

# Aircraft Payload-Range Analysis for Financiers



By: Shannon Ackert

## Abstract

The role of aircraft performance analysis is to examine the capabilities and limitations of an aircraft in context to an operator's requirements. A carrier, for example, might be looking at aircraft optimized for particular routes in their network, or it might be more interested in the flexibility to operate an aircraft profitably across multiple routes. One of the most widely means used by airlines to compare the operating economics of an aircraft is by evaluating its payload-range performance, which can be illustrated graphically through the payload-range diagram.

This report provides an introduction to aircraft payload-range performance analysis by examining the details that make up its capabilities; aircraft operational weights are studied, and their cause and effect relationship on payload-range performance are investigated in great length. In particular, payload-range analysis involves examining Maximum Take-off Weights (MTOW) and its various components to assess the aircraft's payload capability at different ranges, as well as range capability with different payloads.

Finally, the report illustrates how multi-range versions of an aircraft type can help the airline better achieve both operational flexibility and cost advantages to particular parts of its network. Ideally, there should be a match between the stage lengths in the airline network and optimum payload-range of the aircraft employed.

# Aircraft Payload-Range Analysis for Financiers

## TABLE OF CONTENTS

<b>1. INTRODUCTION .....</b>	<b>2</b>
<b>2. AIRCRAFT CERTIFIED OPERATING WEIGHTS .....</b>	<b>2</b>
2.1. Manufacturer Certified Weights.....	2
2.2. Operator Certified Weights.....	3
2.3. Aircraft Weight Build-up.....	5
<b>3. AIRCRAFT PAYLOAD-DIAGRAM.....</b>	<b>6</b>
3.1. Payload-Range Tradeoff .....	6
3.2. Payload-Range Diagram Boundaries & Limitations .....	7
3.3. Payload-Range – Example Characteristic Summary.....	9
3.4. Payload-Range - Example Comparison.....	10
3.5. Design Payload-Range Carrying Performance.....	11
3.6. Limitations & Drawbacks of Payload-Range Diagrams.....	13
<b>4. HOW DESIGN CHANGE AFFECT THE PAYLOAD-RANGE DIAGRAM .....</b>	<b>14</b>
4.1. Changing the MZFW limit .....	14
4.2. Changing the OEZW limit .....	15
4.3. Changing the MTOW limit .....	16
4.4. Changing the MFC limit .....	17
4.5. Use of Wingtip Devices.....	18
<b>REFERENCES .....</b>	<b>19</b>

# Aircraft Payload-Range Analysis for Financiers

## 1. INTRODUCTION

The choice of an aircraft is predicated upon the requirements of its mission and specific operating economics. Each aircraft type has unique capabilities and limitations that dictate its optimum deployment within a carrier's network. One method employed by airlines to assess aircraft selection involves the evaluation of its payload and range performance. Ideally, there should be a match between the stage lengths in an airline's network and the optimum payload-range of the aircraft employed. This report discusses the components that affect aircraft payload-range performance, which includes analysis of the airplane operating weights and fundamentals of interpreting its associated payload-range diagram.

## 2. AIRCRAFT OPERATING WEIGHTS

Aircraft weights can be categorized by how they are certified. There are two authorities that are responsible for certifying weight limits; those weights that are certified by the **manufacturer** during the design and certification of an aircraft, and those weights certified by the **operator**. As we'll explain later, weights certified by the operator are often dependent on the specification/configuration of the aircraft and factored into the calculation of certain manufactured certified weights.

### 2.1 Manufacturer Certified Weights

Manufactured certified operating weights are developed during the aircraft design and certification phase and are laid down in the aircraft type certificate and manufacturer's specification documents such as the Aircraft Flight Manual (AFM) and Aircraft Weight & Balance Manual (AWBM). Manufacturer certified operating weights can be broken down into the following weight categories:

- **Maximum Taxi Weight (MTW)** means the maximum weight for ground maneuver as limited and/or authorized by airplane strength and airworthiness requirements. (This includes the weight of fuel for taxiing to the takeoff position.).
- **Maximum Takeoff Weight (MTOW)** (also referred to as Brake Release Gross Weight) means the maximum weight for takeoff as limited and/or authorized by airplane strength and airworthiness requirements. This is the maximum weight at the start of the takeoff.
- **Maximum Landing Weights (MLW)** means the maximum weight for landing as limited and/or authorized by airplane strength and airworthiness requirements
- **Maximum Zero-fuel Weight (MZFW)** means the maximum weight permitted before usable fuel and other specified usable fluids are loaded. The MZFW is limited and/or authorized by strength and airworthiness requirements.

