of revenue impacts from an MTOW constraint were identified:

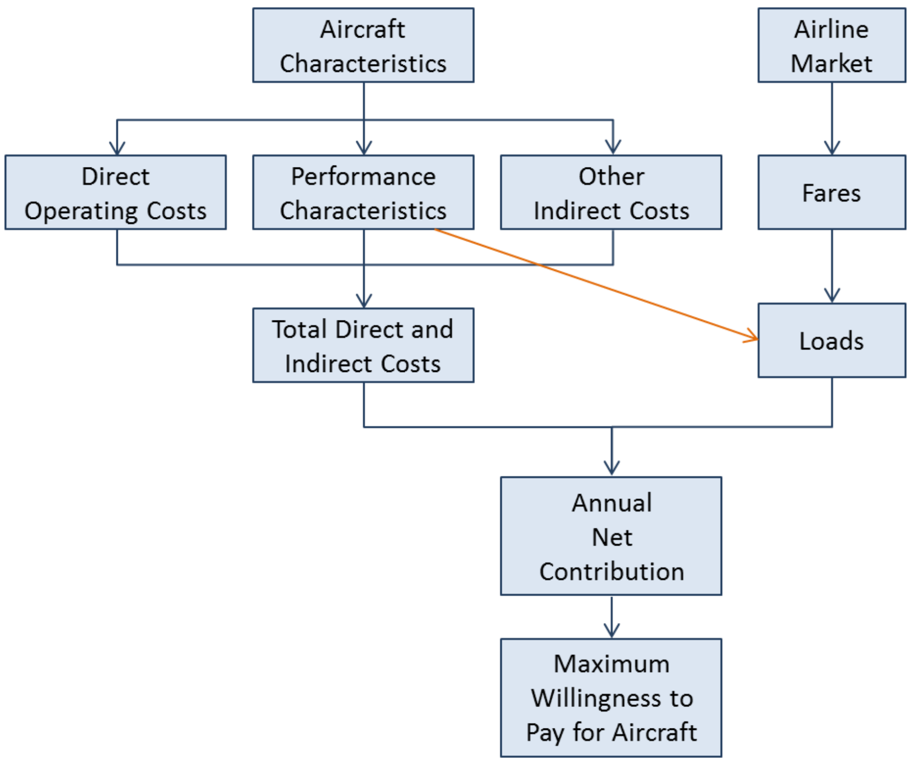
- Loss in passenger revenue
- Loss in cargo revenue
- Savings in fuel costs

A second modeling approach was used for the business jet analysis. Revenues were held fixed and the analysis focused instead on the increase in costs associated with making a fuel stop that would not have otherwise been required without the MTOW constraint. Two specific sources of cost impacts from an MTOW constraint were identified:

- Increased operating and maintenance (O&M) aircraft costs associated with the fuel stop
- Value of time costs for the passengers on-board

Figure 1 illustrates the generalized factors considered in the analysis. For commercial aircraft, the model is designed to estimate the change in annual net revenue contribution for the affected flights. This is based on the fares and passenger and cargo loads that can be carried. For the business aircraft, the model considers the increase in costs associated with a fuel stop. In both cases, the analysis considers the changes in fuel consumption and fuel costs for operations impacted by the MTOW cap. No attempt was made to quantify the system-level impacts, either on revenue, fuel cost, or emissions, due to payload precluded from a given mission or due to increased congestion from additional stops imposed by the MTOW constraint on business jets as those effects are outside of the study's scope. The estimated changes in revenue or costs are aggregated over the life of the aircraft to estimate a change in willingness to pay for the aircraft.

Figure 1: Factors Affecting Willingness to Pay Calculations



In addition, an aircraft operating cost model was developed for each of the four aircraft types. The models are sensitive to flight segment distance and changes in aircraft weight. The models for commercial aircraft were developed using airline cost data filed with the U.S. DOT (based on airline data provided to DOT on Form 41 or other sources). For the business jet aircraft, the cost estimates were developed using an industry standard model (Conklin & de Decker). The models contain cost elements for fuel, crew, maintenance, ownership and other costs. These data are structured similarly to that in the recommended data that FAA uses in its benefit-cost analyses of investments and the impacts of regulations.[5]

Whether counted as reductions in revenue or increases in cost, the changes were computed on an annual basis and then converted to a present value using a 25-year expected aircraft life and a selected discount rate. Depreciation and possible tax effects were not considered.

For present purposes, we are interested only in the *change* in willingness to pay (WTP) for an aircraft due to the MTOW constraint; the present value of the change can be written as:

$$Present\ Value\ of\ WTP = \sum_{i=1}^{N} \frac{Annual\ Change\ in\ Revenue\ or\ Cost_i}{(1+r)^i}$$

where i references the year, r is the discount rate, and N=25. The discount rate is an important parameter in determining the present value. The analysis was conducted using constant dollars and a range of discount rates. These were based on consideration of reasonable estimates of airlines' cost of capital, discount rates used by FAA in its investment analyses, and rates used by ICAO in its CAEP analyses. However, a specific airline or aircraft manufacturer will base its economic decisions on a discount rate that reflects its actual risk-adjusted cost of capital.

Estimation of Flights Affected and Per Aircraft Effects

Performance data provided by ICCT from the PIANO model was used for the selected aircraft types to determine the payload-range and fuel consumption of the baseline and MTOW-limited aircraft. GRA used annualized OAG, ETMS and DOT T-100 data to identify the universe of flights for each aircraft type that might be affected by the MTOW limit and to determine the impact on payload for each. These flights were grouped into 250-mile distance blocks, and each distance block was treated independently to ascertain whether the flights in that block would be affected by a given MTOW constraint. Once the annual impacts across all flights were estimated, an effective impact per aircraft was calculated by applying an estimated annual utilization rate for each case.

GRA utilized the data and models developed above to provide estimates in the change in market value (based on willingness to pay) for the four specific

---

[5] GRA, Incorporated (2007). *Economic Values for FAA Investment and Regulatory Decisions - A Guide*. Jenkintown, PA. (Prepared for FAA Office of Aviation Policy and Plans)

aircraft types that were analyzed. This was based on the estimates of the present value of the differences in revenues and costs for all missions flown with these aircraft over their useful life.

Detailed Analysis

The detailed analysis presented here is divided into two major sections: commercial aircraft modeling and business aircraft modeling. The commercial aircraft modeling is based on fixed mission activity; MTOW effects are observed through reductions in payload and fuel carried. The business aircraft modeling is based on a fixed payload; MTOW effects are observed solely through additional en route stops required to complete the desired mission length. The analyses are based on published data for long-range cruise speeds and altitudes. While it is recognized that an operator has some ability to vary these factors to increase fuel efficiency, the analysis does not use these factors. Correspondingly, the results of this analysis are conservative.

Commercial Aircraft Modeling

The effects of MTOW restriction were analyzed in terms of potential annual revenue/cost impacts per aircraft in the following areas:

- Loss in passenger revenue
- Loss in cargo revenue
- Savings in fuel costs

The impacts of MTOW restrictions were estimated relative to a baseline aircraft operating without these restrictions. We estimated the annual change in revenue and costs (net cash flow) per aircraft which were then discounted over the life of the aircraft.

Baseline aircraft performance data were obtained from manufacturer web sites and the data were converted from statute to nautical miles.[6] All missions assume that the aircraft would operate at sea level, on a standard day, (a standard day is defined as sea level at 59 degrees Fahrenheit, with an altimeter setting of 29.92, as defined by NASA[7]), with zero wind conditions

---

[6] Boeing Commercial Airplanes (2011). *777-200/300: Airplane Characteristics for Airport Planning*. Seattle, WA;
Airbus S.A.S. (2012). *A320: Aircraft Characteristics - Airport and Maintenance Planning*. Blagnac Cedex, France;
Embraer S.A. (2011). Embraer 190: Airport Planning Manual. São José Dos Campos, Brazil.
[7] http://www.grc.nasa.gov/WWW/K-12/airplane/airprop.html

and carry full IFR reserves relevant for the type of mission flown. The analysis used a standard passenger weight of 250 pounds, which includes carry-on and checked baggage.

For a given type of aircraft, there is a direct trade-off between range and payload for a given MTOW. The actual relationship is complicated somewhat by:

- The amount and associated weight of fuel required for a given stage length (which affects the net payload that may be carried)
- The net payload, which itself is subject to an overall maximum independent of the actual amount of fuel carried
- Airline customization effects (e.g., seats, configuration, catering, and in-flight entertainment amenities), which may affect aircraft operating empty weights

The analyses started with a representative seating capacity for each aircraft type. An expected load factor of 85 percent was used to confirm that the stated payload can be carried over the observed segment distances. Actual load factors for passengers and belly cargo were taken from DOT T-100 segment data, which covers actual U.S. domestic and international operations flown by scheduled passenger airlines.[8] The analysis assumed a two-class seating configuration for the Embraer E190 and Airbus 320, and a three-class seating configuration for the Boeing 777 wide-body aircraft. The modeling used a single fixed average load factor for a given aircraft type/distance block to keep the calculations transparent. A distribution of load factors is tested as a scenario. It is recognized that, in reality, some flights within a given distance block operate with higher-than-average loads (which the modeling may exclude as being unaffected by an MTOW restriction); these will tend to be offset by other operations with lower-than-average loads (which the modeling may include as affected by the MTOW restriction).

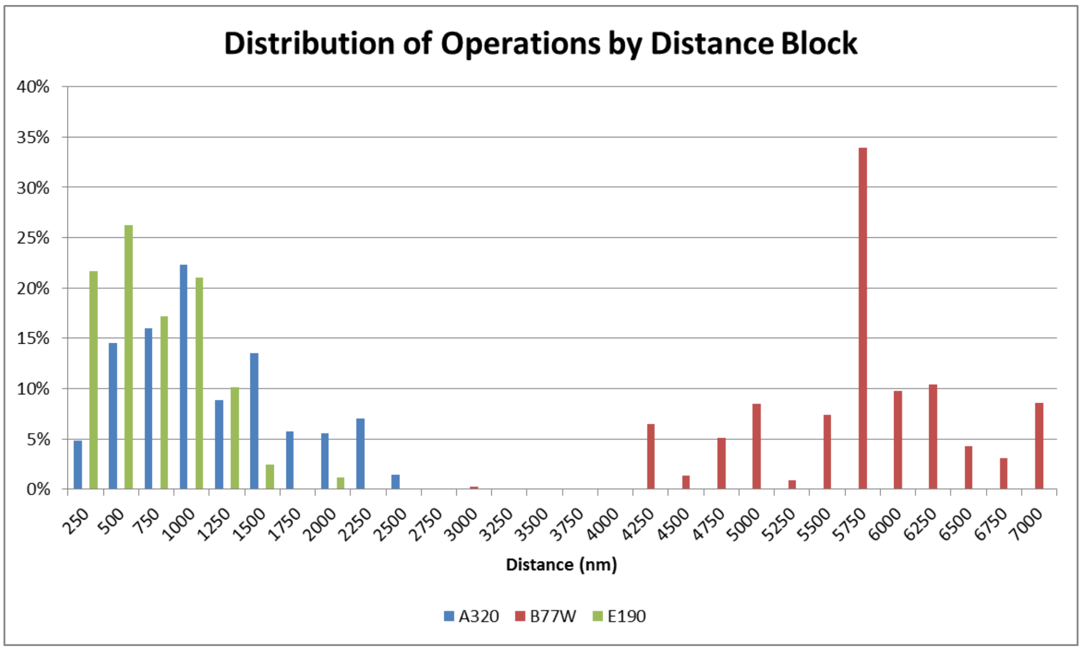
We used the 2011 T-100 flight distance distribution for U.S. domestic operations with the A320 and E190. For the B77W, we instead used scheduled international operations data from the 2011 OAG because the T-100 data does not distinguish the ER version of the 777-300 from other variants. All flights for each aircraft type were then aggregated within distance blocks. For modeling purposes, individual aircraft essentially are assumed to rotate through all of the flight distance blocks observed for that make-model (even though this is obviously a simplification because individual carriers may well have a different or narrower set of distance blocks that their aircraft are cycled through). The actual mileage for each operation in a given distance block was estimated by adding a circuity

[8] U.S. DOT, T-100 for Oct 2010-Sep 2011.

penalty to the mid-point of each block; this penalty was estimated based on reported miles actually flown in the ETMS data set, which contains detailed flight information on all IFR operations that are monitored by the U.S. en route air traffic control system.

Figure 2 shows the flights by distance block for the three commercial aircraft types. The majority of E190 flights are in the first four distance blocks (0-249, 250-499, 500-749 and 750-999 nautical miles), with a peak in the second distance block. The A320 flights peak in the fourth distance block (750 to 999 nautical miles), with some flights exceeding 2,000 nm. The 77W flights peak in the 5,750 – 5,999 nautical mile distance block.

Figure 2: 2011 Flights by Distance Block by Aircraft Type



The data set included 154,206 E190 operations, 576,422 A320 operations, and 17,007 B77W operations. Also, the differences in operations in the United States and other regions of the world need to be recognized when interpreting the results. Figure 3 below shows that average segment lengths flown by U.S. operators tend to be longer than those flown in other parts of the world. This would result in a higher percentage of constrained flights in the U.S. than elsewhere.

Figure 3: U.S. vs. Non-U.S. Flight Segment Distances

Aircraft Type	Avg. Stage Length (nm) BTS-U.S. Domestic & International	OAG Excluding U.S. Carriers
Airbus Industrie A320-100/200	1,027	651
Boeing 777-200/200LR/233LR*	2,773	2,039
Embraer 190	583	498
Gulfstream III/V/ G-V Exec/ G-5/550	484	349
* BTS domestic and International		

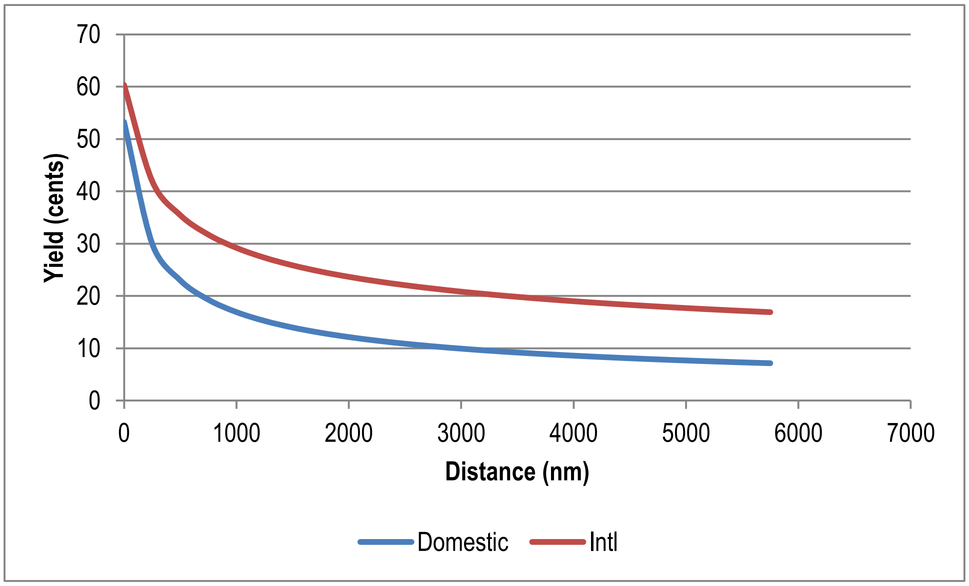
Source: ICCT, 2010 data from DOT BTS and OAG.