# Aircraft Payload-Range Analysis for Financiers

Manufacturer certified weights are often distinguished by limitations based on: a.) The aircraft's structural design and, b.) The authorized weight limits that can be legally used by an operator.

**a) Maximum structural design weights** are absolute maximum weights limited by airplane strength and airworthiness requirements. They are developed in order to avoid overloading the structure or to avoid unacceptable performance or handling qualities during operation. These weights consist of Maximum Design Taxi Weight (MDTW), Maximum Design Takeoff Weight (MDTOW), Maximum Design Landing Weights (MDLW), and Maximum Design Zero-fuel Weight (MDZFW).

**b) Maximum authorized weights** are authorized weight limits that can legally be used by an operator or airline and referenced in both the Aircraft Flight Manual (AFM) and Aircraft Weight & Balance Manual (AWBM), and quite often are documented in the Certificate of Airworthiness (C of A) from the national aviation authority of the country of registration. **Authorized weights may be equal to or lower than the structural design weight limits.**

When certified weights are below the design thresholds, the lower values are referred to more simply as Maximum Taxi Weight (MTW), Maximum Takeoff Weight (MTOW), Maximum Landing Weights (MLW), and Maximum Zero-fuel Weight (MZFW).

The authorized weight limits are chosen by the airline and often referred as the "**purchased weights**". An operator may purchase a certified weight below the maximum design weights as means to reduce those fees (i.e. airport landing and navigation fees) that are indexed to certain maximum weights (e.g. MTOW, MLW, etc.). Figure 1 illustrates the authorized maximum certified weights for the 737-800.

FIGURE 1- EXAMPLE AUTHORIZED CERTIFIED DESIGN WEIGHTS

Boeing 737-800: Authorized Design Weights		
Manufacturer Certified Weight	Baseline Operational Maximum	Structural Design Maximum
Maximum Taxi Weight	156,200 Pounds	174,900 Pounds
Maximum Takeoff Weight	155,500 Pounds	174,200 Pounds
Maximum Landing Weight	144,000 Pounds	146,300 Pounds
Maximum Zero Fuel Weight	136,000 Pounds	138,300 Pounds

Source: Boeing

## 2.2 Operator Certified Weights

While some weight parameters are certified at the manufacturer stage, others are operator-established and vary by the specification/configuration of the aircraft. Operator weights are made up of: a.) **Operating Empty Weight (OEW)** and, b.) **Maximum Structural Payload (MSP)**.

## Aircraft Payload-Range Analysis for Financiers

- a) **Operator's Empty Weight (OEW)** means the weight of the aircraft prepared for service and is basically the sum of the Manufacturer's Empty Weight (MEW), Standard Items (SI), and Operator Items (OI) :
- **Manufacturer's Empty Weight (MEW)** - is the aircraft weight as it leaves the manufacturing facility and generally consists of the weight of the structure, power plant, furnishings, systems and other items of equipment that are an integral part of a particular aircraft configuration. MEW also includes only those fluids contained in closed systems.
  - **Standard Items** - Equipment and fluids not considered an integral part of a particular aircraft. These items may include the following: a.) Unusable fuel & other unusable fluids, b.) Engine oil, c.) Toilet fluids & chemicals, d.) Fire extinguishers, pyrotechnics & emergency oxygen equipment, e.) Galley structures, e.) Supplementary electronic equipment.
  - **Operator Items** - Personnel, equipment & supplies necessary for a particular operation. These items may vary for a particular aircraft and may include the following: a.) Crew & Baggage, b.) Aircraft documents, c.) Food & beverages, d.) Passenger seats, e.) Life rafts & life vests
- b) **Maximum Structural Payload (MSP)** means the maximum design payload (made up of passengers & baggage, and cargo) calculated as a structural limit weight. For any aircraft with a defined MZFW, the maximum payload can be calculated as the MZFW minus the OEW.