Revenue Estimates

The change in flight revenues is an important factor in evaluating the MTOW constraint. Baseline passenger and cargo loads were estimated using the observed average T-100 passenger load factor and cargo weight carried for each aircraft type/distance block (directly from the 2011 T-100 database for the A320 and E190; the aggregated 2011 T-100 data for the 773 was used to calculate these parameters for the B77W flights). The number of passengers was converted to average observed payload assuming 250 pounds per passenger, including checked and carry-on baggage.

Passenger revenues were estimated using a distance-based yield curve derived from DOT's DB1B ticket sample data set. This is a 10 percent sample of all tickets issued by U.S. carriers, and includes information on specific origin-destination trips, including routing and total trip fares. A segment-based passenger yield curve was developed for the E190 and A320 by allocating domestic trip fares to individual segments, and then estimating a best-fit curve through the data. The same technique was also applied to international trips to develop a yield curve for the B773. Figure 4 shows the two yield curves used for the analysis. While average yields are used in the revenue estimates, we recognize that carriers will seek to shed the least profitable traffic when facing an MTOW constraint.

Figure 4: Domestic and International Yield Curves



For belly cargo revenues, available DOT data submitted by all-cargo carriers (such as Federal Express and UPS) were used to estimate a cargo-based yield curve. That curve was applied to the average belly cargo tonnage in each distance block.

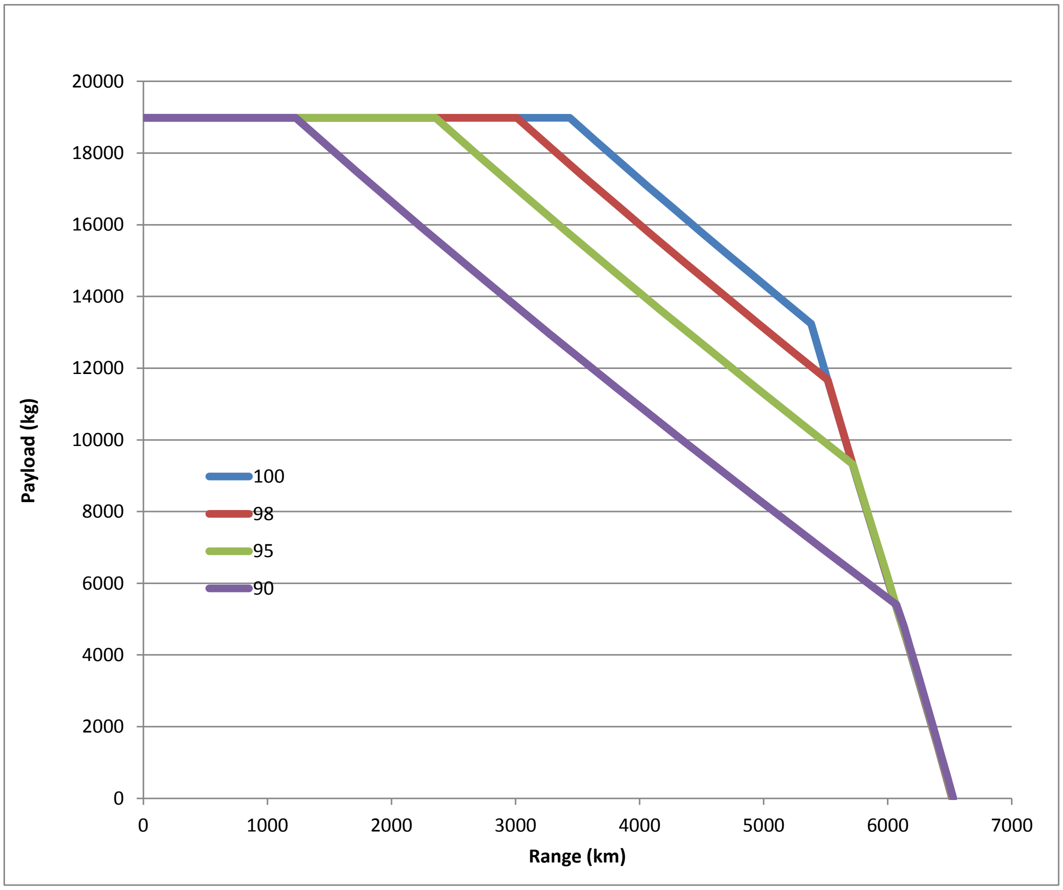
Payload Estimates

Given the baseline observed average passenger and cargo loads, ICCT provided PIANO estimates of the initial fuel required for each set of flights in a given distance block and a payload-performance envelope for the aircraft under three different MTOW constraints: 98%, 95% and 90%.

An airline has to balance the available payload among fuel, passengers and cargo after the operating empty weight (OEW) is considered. Two different sets of results are presented for the analysis – one using the PIANO OEW default weights, as well as fuel for a 100nm diversion to an alternate airport, and a 30-minute hold requirement (at the diversion altitude); and one using PIANO OEW+2%, along with fuel for a 100nm diversion, and a 45-minute hold requirement. These two cases are referred to as the "Low TOW" and "High TOW" cases respectively. The OEW and hold assumptions have significant impacts on the overall results.

Figure 5 provides an example of the payload-performance envelopes utilized in the analysis. This Figure shows envelopes for the A320 using the High TOW assumption, and depicts the effects of imposing the 98%, 95% and 90% MTOW restrictions.

Figure 5: A320 Payload-Performance Envelopes

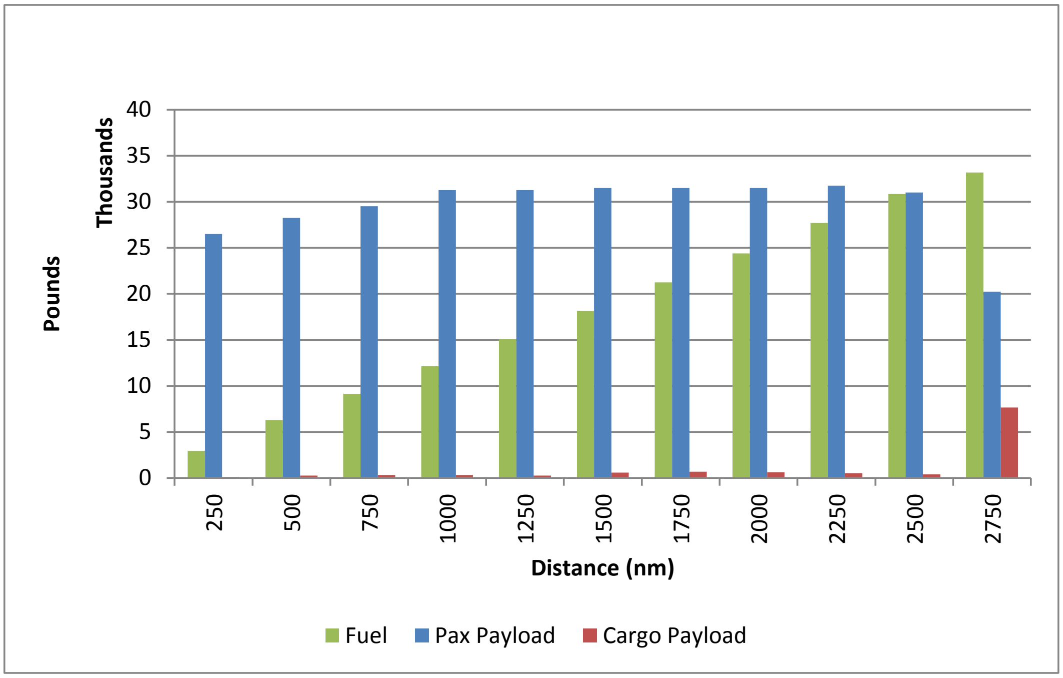


Weights and Revenue Estimates for the Baseline[9]

Figure 6 shows the total weight of all passengers and pounds of cargo observed in each distance block for the A320 aircraft. It also shows the weight of fuel required to operate a mission at the midpoint range in each block. As can be seen, the weight of fuel required is about equal to the combined weight of the passengers and cargo for the longest observed distance blocks flown.

[9] Figures 6 to 9 are all based on the Low TOW assumption; the results are impacted only in a very minor way when imposing the High TOW assumption.

Figure 6: A320 Baseline Weights per Operation by Distance Block



The baseline total revenue per operation was computed using the estimated passenger and cargo weight carried along with the corresponding yield curves. Figure 7 shows the total annualized baseline revenues and fuel costs for the flights in each distance block for the A320. Fuel costs become large relative to revenue in the longer distance blocks.[10]

[10] The longest distance block in Figure 6 shows a reduced payload relative to shorter distances; this is due entirely to the lower than average passenger load factors observed in the T-100 data for these long flights. We elected to use the observed data as is without adjustment; the overall effect on our results is very small either way since there are only a small number of flights in the distance block (see Figure 2).

Figure 7: A320 Baseline Revenues and Fuel Cost per Operation by Distance Block

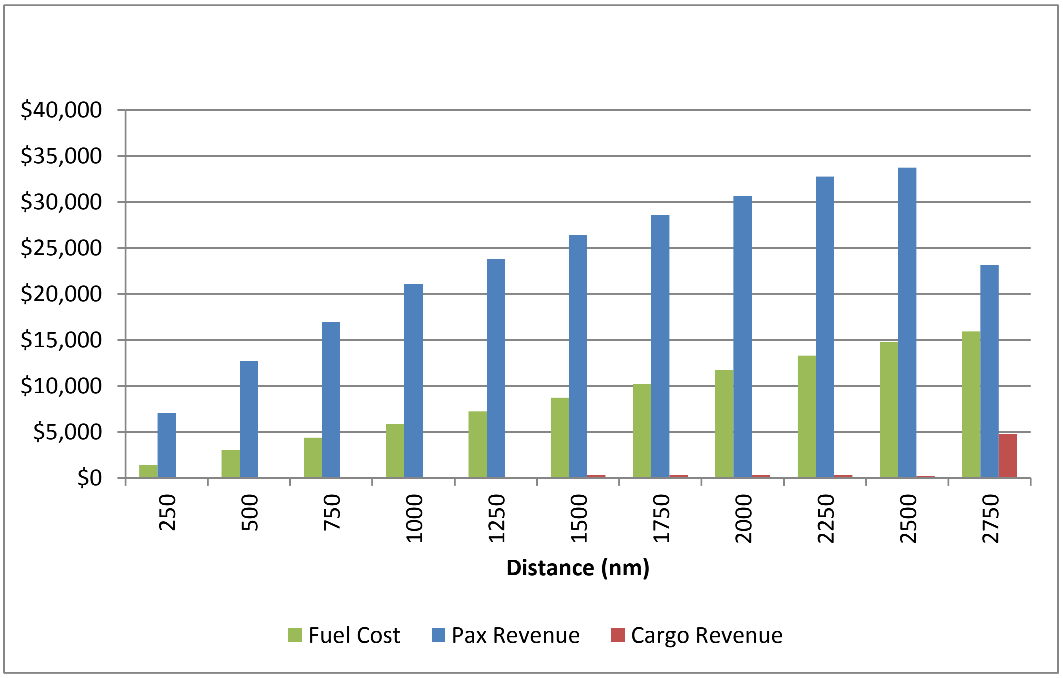
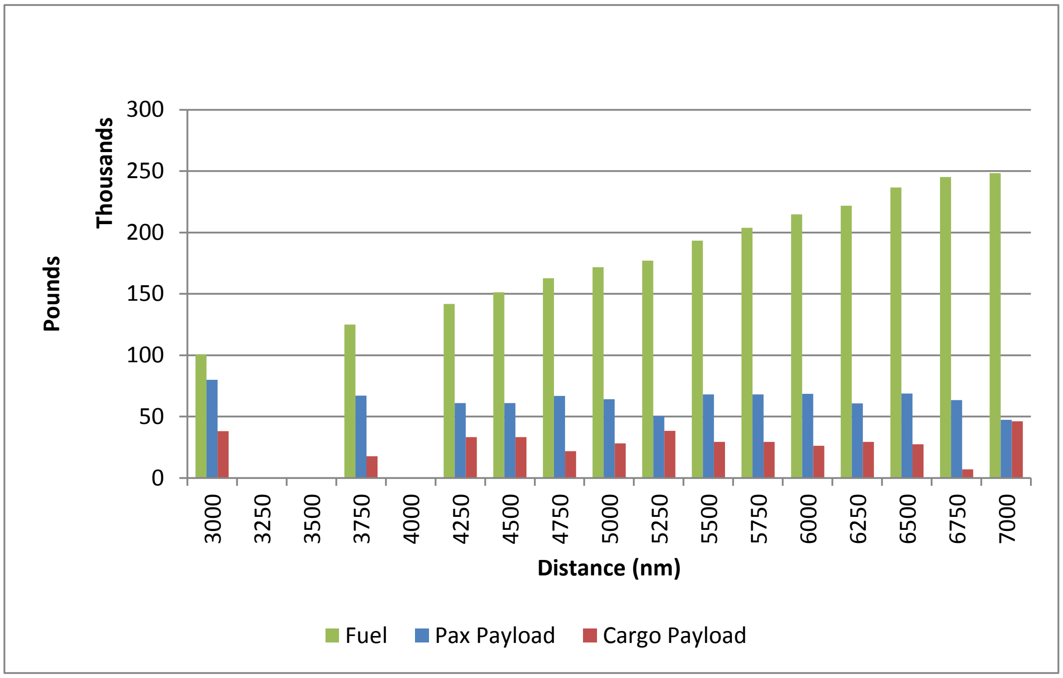


Figure 8 shows the baseline weights for passengers, cargo and fuel for the 77W in international service. It shows that the longest distance block for which flights were observed was the 7,000 nm distance block. At this long distance the weight of the fuel required for the flight (including reserves) can be more than two times the passenger and cargo payload weight. Cargo weight is significant in most distance blocks. However, as shown at the bottom of the figure, passenger revenues are still much larger than cargo revenues. Fuel costs per flight are also a large share of revenues and large in absolute terms.