Both the OEW and MSP weights are generally referenced in the Aircraft Flight Manual (AFM) and Aircraft Weight & Balance Manual (AWBM) since they are required in order to calculate takeoff weight and the aircraft's center of gravity. It's worth noting, however, that weights that are not certified by the manufacturer do not have consistent definitions across manufacturers or operators. Figure 2 below highlights general differences between manufacturer and operator certified weights.

FIGURE 2- MANUFACTURER AND OPERATOR CERTIFIED WEIGHTS

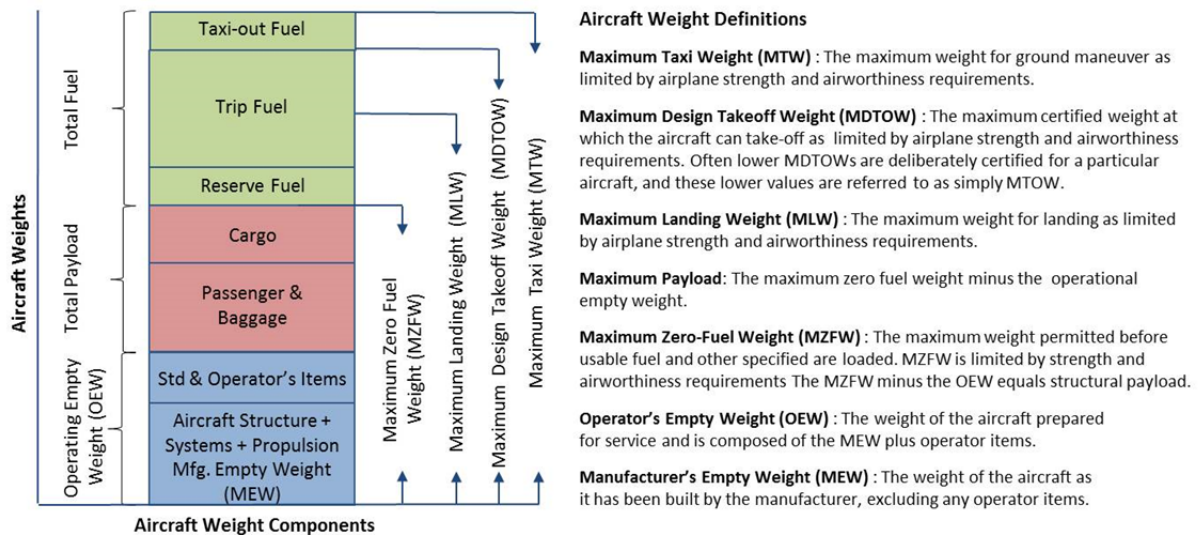
Breakdown of Aircraft Weights & Certification Status		
Operational Weight	Manufacturer Certification	Operator Certification
Maximum Taxi Weight	Certified	Not Applicable
Maximum Takeoff Weight	Certified	Not Applicable
Maximum Landing Weight	Certified	Not Applicable
Maximum Zero Fuel Weight	Certified	Not Applicable
Operating Empty Weight	Not Certified	Certified (in AFM & WBM)
Maximum Payload	Not Applicable	Certified (in AFM & WBM)

# Aircraft Payload-Range Analysis for Financiers

## 2.2 Operator Weight Build-Up

Figure 3 below illustrates the composition of weight categories that are reflected in most commercial aircraft. Starting from the Manufacturer's Empty Weight (MEW) and adding elements to make the aircraft operational. From the chart below we can gain a mathematical perspective on how to calculate a number of weight categories, which are summarized below:

**FIGURE 3- AIRCRAFT WEIGHT BUILD-UP**



- The Operating Empty Weight (OEW) is the sum of the Manufacturer's Empty Weight (MEW), Standard Items (SI), and Operator Items (OI) : **OEW = MEW + SI + OI**
- For any aircraft with a defined MZFW, the maximum payload can be calculated as the MZFW minus the OEW (operational empty weight) : **Max Payload = MZFW – OEW**
- For any aircraft with a defined MTOW, the maximum MTOW can be calculated as the MZFW plus the Reserve & Trip Fuel Capacity : **MTOW = MZFW + Reserve Fuel + Trip Fuel**
- For any aircraft with a defined MTW, the maximum MTW can be calculated as the MTOW plus the Taxi-out Fuel : **MTW = MTOW + Taxi-out Fuel**