Figure 8: B77W Baseline Weights, Revenues and Fuel Cost per Operation by Distance Block



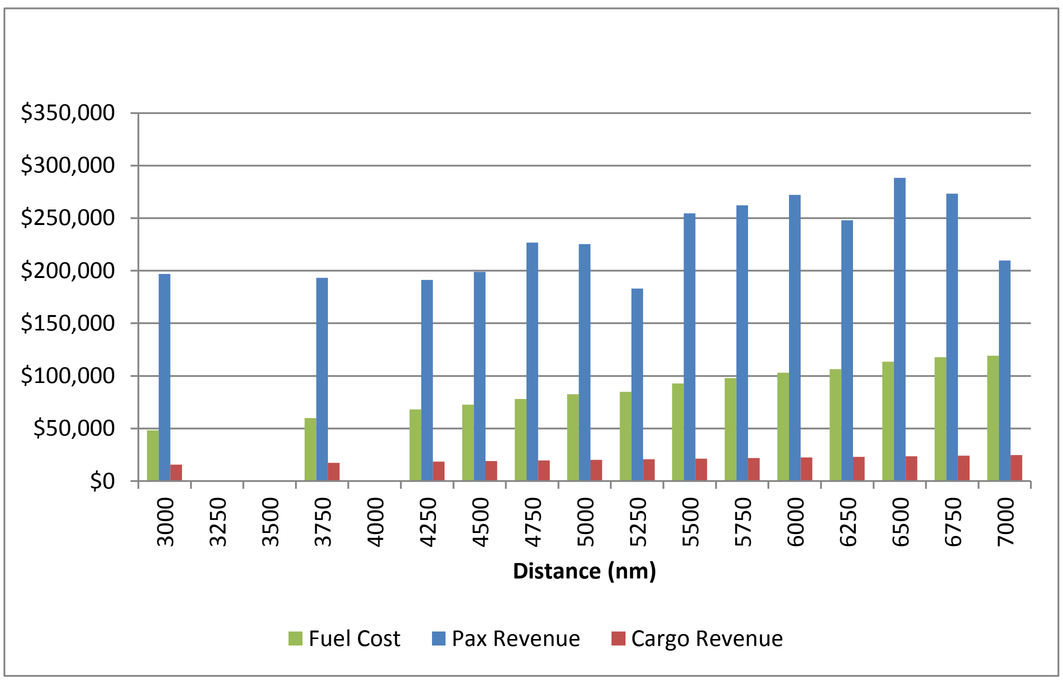
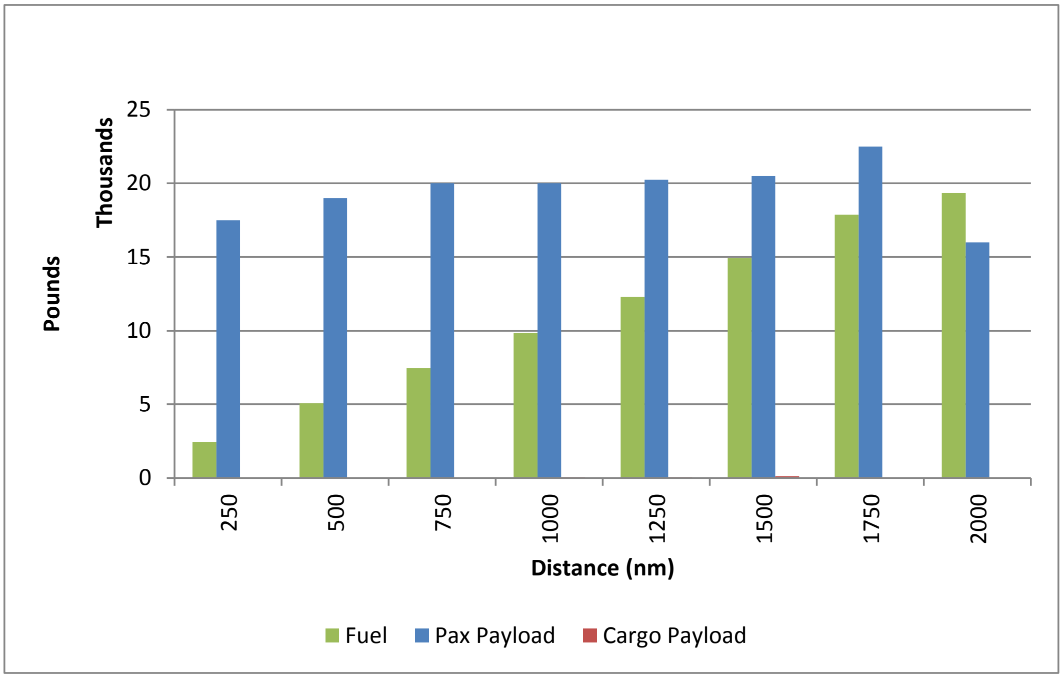
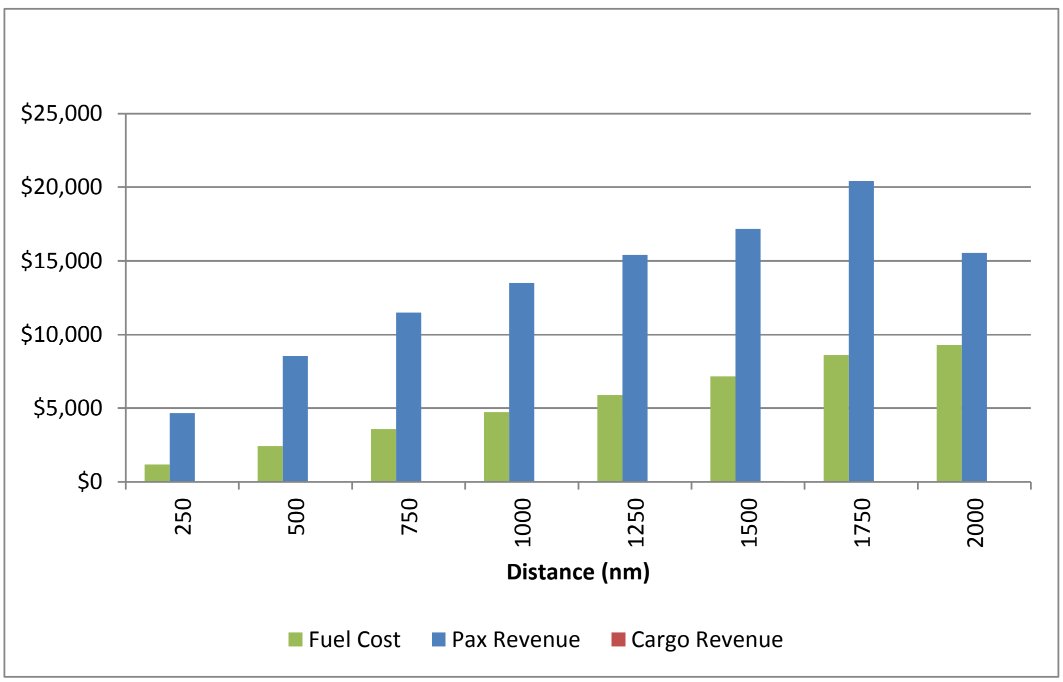


Figure 9 shows the distribution of payload in terms of passenger, cargo and fuel weights for the E190 aircraft. Cargo weights and revenues are not material for this aircraft type.

Figure 9: E190 Baseline Weights, Revenues and Fuel Cost by Distance Block





MTOW-Restricted Revenue Estimation

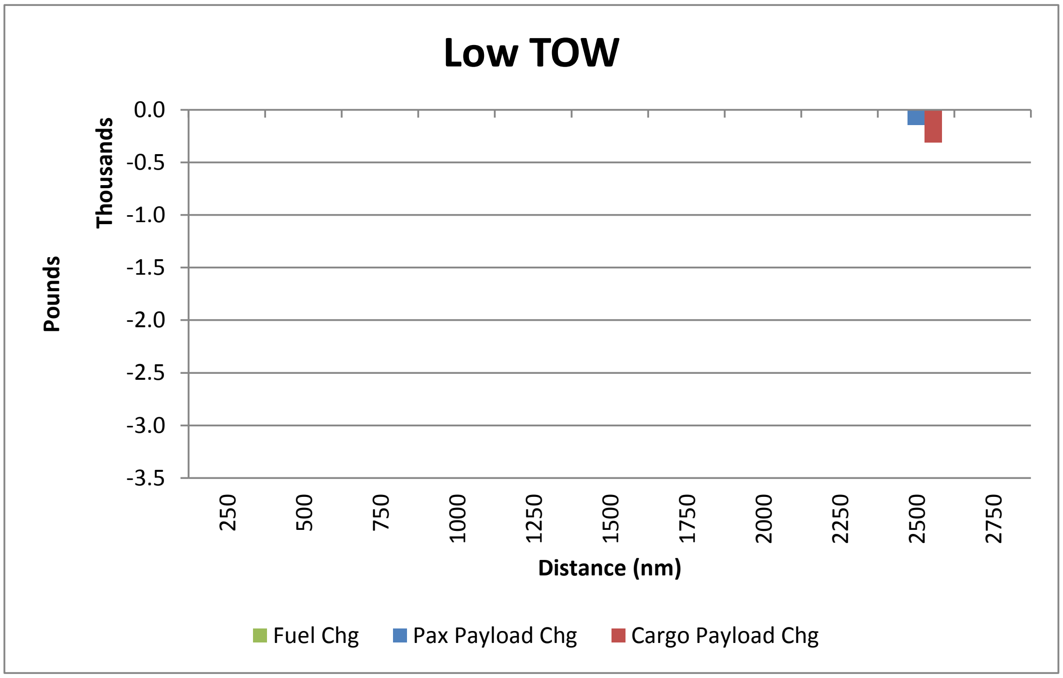
As mentioned earlier, the operations in each distance block were analyzed individually to ascertain whether a given MTOW constraint would impact the flights. The aircraft performance envelopes were applied against observed operations; if baseline payload exceeded the MTOW-restricted maximum payload, cargo was offloaded first, and then the number of passengers was reduced as needed to satisfy the payload-range constraint.

The loss in cargo or numbers of passengers resulting from the MTOW constraint for specific operations was converted to lost revenue per year for an average aircraft. This was based on the numbers of operations observed in each distance block and the annual utilization of aircraft in terms of flight hours. In order to manage the complexity of the analysis, several simplifying assumptions were made about how airlines might react to the potential loss of revenue. All operations were retained if physically feasible, even if the carrier would not operate them because of the large reduction in revenue payloads, or would operate them with different aircraft because of the magnitude of lost revenue. The analysis assumed that revenues and costs for unconstrained operations are not changed, and that there are no changes to aircraft configuration, such as reducing the seating capacity. Adjustments were made for the reduced fuel consumption and any changes in flight time for the constrained flights (calculated using the PIANO model).

The analysis did not adjust cruise speed or other factors to retain passengers in the face of the MTOW constraint by reducing the amount of fuel used. There were also no assumptions made about other actions that may be taken on unconstrained flights to recapture any of the revenue lost on constrained flights. Finally, we did not assume any market effects because of the restricted supply of seats in a market because of the constrained flights. The analysis assumed no recovery of revenue by shifting passengers to other flights because these would come at the cost of operating additional flights. In total, this set of assumptions represents a relatively inflexible response by airlines to an MTOW constraint that may overestimate actual revenue impacts.

The results for the A320 with a 95 percent MTOW restriction are shown in Figure 10. The impacts are very minor in the Low TOW case and only affect operations in the 2500-mile distance block. In the High TOW case, the impacts are greater, but still modest overall. For the affected flights, about 5 passengers must be shed per flight (after the cargo is first offloaded) because of the MTOW restriction.

Figure 10: Change in A320 Fuel and Payload per Operation: 95% MTOW Restriction



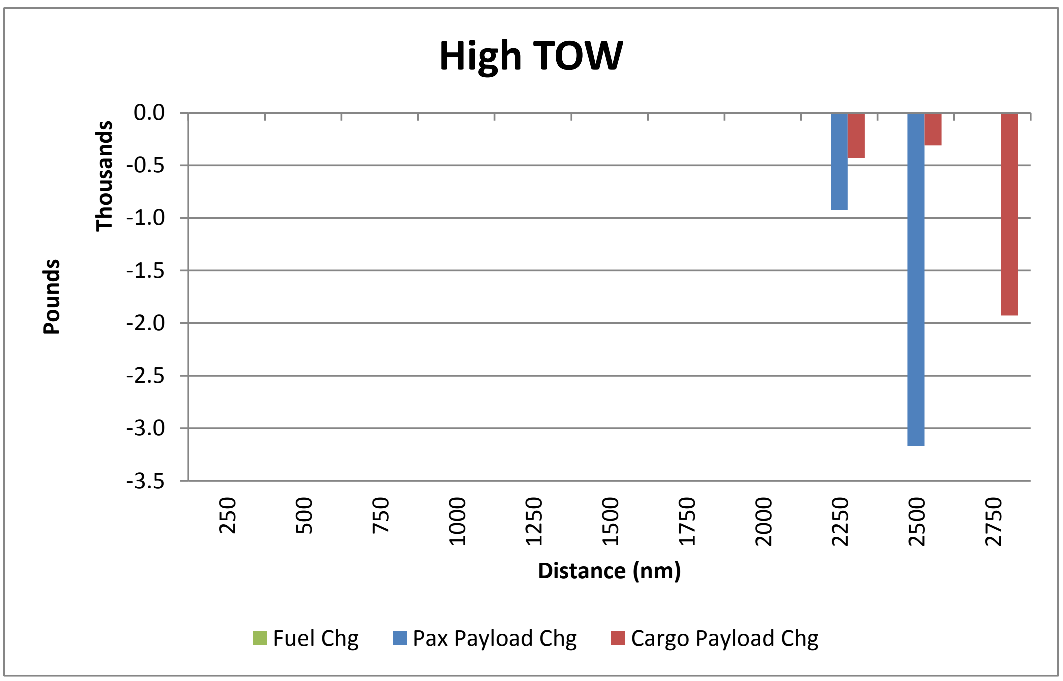
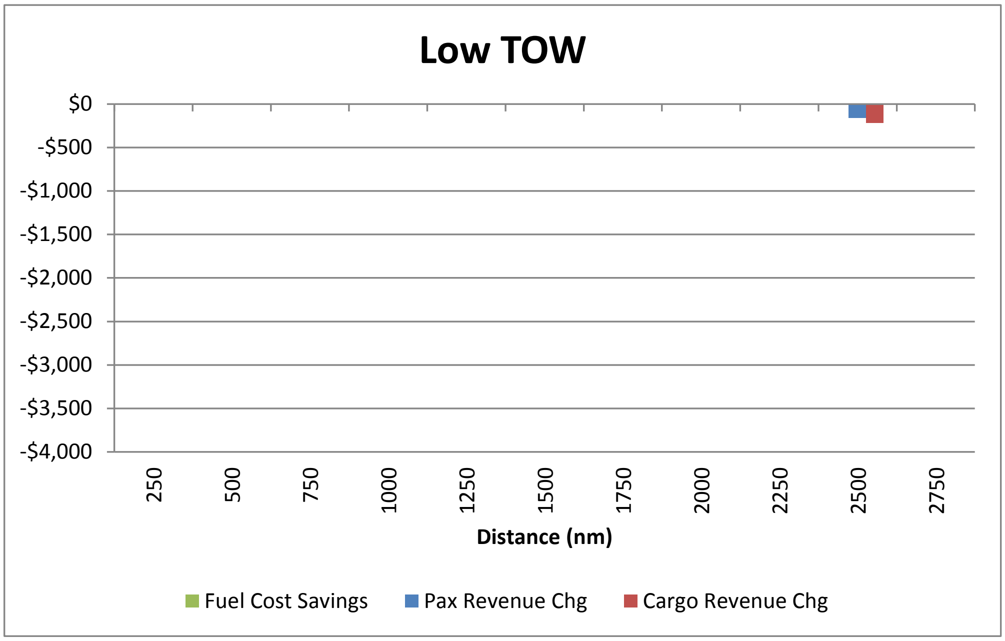
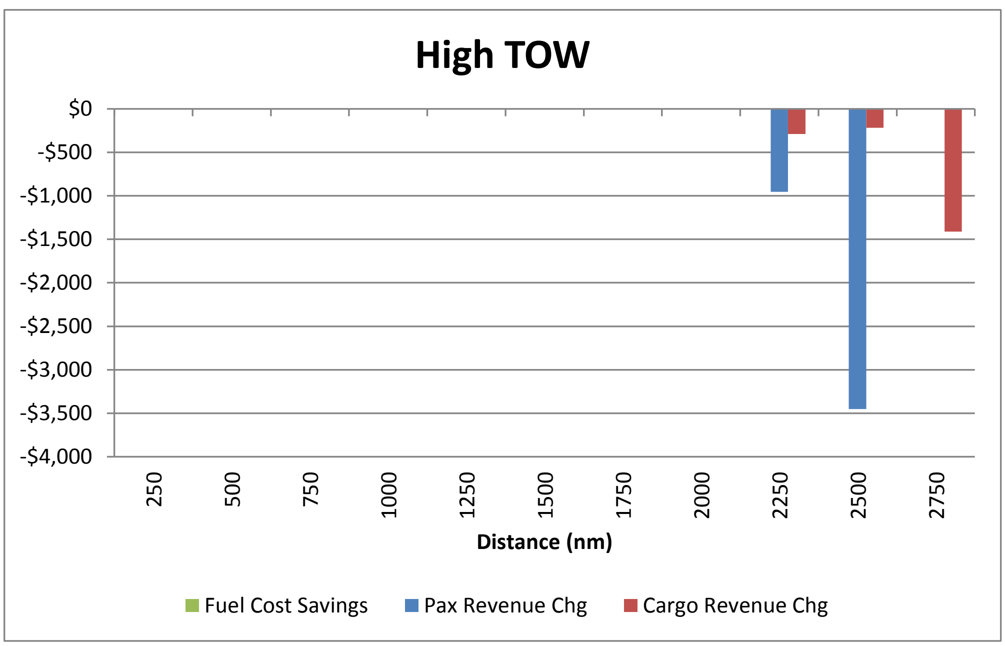