### Aircraft Weight Perspective

Greater distances require more fuel, and more fuel is burned in order to carry the extra fuel to achieve the range. This can be illustrated by examining the components of an aircraft's landing weight:

$$W_{ldg} = \underbrace{(OEW + Payload)}_{\text{Zero Fuel Weight}} + \underbrace{(Reserve Fuel + Fuel Added but Not Used)}_{\text{Fuel on Board at Landing}}$$



# Aircraft Payload-Range Analysis for Financiers

## 3. AIRCRAFT PAYLOAD-RANGE DIAGRAM

We will now examine how the weight of the aircraft is built-up with reference to its payload-range diagram. The payload-range diagram is useful for operators in: a.) comparing payload range capabilities of various aircraft types, and b.) determining how much payload can be flown over what distances according to a set of operational limitations.

The specific shape of the aircraft's payload-range diagram is affected by its aerodynamic design, structural efficiency, engine technology, fuel capacity, and passenger/cargo capacity. Each aircraft has its own corresponding payload-range diagram, with different limitations depending on the engine type installed.

### 3.1 Payload-Range Trade-off

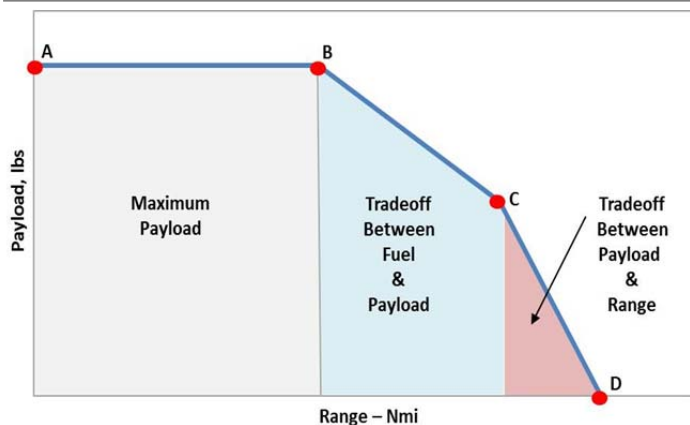
Figure 4 illustrates a typical payload-range diagram. For all aircraft, there is a natural trade-off between its payload and range performance.

The typical shape of the curve is such that the aircraft is able to carry a maximum payload over a specified range – as illustrated in the grey area along points “A” to “B”.

Longer ranges can be flown if an operator is willing to reduce its payload in exchange for fuel – as illustrated in the blue area along points “B” to “C”.

The trade-off continues until point “C”, which is the maximum operational range with full fuel tanks. Along points “C” and “D” fuel is maxed out therefore the trade-off is one of compromising payload in order to achieve greater range.

FIGURE 4- PAYLOAD-RANGE TRADE-OFFS



### Aircraft Payload-Range Tradeoff Perspective

In 2011, Lufthansa German Airlines embarked on a project to reduce the airline's fuel cost through a variety of technical measure, key among them was weight reduction. According to the Lufthansa, by reducing fuel by one kilo on all aircraft saves the airline 30 tons of fuel per year.

One area where the airline was able to compromise on weight was through the removal of auxiliary fuel tanks from their A340-300 aircraft, which saved 230 kilos (506 lbs). The airline concluded the maximum fuel capacity of the aircraft was not required under the route distances flown by Lufthansa. By removing the fuel tanks, the MZFW was increased allowing the aircraft to fly higher payloads at the expense of greater range.