Figure 11 shows the impact of these reductions in terms of the decrease in revenues (negative) and reduction in fuel cost (positive) for the affected A320 flights. The values of fuel savings computed from operating at a reduced MTOW were estimated by ICCT using the PIANO model and were valued using current IATA world jet fuel prices.[11] In this specific case, there are virtually no fuel savings and modest passenger and cargo revenue impacts.

Figure 11: Change in A320 Revenues and Fuel Costs per Operation: 95% MTOW Restriction





[11] http://www.iata.org/publications/economics/fuel-monitor/Pages/price-analysis.aspx

As noted, the results for A320 shown in Figures 8 and 9 reflect the 95% MTOW restriction. The effects of the 90% case are significantly larger; corresponding results for this case are shown in Appendix A. At 98%, the effects disappear altogether.

Figure 12 shows the impact of the 95% MTOW restriction on the B77W flights by distance block in the High TOW case. (There are zero impacts in the Low TOW case.) Starting at 6,500 nm, some offloading of cargo (but no passengers) is required by the MTOW constraint.

Figure 12: Changes in B77W Fuel and Payload per Operation: 95% MTOW Restriction

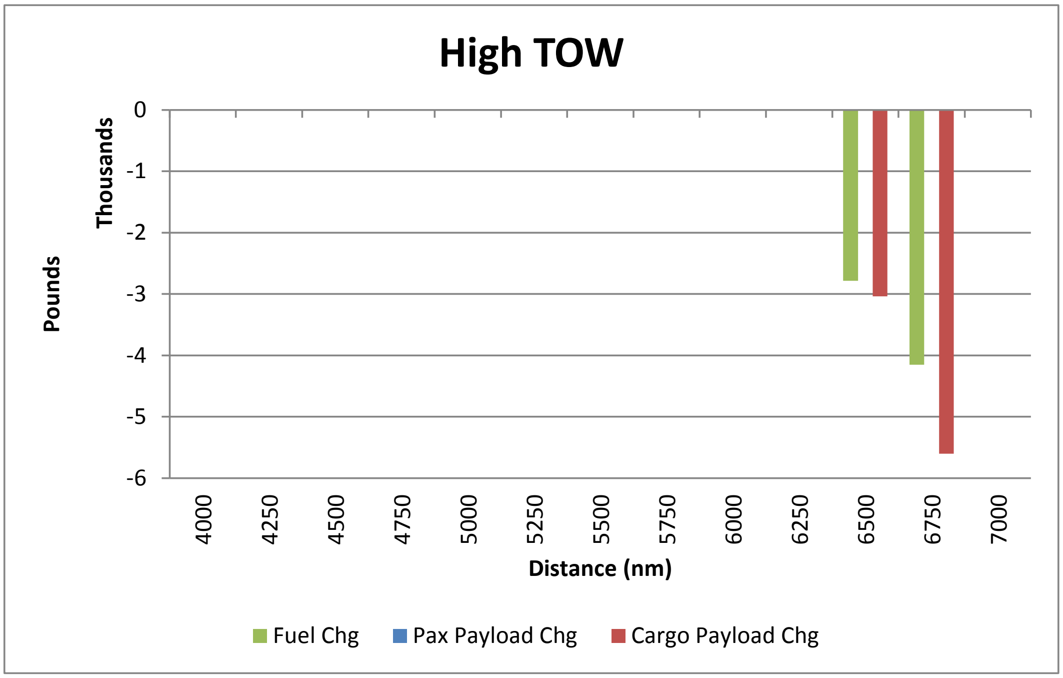
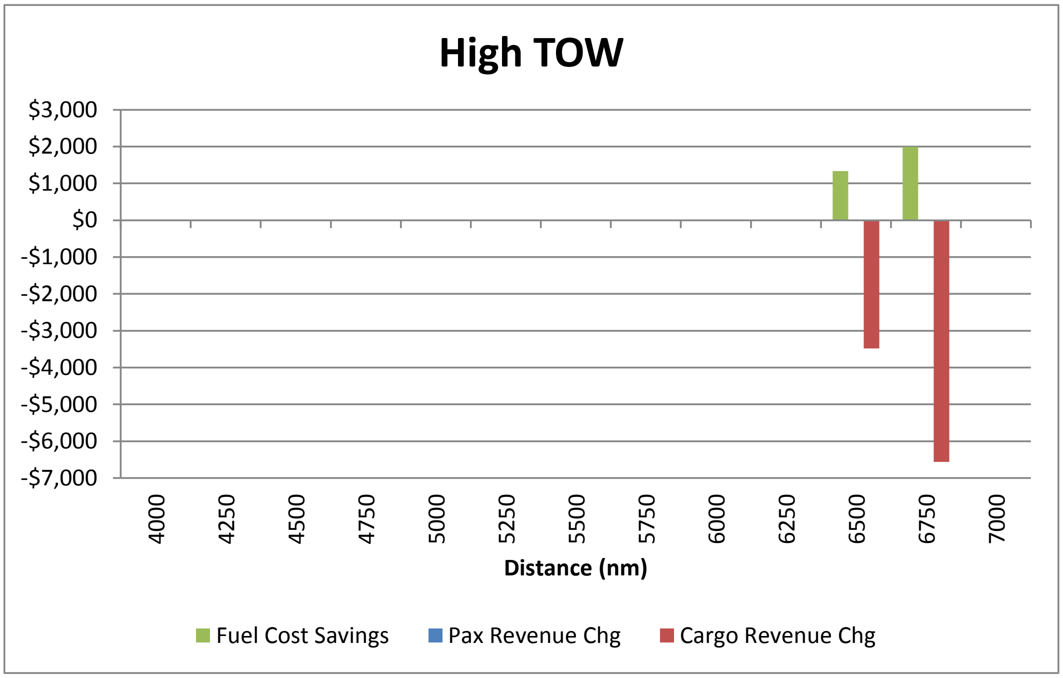


Figure 13 shows the impact on B77W flight revenues and costs for the 95% MTOW restriction. Again, the results are very modest overall.

Figure 13: Change in B77W Revenues and Fuel Cost per Operation: 95% MTOW Restriction



As with the A320, the impacts become markedly higher under a 90% MTOW restriction (shown in Appendix A), but disappear entirely at 98%.

Figures 14 and 15 shows the change in fuel, payload weights and revenues per operation for the 95% MTOW restriction for the E190. (Again, there are no impacts in the Low TOW case.) The impacts are very minor in this case.

Figure 14: Change in E190 Fuel and Payload per Operation: 95% MTOW Restriction

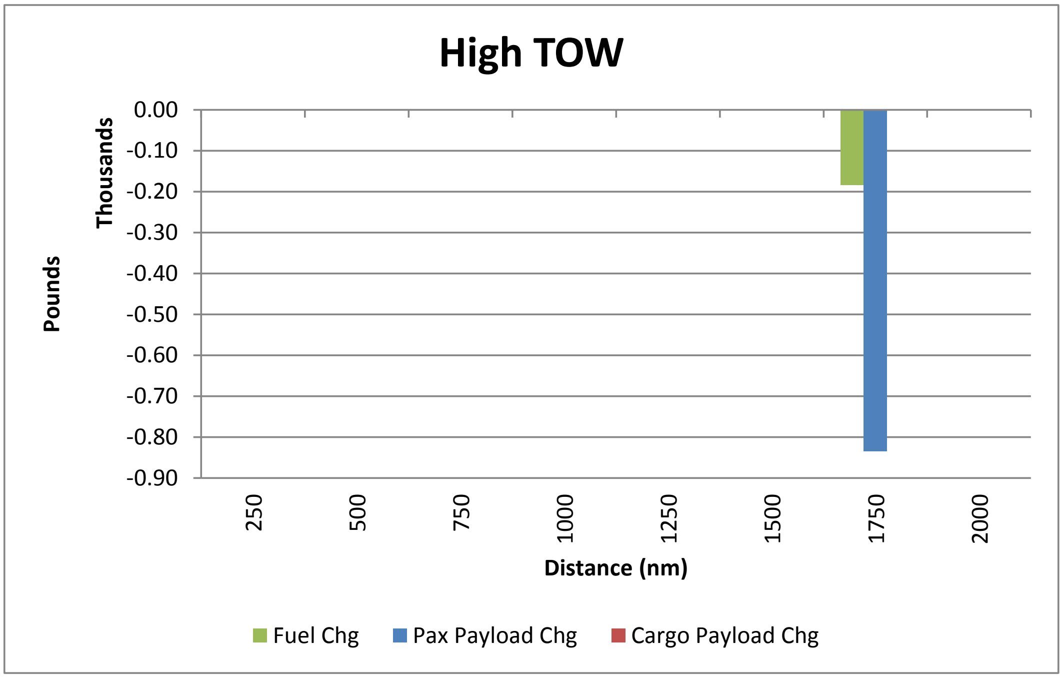
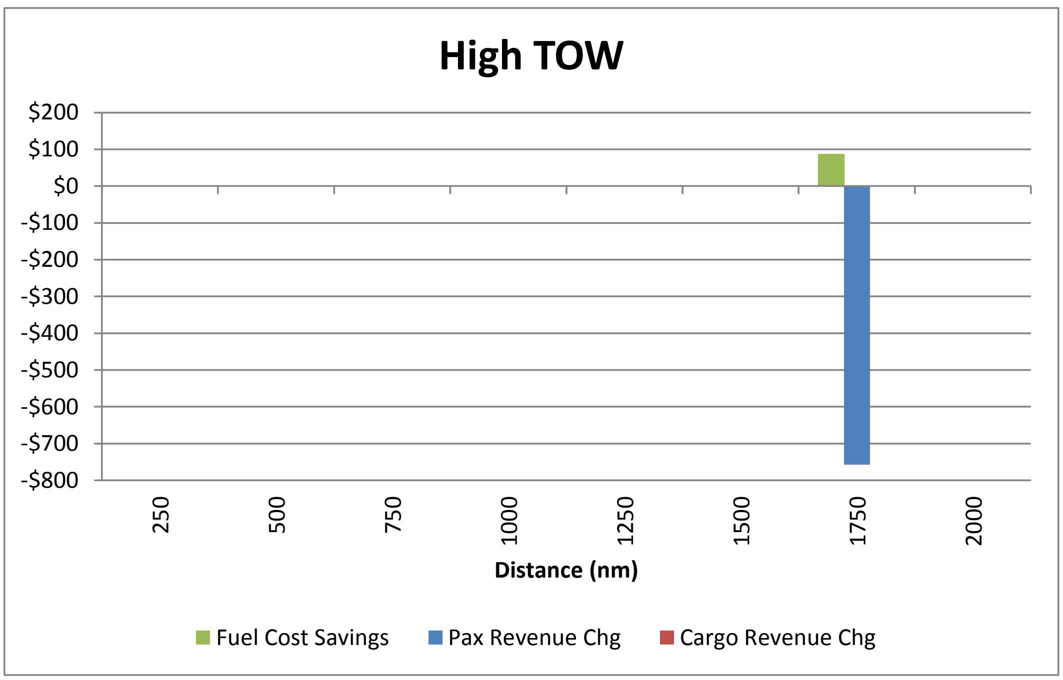


Figure 15: Change in E190 Revenues and Fuel Cost per Operation: 95% MTOW Restriction



Annualized Changes in Revenues and Costs per Aircraft with MTOW Restriction

The revenue impacts per flight described in the prior section were converted to per-aircraft values using the number of flights in each affected distance block and average aircraft utilization rates from the carriers that operated the flights reported above. Figures 16 and 17 show the results of the 95% MTOW restriction for the A320 based on an estimated utilization of 1,237 flights per aircraft per year. The baseline aircraft operates with an 81% average passenger load factor and generates about $26.8 million per year in passenger and cargo revenue. Only 18 of the 1,237 annual flights are affected under the Low TOW case, compared to 106 (about 1.5%) under the High TOW case.

Under the 95% MTOW restriction there is near zero revenue loss in the Low TOW case, and an annual loss of about $175,000 (less than 0.7% of baseline revenue) in the High TOW case for the A320.

The present value of the annual revenue loss per aircraft was computed using assumed discount rates of three percent, seven percent and 11 percent per year and a 25-year expected aircraft life. As shown in the Figures, the 95% MTOW restriction affects the value of the aircraft modestly. To put this into context, Airbus reports an average list price of a new A320 in 2013 as $91.5 million.[12]

Figure 16: A320 Results Per Aircraft: 95% MTOW (Low TOW)

Annual Baseline:	
Annual Operations per Aircraft	1,237
Max Seats per Aircraft	150
Estimated Fleet	466
Average Load Factor (relative to Max Seats)	81%
Total Passengers per Operation	122
Total Annual Fuel per Aircraft (tons)	8,849.9
Total Annual Cargo Revenue per Aircraft	$223,766
Total Annual Passenger Revenue per Aircraft	$26,532,089

[12] http://www.airbus.com/presscentre/corporate-information/key-documents/?eID=dam_frontend_push&docID=14849 accessed 2-28-13

With 95% MTOW Restriction:	
Affected Annual Operations per Aircraft	18
Average Decrease in Passengers per Affected Operation	0.6
Change in Annual Cargo Revenue per Aircraft	($4,002)
Change in Annual Passenger Revenue per Aircraft	($2,896)
Savings in Annual Fuel per Aircraft (tons)	0.0
Savings in Annual Fuel Expense per Aircraft	$0
NPV of Change in Revenue @ 11% for 25 years	($64,485)
NPV of Change in Revenue @ 7% for 25 years	($86,016)
NPV of Change in Revenue @ 3% for 25 years	($123,723)
Change in Annual Revenue as % Baseline	-0.03%

Figure 17: A320 Results Per Aircraft: 95% MTOW (High TOW)

With 95% MTOW Restriction:	
Affected Annual Operations per Aircraft	106
Average Change in Passengers per Affected Operation	5.3
Change in Annual Cargo Revenue per Aircraft	($29,538)
Change in Annual Passenger Revenue per Aircraft	($146,291)
Savings in Annual Fuel per Aircraft (tons)	0.0
Savings in Annual Fuel Expense per Aircraft	$0
NPV of Change in Revenue @ 11% for 25 years	($1,643,671)
NPV of Change in Revenue @ 7% for 25 years	($2,192,468)
NPV of Change in Revenue @ 3% for 25 years	($3,153,584)
Change in Annual Revenue as % Baseline	-0.7%

Turning to the B77W, Figures 18 and 19 show the effects of the 95% MTOW restriction. Again, these impacts are converted from a per-flight basis to a per-aircraft basis. The 77W makes 345 flights per year in the baseline and operates with an observed passenger load factor of 71%.[13] It produces about $92.8 million in annual revenue, including both passenger and cargo revenue. Under the 95% MTOW payload limit, there are no impacts in the Low TOW case, while 25 of 345 annual flights per aircraft are affected in the High TOW case. However, the restriction can be met by offloading cargo only, without affecting passengers. Since all of the reduction is in cargo, the impact on revenues is quite low. Fuel savings are modest, around $41,000 annually.

Under the 95% MTOW restriction there is a net revenue loss of approximately $80,000 per year for the B77W in the High TOW case, or less than 0.1 percent of baseline revenues. In terms of present value, the loss is on the order of around $1 million; Boeing reported an average list price of a new B777-300ER in 2012 as $315 million.[14]

The 90% MTOW restriction affects the value of the aircraft much more significantly, as reported in Appendix A, ranging from about 0.5 percent to 2.5 percent of revenues. There are no impacts for the 98% MTOW case for the B77W.

Figure 18: B77W Results Per Aircraft: 95% MTOW (Low TOW)

Annual Baseline Per Aircraft	
Annual Operations per Aircraft	345
Max Seats per Aircraft	365
Estimated Fleet	49
Average Load Factor (relative to Max Seats)	71%
Total Passengers per Operation	258
Total Annual Fuel per Aircraft (tons)	35,661.8
Total Annual Cargo Revenue per Aircraft	$7,551,630
Total Annual Passenger Revenue per Aircraft	$85,208,973

[13] The average load factor is computed relative to the maximum number of seats assumed for the 77W; this is higher than the actual seat sizes reported in the T-100 data.
[14] http://www.boeing.com/commercial/prices/index.html accessed 2-28-13

With 95% MTOW Restriction:	
Affected Annual Operations per Aircraft	0
Average Change in Passengers per Affected Operation	0.0
Change in Annual Cargo Revenue per Aircraft	$0
Change in Annual Passenger Revenue per Aircraft	$0
Savings in Annual Fuel per Aircraft (tons)	0.0
Savings in Annual Fuel Expense per Aircraft	$0
NPV of Change in Revenue @ 11% for 25 years	$0
NPV of Change in Revenue @ 7% for 25 years	$0
NPV of Change in Revenue @ 3% for 25 years	$0
Change in Annual Revenue as % Baseline	0.0%

Figure 19: B77W Results Per Aircraft: 95% MTOW (High TOW)

With 95% MTOW Restriction:	
Affected Annual Operations per Aircraft	25
Average Change in Passengers per Affected Operation	0.0
Change in Annual Cargo Revenue per Aircraft	($120,994)
Change in Annual Passenger Revenue per Aircraft	$0
Savings in Annual Fuel per Aircraft (tons)	42.6
Savings in Annual Fuel Expense per Aircraft	$40,883
NPV of Change in Revenue @ 11% for 25 years	($748,890)
NPV of Change in Revenue @ 7% for 25 years	($998,933)
NPV of Change in Revenue @ 3% for 25 years	($1,436,837)
Change in Annual Revenue as % Baseline	-0.1%

Figures 20 and 21 shows the results of the 95% MTOW restriction for the E190, which has 1,472 flights per aircraft per year. The baseline aircraft operates with a 78% passenger load factor and generates about $15.1 million per year in revenue. Again, there are no impacts in the Low TOW case, and extremely minor impacts in the High TOW case. As a way of comparison with the other aircraft, the average list price of a new E190 in 2013 is around $30 million.[15]

Figure 20: E190 Results Per Aircraft: 95% MTOW (Low TOW)

Annual Baseline:	
Annual Operations per Aircraft	1,472
Max Seats per Aircraft	98
Estimated Fleet	105
Avg Load Factor (relative to Max Seats)	78%
Total Passengers per Operation	77
Total Annual Fuel per Aircraft (tons)	5,289.5
Total Annual Cargo Revenue per Aircraft	$28,708
Total Annual Passenger Revenue per Aircraft	$15,090,057

With 95% MTOW Restriction:	
Affected Annual Operations per Aircraft	0
Average Change in Passengers per Affected Operation	0.0
Change in Annual Cargo Revenue per Aircraft	$0
Change in Annual Passenger Revenue per Aircraft	$0
Savings in Annual Fuel per Aircraft (tons)	0.0
Savings in Annual Fuel Expense per Aircraft	$0
NPV of Change in Revenue @ 11% for 25 years	$0
NPV of Change in Revenue @ 7% for 25 years	$0
NPV of Change in Revenue @ 3% for 25 years	$0
Change in Annual Revenue as % Baseline	0.0%

[15] http://www.aircraftcompare.com/helicopter-airplane/Embraer-190/116 accessed 2-28-13.

Figure 21: E190 Results Per Aircraft: 95% MTOW (High TOW)

With 95% MTOW Restriction:	
Affected Annual Operations per Aircraft	2
Average Change in Passengers per Affected Operation	3.3
Change in Annual Cargo Revenue per Aircraft	$0
Change in Annual Passenger Revenue per Aircraft	($1,141)
Savings in Annual Fuel per Aircraft (tons)	0.1
Savings in Annual Fuel Expense per Aircraft	$133
NPV of Change in Revenue @ 11% for 25 years	($9,427)
NPV of Change in Revenue @ 7% for 25 years	($12,574)
NPV of Change in Revenue @ 3% for 25 years	($18,086)
Change in Annual Revenue as % Baseline	0.0%

Sensitivity Analyses for Commercial Aircraft

The entire baseline analysis for commercial aircraft was developed with the various assumptions described above. To investigate the sensitivity of the results to the assumptions, we performed two sensitivity analyses.

The first involved the assumption of constant load factors for the operations within each distance block. These distance block-specific load factors are typically very close to each other (for a given aircraft type). But in practice, we would expect that the passenger loads could vary quite significantly on individual flights, and the effects of a higher-than-average load factor flight that could push a flight over the MTOW constraint might not be symmetrically offset by a lower-than-average load factor flight where the constraint is not binding to begin with. This suggests that the summary revenue impacts presented above may be on the low side.

To investigate this possibility, we performed a Monte Carlo simulation for the A320 95% MTOW (High TOW) case. Recall that the baseline results presented above showed a -0.7% revenue loss. For the sensitivity analysis, we allowed the average passenger count per flight within each distance block to vary—the variance was based on the observed variations in the raw T-100 data that was used as the source data for the analysis. The simulation involved 10,000 runs, picking a different passenger count for each run for the flights within each distance block.

When aggregated across all distance blocks for the A320, the results from the Monte Carlo simulation show that the average revenue loss increases from 0.7 percent to 1.0 percent. So while the effects are not insignificant, they do not change the overall conclusion that the impacts of a 95% MTOW restriction are modest for the A320.

We also investigated the effect of headwinds and tailwinds, which can affect aircraft performance. In essence they increase or decrease the required time of flight which affects fuel burn and therefore payload range.

Carriers typically flight plan with the expected level of winds taken into consideration. But even without an MTOW restriction, there may be a payload reduction required when strong headwinds are encountered. We simulated this by calculating the effects of a 30-knot headwind and tailwind and converting them to equivalent changes in flight distance (based on the average cruise speed). We then compared the changes in revenues and fuel costs to the baseline to get the average annual impact per aircraft.

The results for the A320 High TOW case with a 95% MTOW restriction show de minimus impacts of a 30-knot tailwind. This may be because of the aggregation of flights into distance blocks – the impacts were not large enough to shift operations from one distance block to another. However, the impacts of a 30-knot headwind imposed on every flight did increase the annual revenue loss from 0.7 percent to 1.9 percent.

A similar analysis for the E190 showed no change with a 30-knot tailwind, and a revenue change from less than 0.1 percent in the base analysis to about 0.3 percent with a 30-knot headwind.

While these results suggest that wind factors may also not be symmetric in terms of the reported revenue results, we cannot make definitive conclusions about the magnitude of the impact, as the aggregate effects depend on a variety of factors such as the distance block definitions, direction and length of flight, incidence and direction of winds, and actual flight routings.[16]

Business Aircraft Modeling

Turning to the business aircraft modeling, the analysis also examined the effects of implementing an MTOW restriction for the Gulfstream G450

[16] A wind sensitivity analysis was not conducted for the 77W because of its very large cargo capacity. Most impacts could be accommodated by offloading cargo which would not have a large effect on revenues in the 95% MTOW case.

aircraft, a 12-seat business jet. Given that this aircraft is generally chartered or operated by a company flight department, a traditional approach using revenues per passenger is not appropriate. Therefore, throughout the analysis, the G450 MTOW is constrained while payload remains constant, which results in a reduced aircraft range because a penalty has to be taken by reducing the amount of fuel carried. This means that the G450 may have to make a fuel stop on long flights, which adds both additional operating costs and additional time to the trip.

Assumptions

For all flights, it was assumed that the G450 has a fixed payload of seven passengers and each passenger weighs 250 pounds, including baggage. If a stop is required under an MTOW constraint, it is one hour in duration. The value of time for the passengers on the aircraft is $75 per hour per passenger; however, we recognize that this is likely very low for people travelling on this type of aircraft.[17] For example one trade magazine catering to this market says that the typical reader is an executive with an average annual income of $1.3 million, or more than $600 per hour.[18] Each aircraft has a utilization of 407 flight hours per year.[19] As shown in Figure 22, most flights observed in ETMS are relatively short range (maximum range for G450 is 4,750 nm). The number of flights was taken from the FY 2011 ETMS dataset for all G450X-coded aircraft.

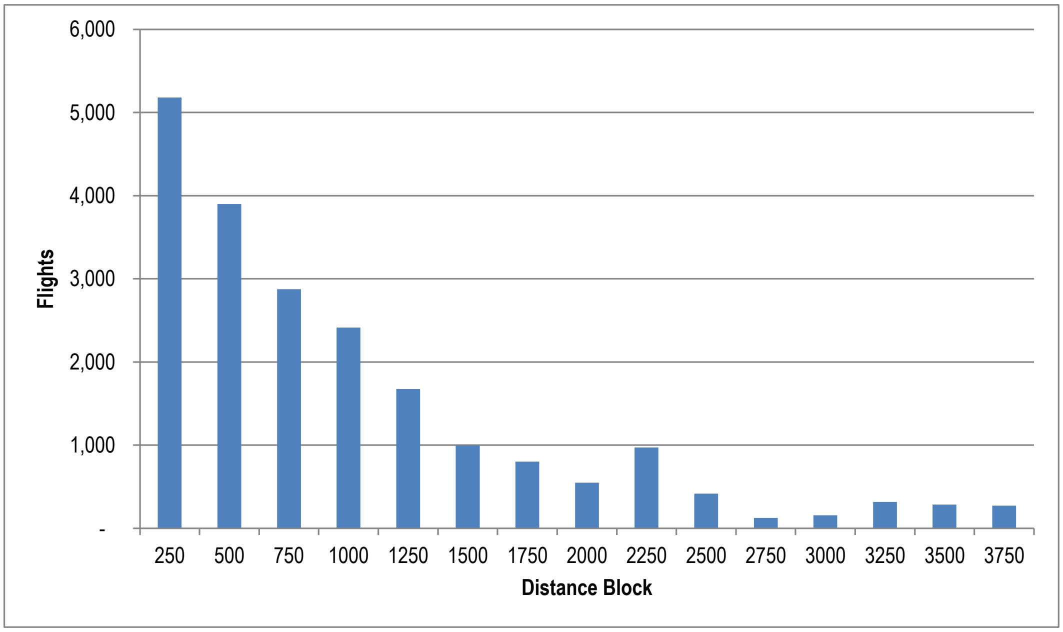
---

[17] This value was assumed by GRA, Incorporated, in accordance with FAA Value of Time for Benefit-Cost Analysis, see Footnote 4.

[18] FAA. *General Aviation and Part 135 Activity Surveys - CY 2010*. http://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2010/. Accessed 3-1-13.

[19] *Federal Aviation Administration*. General Aviation Survey, 2010 ed.

Figure 22: Total ETMS Flights for G450X by Distance Block



The distance between the origin airport and destination airport (in nautical miles) was calculated and flights were put into 250 nautical mile distance blocks. Using 0.5% of total flights as a minimum for robust data, we eliminated flight distance blocks that contained fewer flights than this threshold from the analysis.

Using a fixed payload of seven passengers each weighing 250 pounds, the maximum payload of a flight is 1,750 pounds. The amount of fuel required to complete the mission at the midpoint of the flight distance block was taken from the PIANO data. Based on the take-off weight constraint, the next consideration was whether the aircraft could complete the mission without a stop to refuel, given its payload and length of flight. If the aircraft could not complete the flight, a fuel stop was assumed for the flights in this distance block. To determine the economic cost of the stop, it is assumed to take an additional eight-tenths of an hour[20] to descend from altitude, land, take-off and return to altitude, and one additional hour for refueling and ground handling.

Aircraft operating costs, the amount of passenger time and fuel consumption are calculated for the 100% MTOW (baseline), 98% MTOW, 95% MTOW, and 90% MTOW cases.[21] Next, the NPV of aircraft operating costs and value of time are calculated, and the differences in the net present values for the

[20] It is assumed that 80% of this is flight time.
[21] Conklin & de Decker (2012). *Aircraft Cost Evaluator*. Orleans, MA.

constrained versus the baseline case provide the economic costs of the MTOW constraint over the aircraft's assumed lifetime of 25 years.