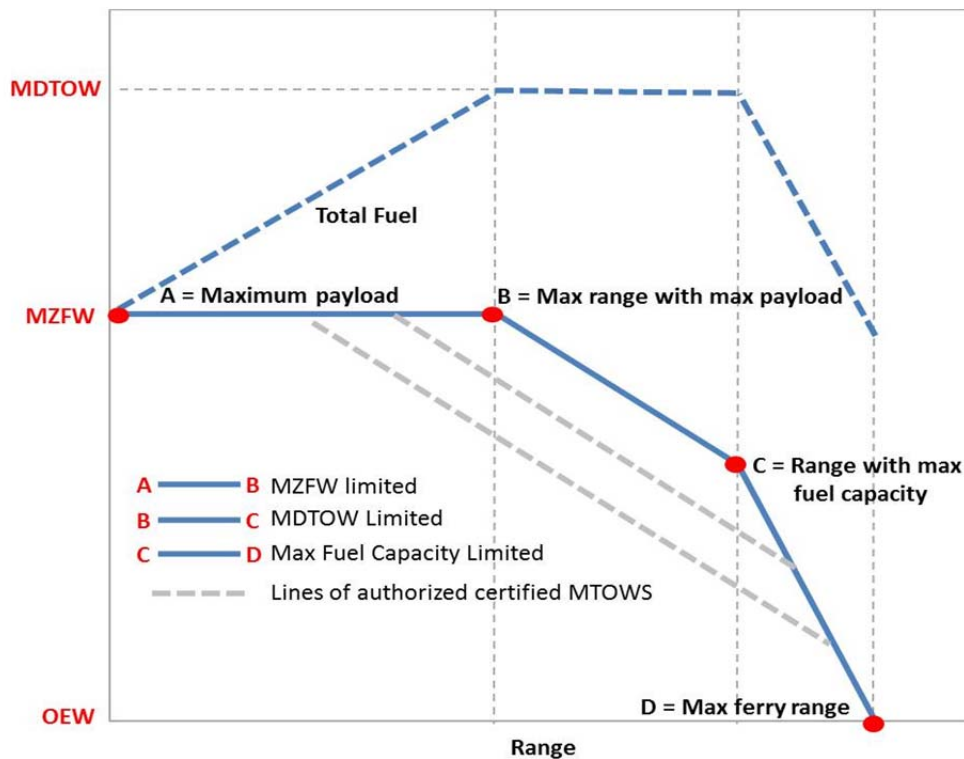


# Aircraft Payload-Range Analysis for Financiers

## 3.2 Payload-Range Diagram Boundaries & Limitations

Figure 5 illustrates a typical payload-range diagram expanded to highlight the various weight categories of an aircraft. While the **specific shape** of the diagram is affected by an aircraft's aerodynamic design, engine technology, fuel capacity and typical passenger/cargo configuration, the **boundary** of the diagram is limited by the structural design characteristics of the aircraft.

FIGURE 5- PAYLOAD-RANGE DIAGRAM



Key design characteristics inherent in payload-range diagrams are as follows:

- At **Point A** the aircraft is at maximum payload with no fuel on-board. When the aircraft is carrying maximum payload its capacity is limited by its MZFW. If the manufacturer can increase this design weight then more payload can be carried. Alternatively, given the MZFW is a fixed value, whereas the OEW varies according with the airline's operating items, if the airline can lower the OEW then the aircraft is capable of carrying more payload.
- Along **Points A to B – maximum payload range**; fuel is added so that a certain range can be flown. Maximum payload is achieved at the expense of range and the decision to operate at design limitations is purely a financial one. The topside of the envelope is limited by the Maximum Zero Fuel Weight (MZFW).