Figure 23 shows the estimated economic costs of the MTOW restrictions for the G450X. (The fuel stops in the baseline result from the use of PIANO data for the G450SP, which has a shorter range. It is the closest variant to the G450X for which ICCT has PIANO results. These are carried in the baseline aircraft for accuracy when calculating the differences because of the MTOW constraint.) As can be seen, the MTOW limitations do not have a large impact. In part this is due to the fact that most flights with this aircraft are at distances well below maximum range and the MTOW constraints affects a very small number of flights, even when it is at 90%. As a point of reference, the purchase price of a G450X is approximately $38 million.[22]

Figure 23: G450X Annual and Lifecycle Results per Aircraft (High TOW)

	98% MTOW	95% MTOW	90% MTOW
Average Annual Number of Stops per Aircraft	4.7	7.4	9.8
Annual Length of Stops per Aircraft (Hours)	4.7	7.4	9.8
Cost of Additional Aircraft Usage, Stops, per Aircraft	$25,686	$40,206	$53,163
Economic Value of Lost Time per Aircraft	$4,482	$7,016	$9,277
Total Cost of Missions per Aircraft	$2,612,640	$2,612,640	$2,612,640
Total Cost of Missions Including Stops per Aircraft	$2,642,808	$2,659,862	$2,675,081
NPV @ 11% (per Aircraft)	$24,705,330	$24,864,751	$25,007,019
NPV @ 7% (per Aircraft)	$32,954,055	$33,166,704	$33,356,473
NPV @ 3% (per Aircraft)	$47,400,193	$47,706,062	$47,979,021
Change in NPV @ 11% Discount Rate	$143,782	$303,203	$445,471
Change in NPV @ 7% Discount Rate	$191,788	$404,437	$594,206
Change in NPV @ 3% Discount Rate	$275,863	$581,731	$854,690
Change in Cost vs. Baseline (%)	**1.2%**	**1.8%**	**2.4%**

We found that the insignificant nature of the potential MTOW limits on the G450X are due, in part, to a low flight count at the higher end of the aircraft range. More importantly, when considering the "significant level" of flights, we see that no flights exceed the 3,750 nm distance block, thus the number of flights at the margin is relatively small. This is illustrated in Figure 24.

[22] Aircraft cost derived from Conklin & de Decker's Aircraft Library.

Figure 24: G450X Annual Flights, Fleet-Wide

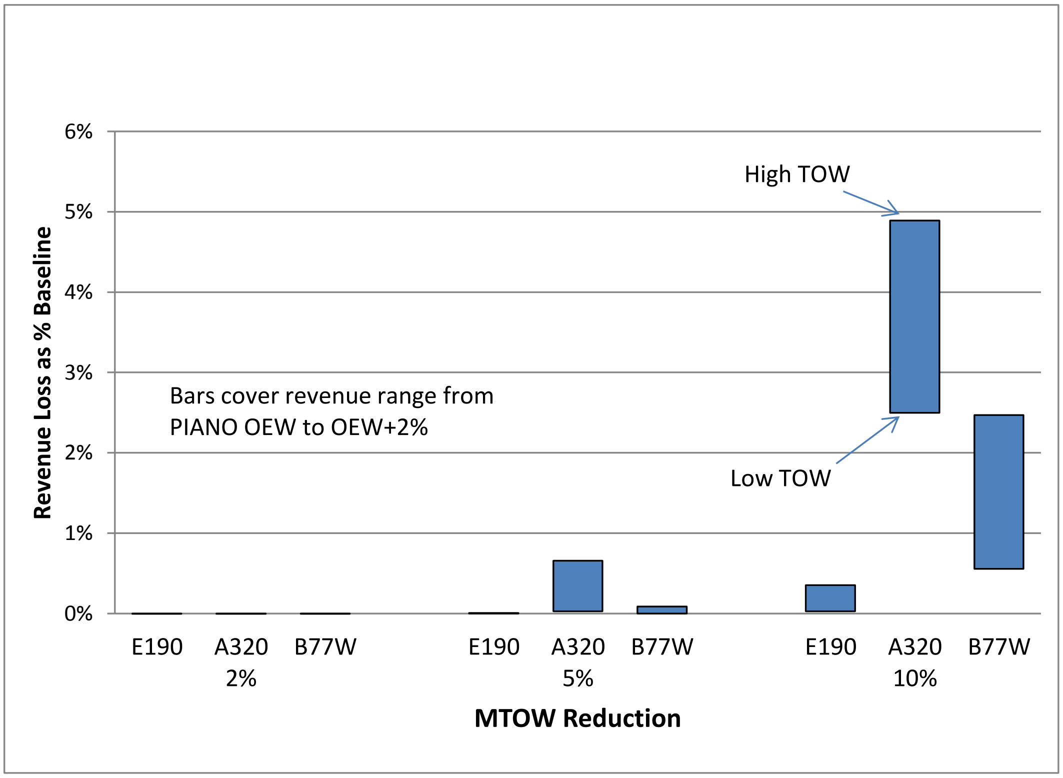
Distance Block	Flights, Base Case	
nm	Number	Percent
250	5,182	24.7%
500	3,900	18.6%
750	2,877	13.7%
1,000	2,415	11.5%
1,250	1,674	8.0%
1,500	999	4.8%
1,750	803	3.8%
2,000	548	2.6%
2,250	972	4.6%
2,500	416	2.0%
2,750	124	0.6%
3,000	158	0.8%
3,250	316	1.5%
3,500	285	1.4%
3,750	274	1.3%

Summary

Overall, the lower MTOW restrictions (from two to five percent) have relatively little impact on the revenues and costs for each aircraft as shown in Figure 25 below. It also shows how these impacts vary between the Low TOW and High TOW cases.

A ten percent restriction on MTOW would be more severe, with up to a five percent revenue impact as shown below. The A320 is the most severely impacted aircraft model; but it is scheduled to be replaced later in this decade by a more efficient model (the A320 NEO).

Figure 25: Annual Revenue Losses from MTOW Reductions



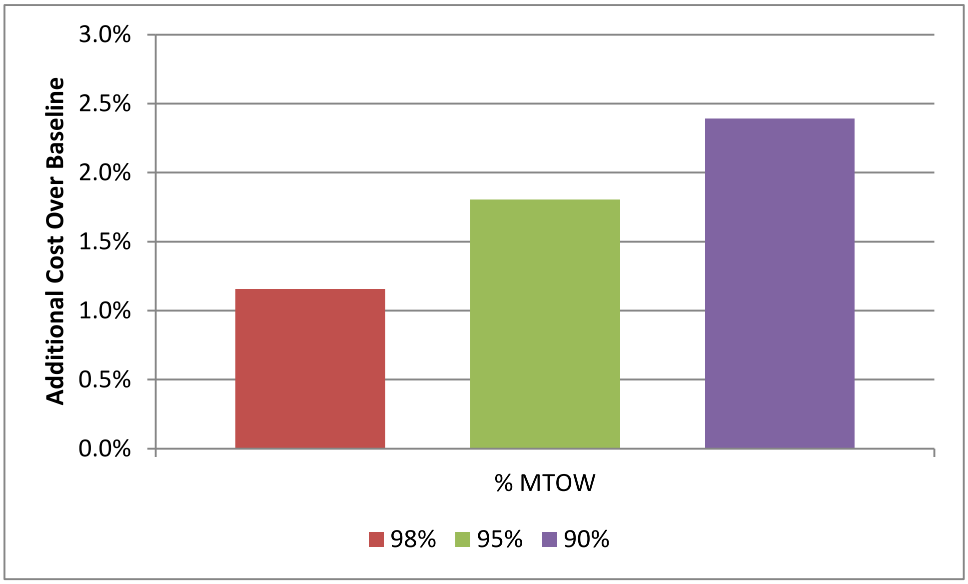
As can be seen, the 98% MTOW scenario (equal to a 2% reduction), literally has no effect on operators. This is indicative of the fact that most operations are carried out well below the maximum payload-performance capabilities of each aircraft type. Movement to a 95% MTOW restriction begins to modestly affect operations. The results for both the E190 and B77W are very small at this restriction level, while the A320 impacts are larger, though still very modest (well under 1 percent of baseline revenues). At 90%, the impacts begin to become much more significant, in the 0.5-2.5 percent range for the B77W and from 2.5-5.0 percent for the A320.

These impacts would be larger for flights that encounter strong headwinds or that are operated with higher average load factors than used in this analysis. These revenue losses assume that the operator takes no mitigating actions, and may be viewed as conservative. In summary, it is unlikely that a more sophisticated treatment of winds and variance in load factors around the mean would materially alter the above findings.

As shown in Figure 26 below, the impact of MTOW limitations for the G450X are very small. In part this is due to the fact that most flights with this aircraft are at distances well below maximum range and the MTOW constraints affect a very small number of flights. The percentage changes in cost for the G450X range from about 1.2% for the 98% MTOW restriction to 2.4% for the 90%

MTOW restriction. These do not differ between the Low TOW and High TOW cases.

Figure 26: Change in G450X Costs at Different MTOW Restrictions



Appendix A: Results for 90 Percent MTOW Case

Figure A-1: Change in A320 Fuel and Payload per Operation: 90% MTOW Restriction (Low TOW)

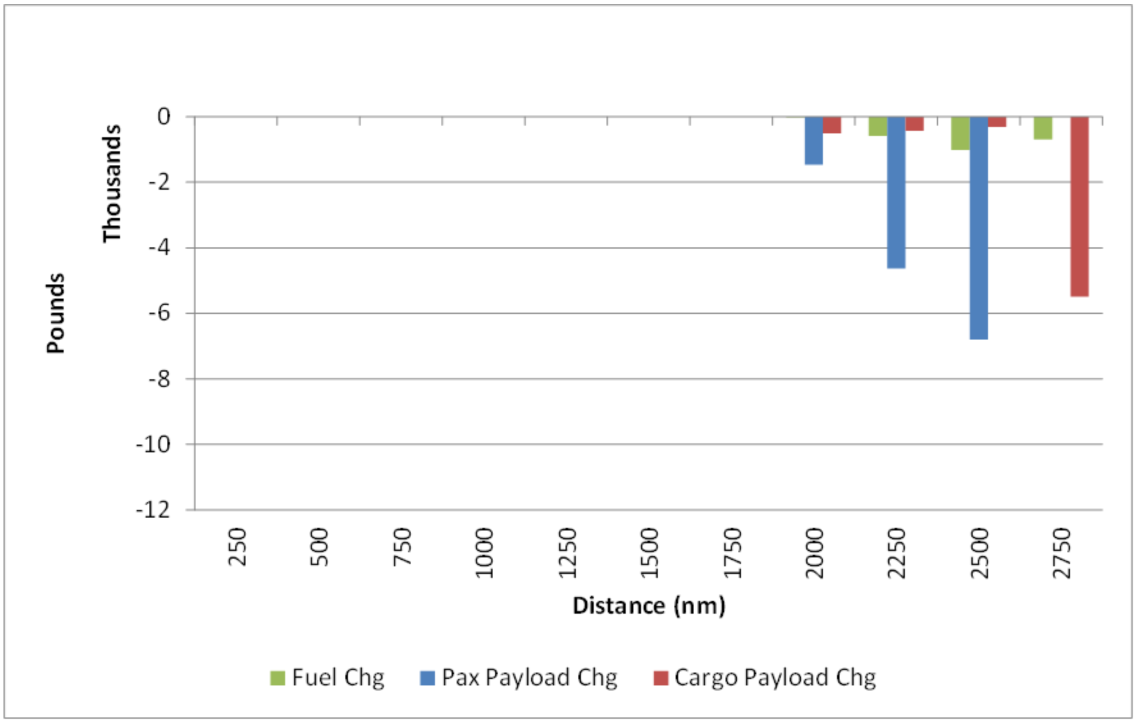


Figure A-2: Change in A320 Revenues and Fuel Costs per Operation: 90% MTOW Restriction (Low TOW)

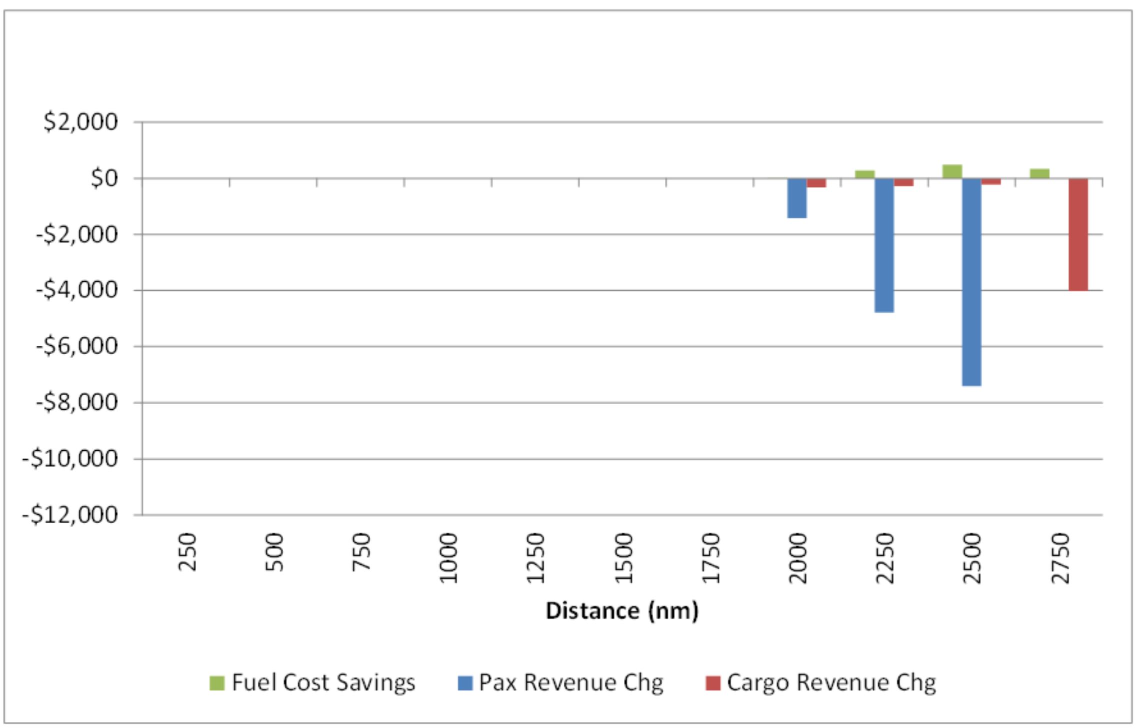


Figure A-3: A320 Results Per Aircraft: 90% MTOW (Low TOW)

Affected Annual Operations per Aircraft	174
Average Change in Passengers per Affected Operation	14.4
Change in Annual Cargo Revenue per Aircraft	($52,614)
Change in Annual Passenger Revenue per Aircraft	($649,722)
Savings in Annual Fuel per Aircraft (tons)	35.7
Savings in Annual Fuel Expense per Aircraft	$34,246
NPV of Change in Revenue @ 11% for 25 yrs	($6,245,399)
NPV of Change in Revenue @ 7% for 25 yrs	($8,330,640)
NPV of Change in Revenue @ 3% for 25 yrs	($11,982,561)
Change in Annual Revenue as % Baseline	-2.5%

Figure A-4: Change in A320 Fuel and Payload per Operation: 90% MTOW Restriction (High TOW)

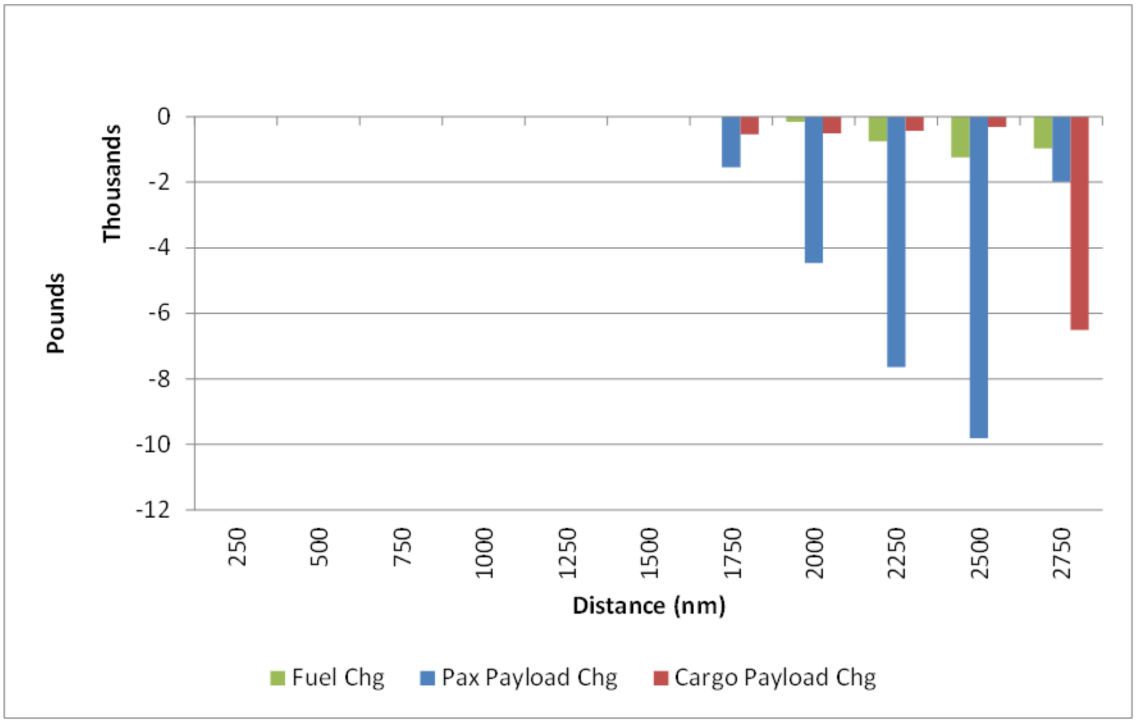


Figure A-5: Change in A320 Revenues and Fuel Costs per Operation: 90% MTOW Restriction (High TOW)

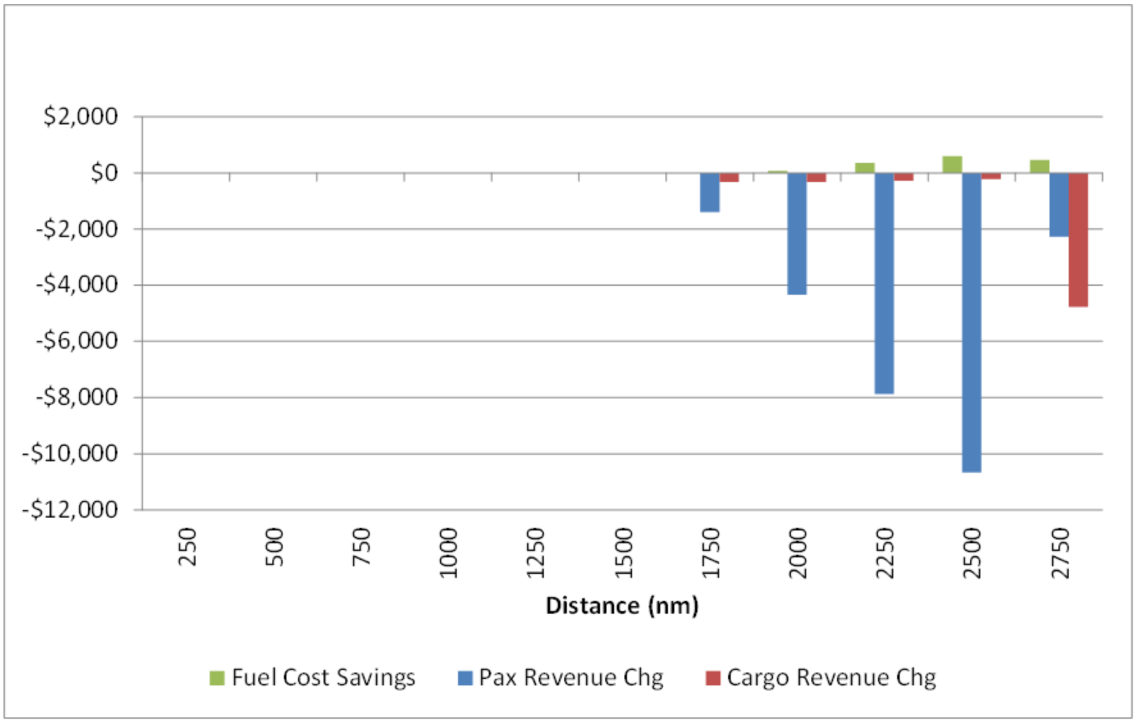


Figure A-6: A320 Results Per Aircraft: 90% MTOW (High TOW)

Affected Annual Operations per Aircraft	246
Average Change in Passengers per Affected Operation	20.6
Change in Annual Cargo Revenue per Aircraft	($76,604)
Change in Annual Passenger Revenue per Aircraft	($1,279,823)
Savings in Annual Fuel per Aircraft (tons)	49.9
Savings in Annual Fuel Expense per Aircraft	$47,906
NPV of Change in Revenue @ 11% for 25 yrs	($12,232,235)
NPV of Change in Revenue @ 7% for 25 yrs	($16,316,389)
NPV of Change in Revenue @ 3% for 25 yrs	($23,469,038)
Change in Annual Revenue as % Baseline	-4.9%

Figure A-7: Change in B77W Fuel and Payload per Operation: 90% MTOW Restriction (Low TOW)

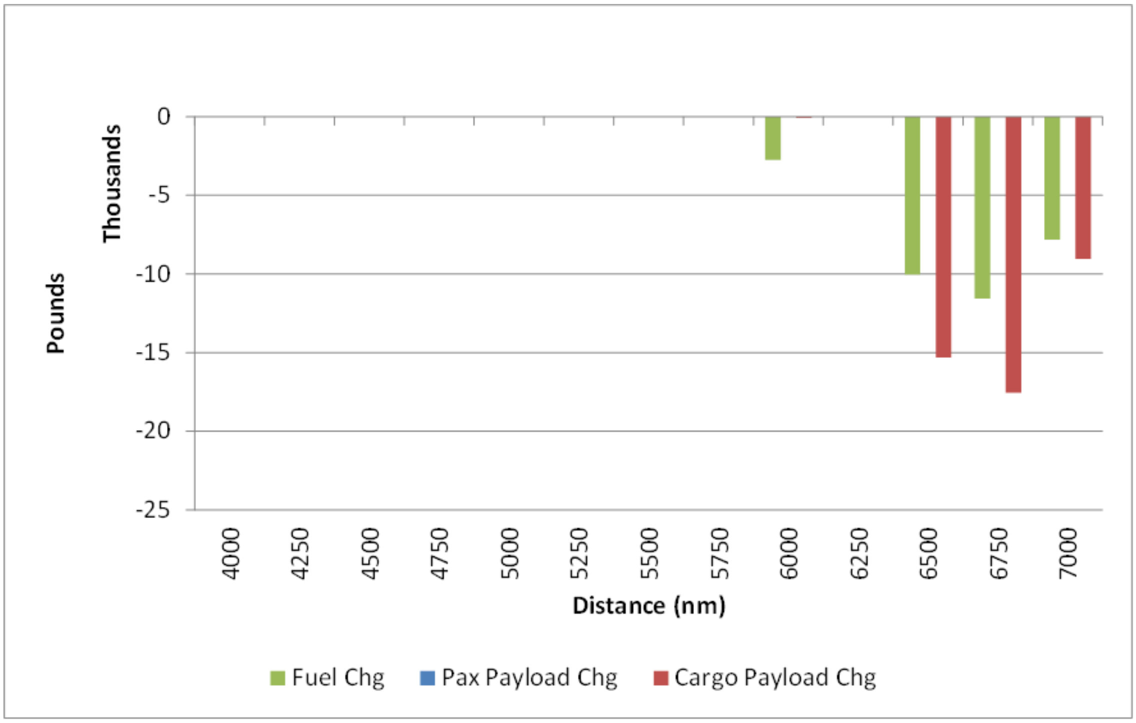


Figure A-8: Change in B77W Revenues and Fuel Costs per Operation: 90% MTOW Restriction (Low TOW)

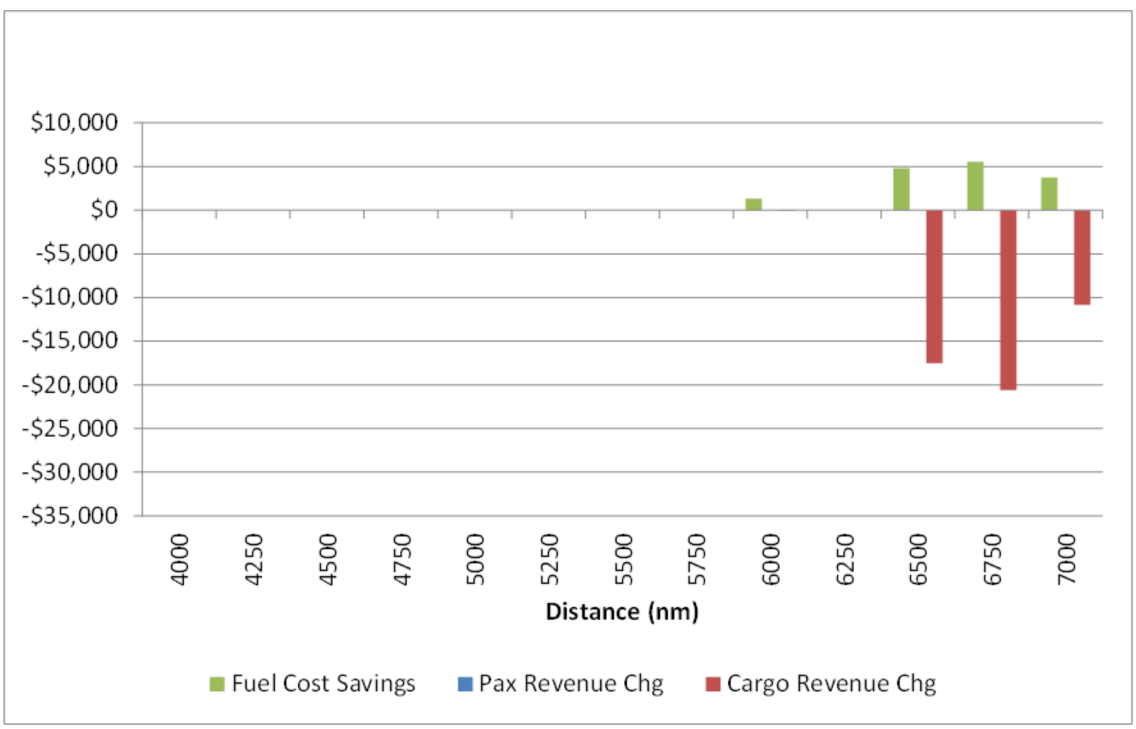


Figure A-9: B77W Results Per Aircraft: 90% MTOW (Low TOW)

Affected Annual Operations per Aircraft	89
Average Change in Passengers per Affected Operation	0.0
Change in Annual Cargo Revenue per Aircraft	($800,359)
Change in Annual Passenger Revenue per Aircraft	$0
Savings in Annual Fuel per Aircraft (tons)	296.9
Savings in Annual Fuel Expense per Aircraft	$285,002
NPV of Change in Revenue @ 11% for 25 yrs	($4,817,631)
NPV of Change in Revenue @ 7% for 25 yrs	($6,426,163)
NPV of Change in Revenue @ 3% for 25 yrs	($9,243,213)
Change in Annual Revenue as % Baseline	-0.6%

Figure A-10: Change in B77W Fuel and Payload per Operation: 90% MTOW Restriction (High TOW)

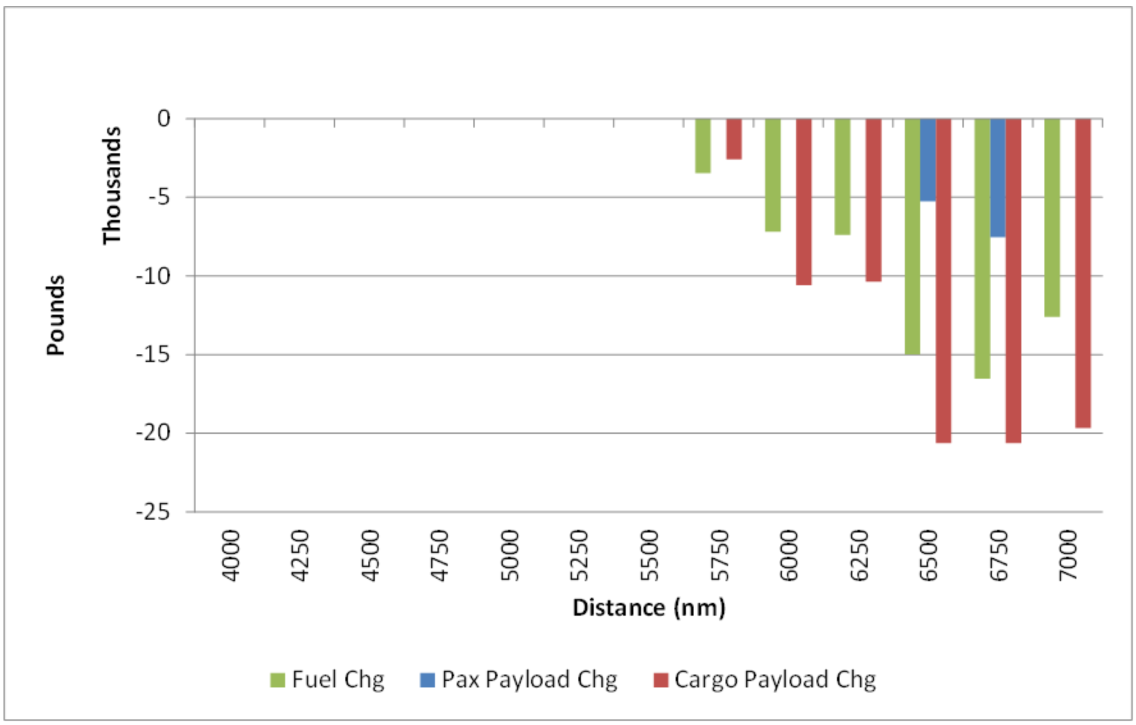


Figure A-11: Change in B77W Revenues and Fuel Costs per Operation: 90% MTOW Restriction (High TOW)