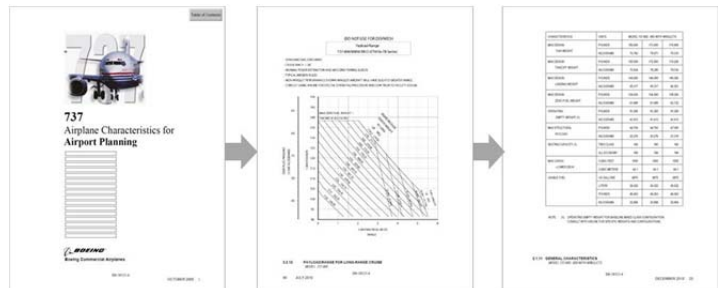


# Aircraft Payload-Range Analysis for Financiers

- **Point B** represents the maximum range the aircraft can fly with maximum payload. It is a characteristic feature of aircraft design that when an aircraft is at maximum payload, the fuel tanks are not full, which explains why in order to increase the range beyond this point we need to increase fuel at the expense of payload.
- Along **Points B to C – payload limited by MTOW**; payload is traded for fuel to attain greater range. The higher the MTOW, the more fuel or payload can be carried. The more fuel carried, the greater the range. This tends to be the region of greatest interest in terms of performance. The first angled part of the envelope is limited by the Maximum Design Takeoff Weight (MDTOW)
- At **Point C** the maximum fuel volume capacity has been reached and this is where the aircraft is most structurally efficient in terms of fuel carriage, and represents the maximum range with full fuel tanks where a reasonable payload can be carried. However, this can be misleading as the reduced payload at this point may in fact not be economical at all.
- Along **Points C to D – payload limited by fuel**; only payload can be offloaded to make the aircraft lighter, thereby improving its range capability. Generally speaking it is not commercially sound to operate in this region because it requires large reductions in payload to achieve small increases in range. The second angled part of the envelope is limited by the aircraft's Maximum Fuel Capacity (MFC).
- Finally, at **Point D** the aircraft is theoretically at the Operator's Empty Weight (OEW), and range flown at this point is considered the maximum ferry-range. This condition is typically used when the aircraft is delivered to its customer (i.e., the airline) or when a non-critical malfunction precludes the carrying of passengers.
- The region inside of the boundary represents feasible combinations of payload and range missions. A contour line inside of the boundary and parallel with the MDTOW boundary represents lines of alternative, authorized MTOWs. The authorized weight limits are chosen by the airline and often referred to as the purchased weights.

## Aircraft Payload-Range Source

The primary source for aircraft payload-range diagrams is the Airplane Characteristics for Airport Planning document, which is published by each aircraft manufacturer. These documents provide, in an industry-standardized format, airplane characteristics data for general airport planning. Sections within each document include: airplane description, airplane performance (including payload-range performance), ground maneuvering, terminal servicing, operating conditions, and pavement data.

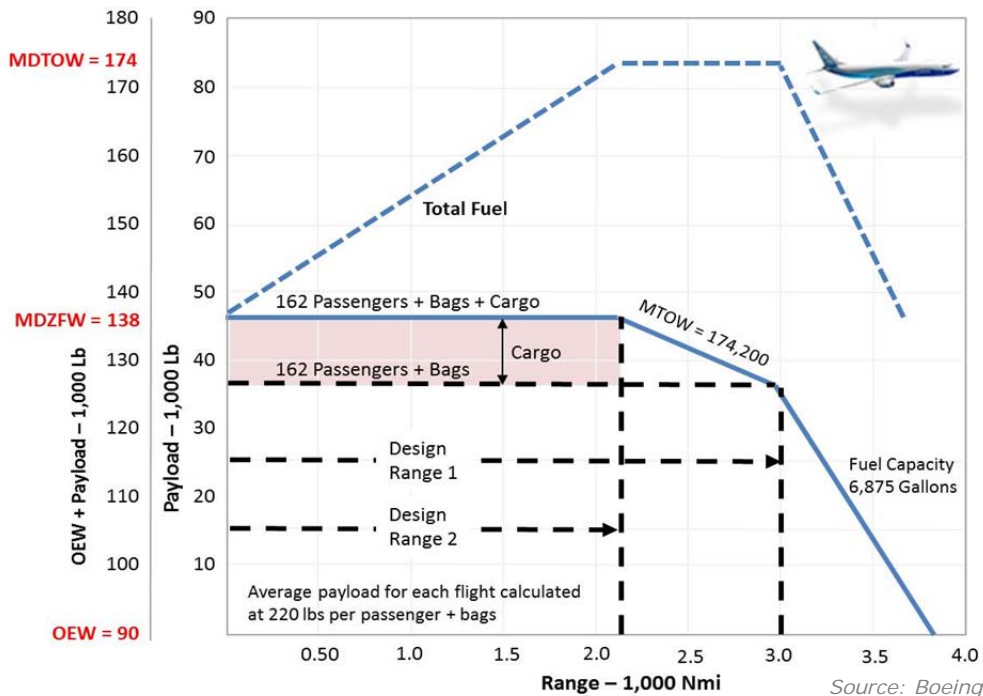


# Aircraft Payload-Range Analysis for Financiers

## 3.3 Payload-Range – Example Characteristic Summary

The following example summarizes the payload-range design characteristics for the 737-800 certified to operate at the aircraft's maximum design weights – Figure 6.