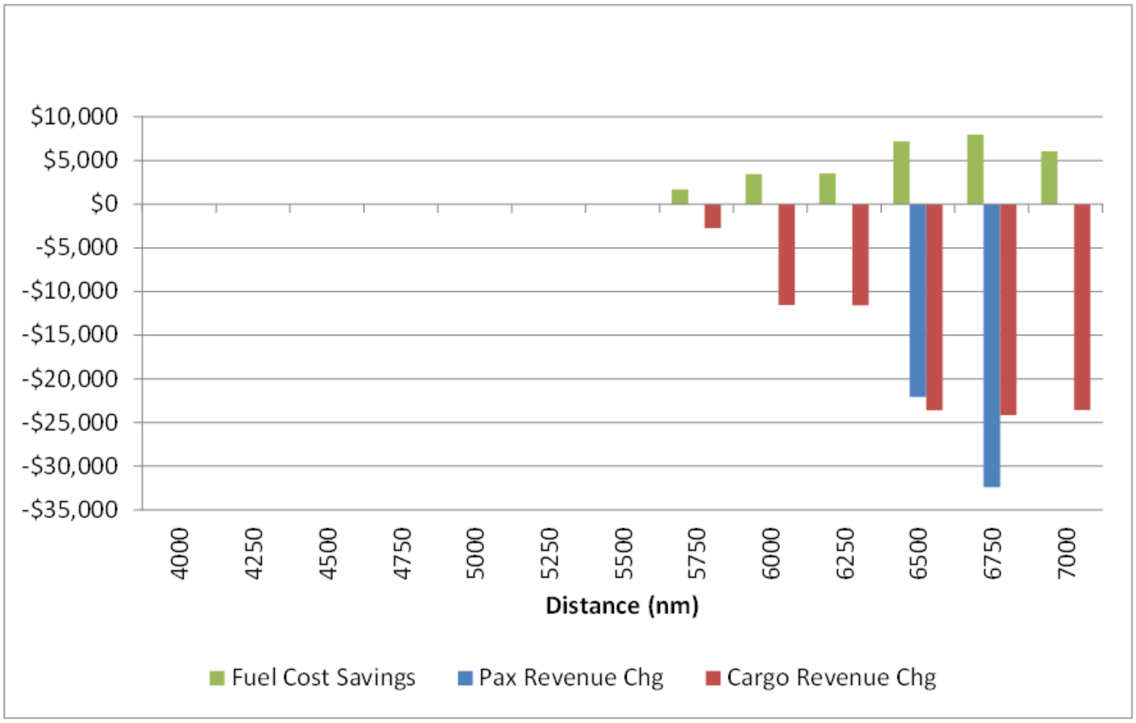


Figure A-12: B77W Results Per Aircraft: 90% MTOW (High TOW)

Affected Annual Operations per Aircraft	242
Average Change in Passengers per Affected Operation	2.6
Change in Annual Cargo Revenue per Aircraft	($2,425,340)
Change in Annual Passenger Revenue per Aircraft	($669,910)
Savings in Annual Fuel per Aircraft (tons)	839.4
Savings in Annual Fuel Expense per Aircraft	$805,780
NPV of Change in Revenue @ 11% for 25 yrs	($21,402,282)
NPV of Change in Revenue @ 7% for 25 yrs	($28,548,172)
NPV of Change in Revenue @ 3% for 25 yrs	($41,062,894)
Change in Annual Revenue as % Baseline	-2.5%

Figure A-13: Change in E190 Fuel and Payload per Operation: 90% MTOW Restriction (Low TOW)

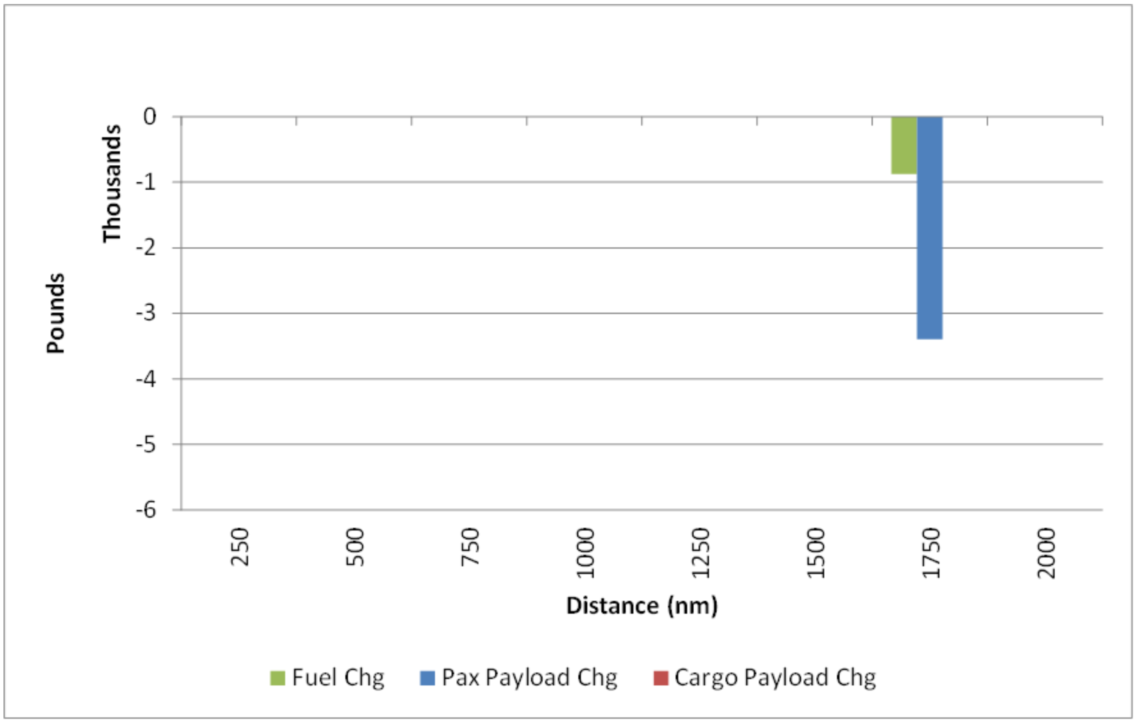


Figure A-14: Change in E190 Revenues and Fuel Costs per Operation: 90% MTOW Restriction (Low TOW)

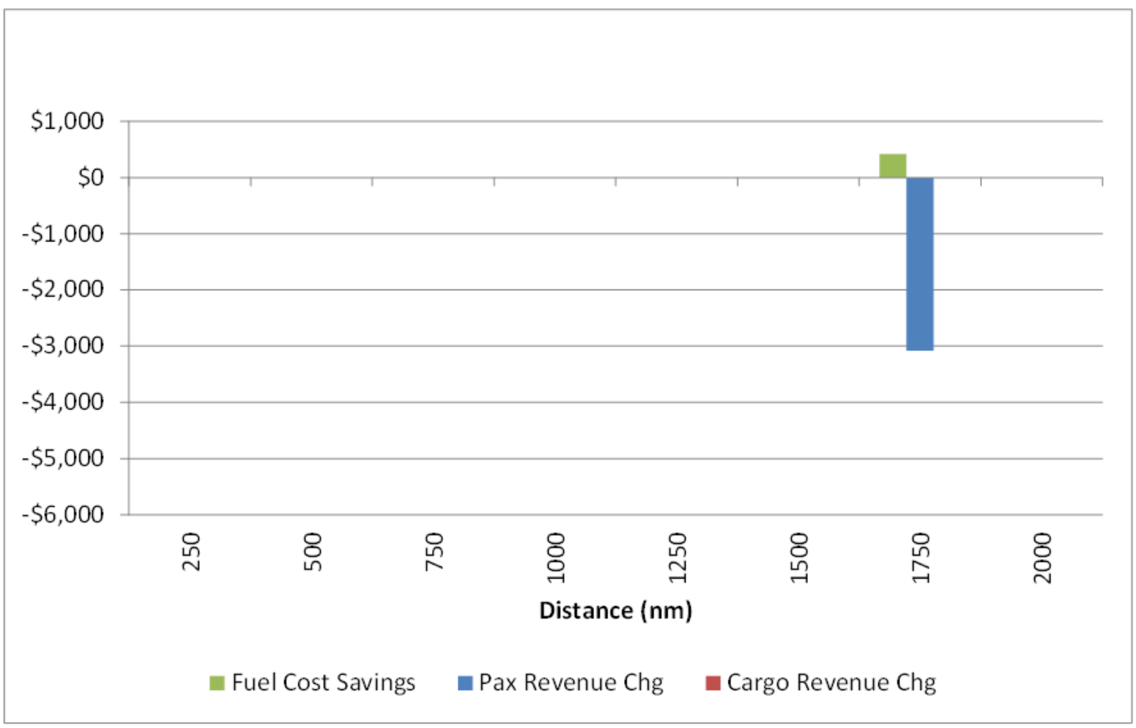


Figure A-15: E190 Results Per Aircraft: 90% MTOW (Low TOW)

Affected Annual Operations per Aircraft	2
Average Change in Passengers per Affected Operation	13.6
Change in Annual Cargo Revenue per Aircraft	$0
Change in Annual Passenger Revenue per Aircraft	($4,652)
Savings in Annual Fuel per Aircraft (tons)	0.7
Savings in Annual Fuel Expense per Aircraft	$632
NPV of Change in Revenue @ 11% for 25 yrs	($37,577)
NPV of Change in Revenue @ 7% for 25 yrs	($50,123)
NPV of Change in Revenue @ 3% for 25 yrs	($72,095)
Change in Annual Revenue as % Baseline	-0.03%

Figure A-16: Change in E190 Fuel and Payload per Operation: 90% MTOW Restriction (High TOW)

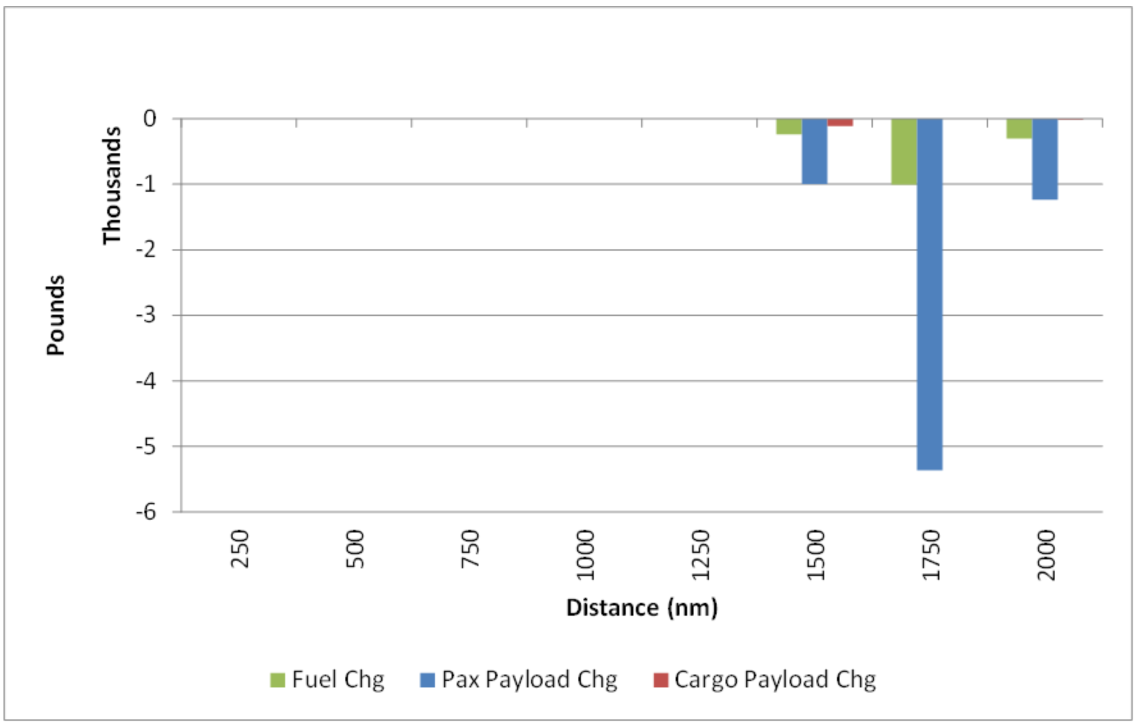


Figure A-17: Change in E190 Revenues and Fuel Costs per Operation: 90% MTOW Restriction (High TOW)

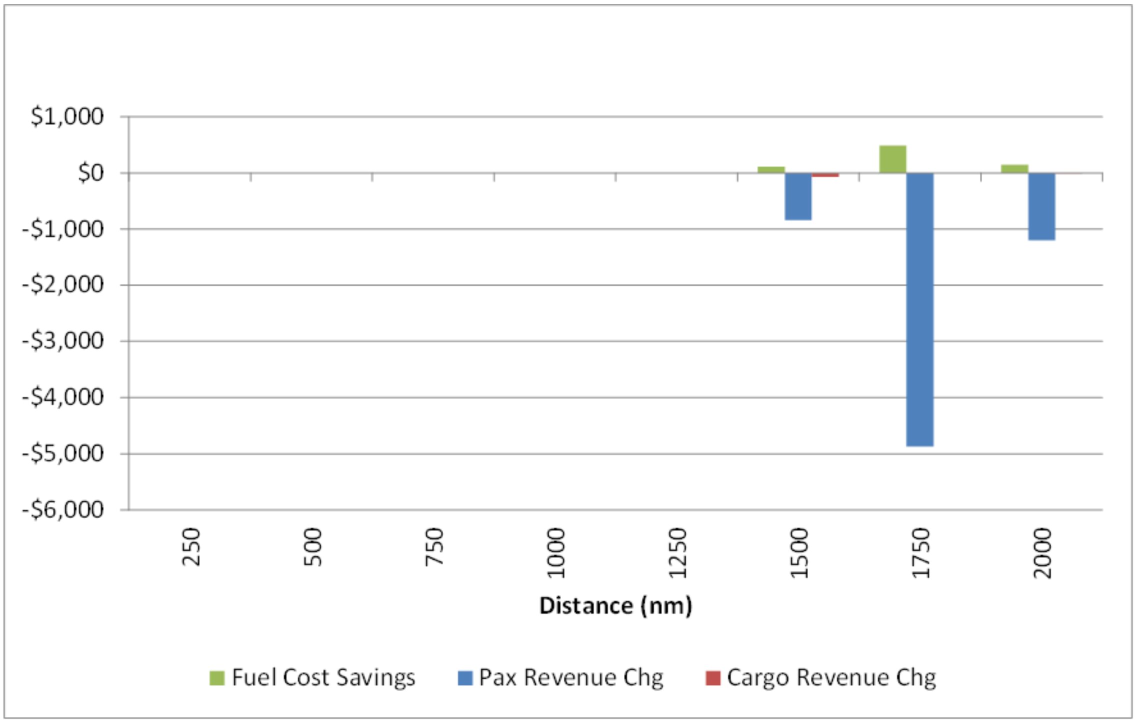


Figure A-18: E190 Results Per Aircraft: 90% MTOW (High TOW)

Affected Annual Operations per Aircraft	55
Average Change in Passengers per Affected Operation	4.8
Change in Annual Cargo Revenue per Aircraft	($2,564)
Change in Annual Passenger Revenue per Aircraft	($58,110)
Savings in Annual Fuel per Aircraft (tons)	7.7
Savings in Annual Fuel Expense per Aircraft	$7,357
NPV of Change in Revenue @ 11% for 25 yrs	($498,419)
NPV of Change in Revenue @ 7% for 25 yrs	($664,833)
NPV of Change in Revenue @ 3% for 25 yrs	($956,277)
Change in Annual Revenue as % Baseline	-0.4%