FIGURE 6- 737-800 PAYLOAD-RANGE DIAGRAM



### Aircraft Maximum Design Weights (Lb)

Maximum Taxi Weight	174,700
Maximum Takeoff Weight	174,200
Maximum Landing Weight	146,300
Maximum Zero Fuel Weight	138,300
Operator Empty Weight	90,000

### Design Capacities

Interior Layout – Dual Class	162
Below Floor Volume (Cu Ft)	1,555
Fuel (US Gallons)	6,875
Fuel (Lb @ 6.5 Lb / Gal)	44,688

### Payloads (Lb)

Maximum Design Payload = (Maximum Zero Fuel Weight - Operator Empty Weight)	48,300
100% Passenger Payload (220-Lb per Pax)	35,640
Cargo at Weight Limit Payload with Full Pax = (Maximum Design Payload – 100% Pax Payload)	12,660

### Design Range (Nm)

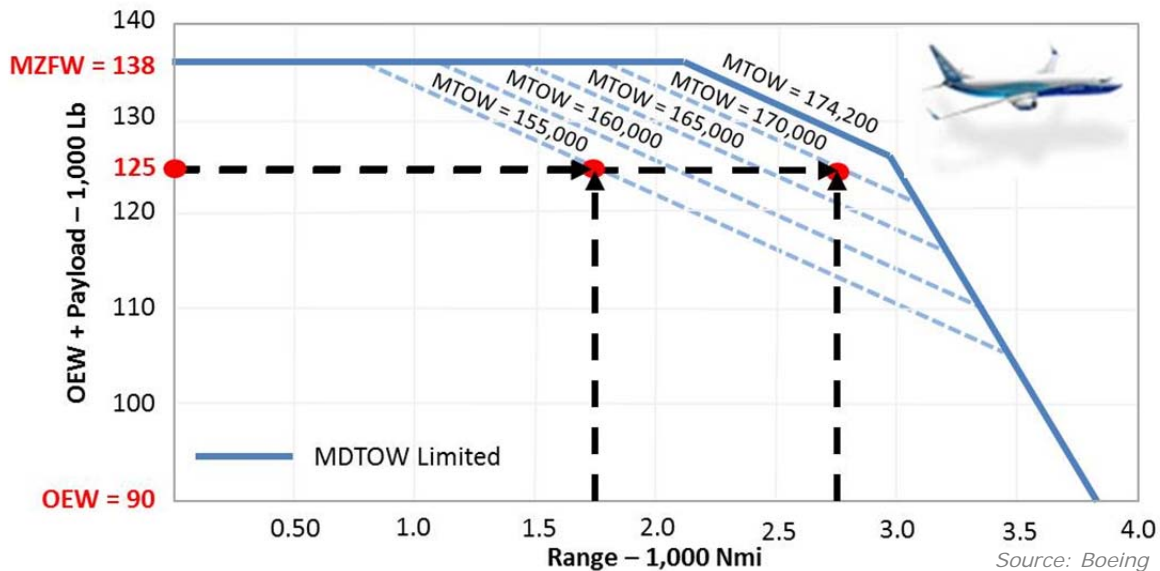
Design Range 1 – Payload Limited by MTOW (100% Max Passenger Payload)	3,065
Design Range 2 - Maximum Payload Range (100% Max Passenger Payload + Max Cargo)	2,150

# Aircraft Payload-Range Analysis for Financiers

## 3.4 Payload-Range - Example Comparison

Figure 7 provides the payload-diagram characteristics for the 737-800. Thus, if you want to fly ~35,000 lbs of payload 1,750nm, then on the left vertical axis you would go to 125,000 lbs (35,000 lbs payload + 90,000 lbs OEW) and then track to the right horizontally until intercepting the range of 1,750nm on the horizontal axis. At this point of intercept, you would also be intersecting the diagonal line for the MTOW (Brake Release Gross Wt), which in this case would be ~155,000 pounds. If you want to fly the same payload an extra 1,000nm you would need to upgrade the aircraft's MTOW to ~170,000 pounds. This normally requires purchasing the additional MTOW from the manufacturer.

FIGURE 7- 737-800 PAYLOAD-RANGE DIAGRAM WITH ALTERNATIVE MTOW OPTIONS



## Aircraft Payload-Range Perspective

Airline demands for range and payload characteristics better tailored to their specific needs have prompted a shift in how Boeing approaches optimization in aircraft design. Studies centered on market demand for a potential third version of the 787 Dreamliner, known as the 787-10X, have sent Boeing in a direction toward an airplane that offers less range than expected in exchange for still better economics. Boeing has identified an optimal range of just 6,800 nm for the 787-10X, compared to 8,200 nm for the 787-8 and 8,500 nm for the 787-9.

Most widebodies operate in medium-range segments covering the inter-Asia market, domestic China, the Middle East to Europe and over the Atlantic Ocean. As airlines have changed some of their buying behavior in volatile fuel-price environment, they are looking for airplanes that more uniquely fit the routes and the missions in their networks. Greater distances require more fuel, and more fuel is burned in order to carry the extra fuel to achieve the range.



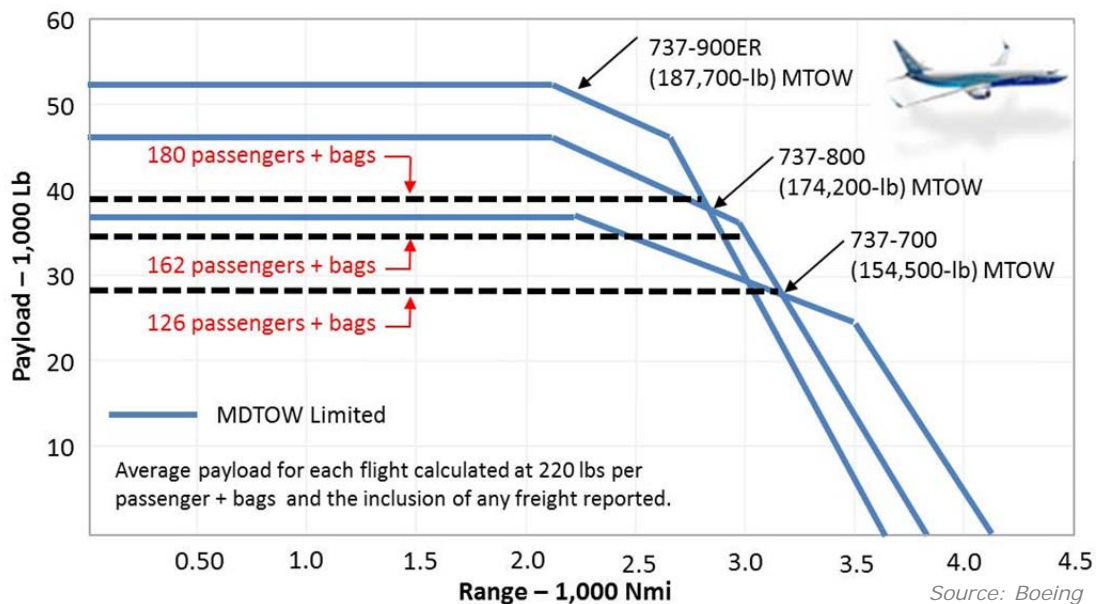
# Aircraft Payload-Range Analysis for Financiers

## 3.5 Design Payload-Range Carrying Performance

As discussed previously, the payload-range diagram is an important resource in determining each aircraft's representative payload-range missions. In this section we'll discuss how to establish an aircraft's optimum design range, which defines the maximum range with a full complement of passengers and baggage. This point is somewhere on the portion of the curve labeled maximum take-off weight, but often at a point considerably lower than that associated with maximum zero fuel weight.

Figure 8 below illustrates the optimal ranges for each of the 737 NG models operating at its Maximum Design Takeoff Weight (MDTOW). In reference to the 737-900ER with an MDTOW of 187,700 lbs, the aircraft is optimized to carry 180 passengers + bags for a design range of approximately 2,800 nautical miles. A 737-800 is optimized to carry 162 passengers + bags for a design range a little over 3,000 nautical miles, while the 737-700 is optimized to carry 126 passengers + bags for a design range of approximately 3,200 nautical miles.

FIGURE 8- 737NG FAMILY PAYLOAD-RANGE DIAGRAM DESIGN RANGES



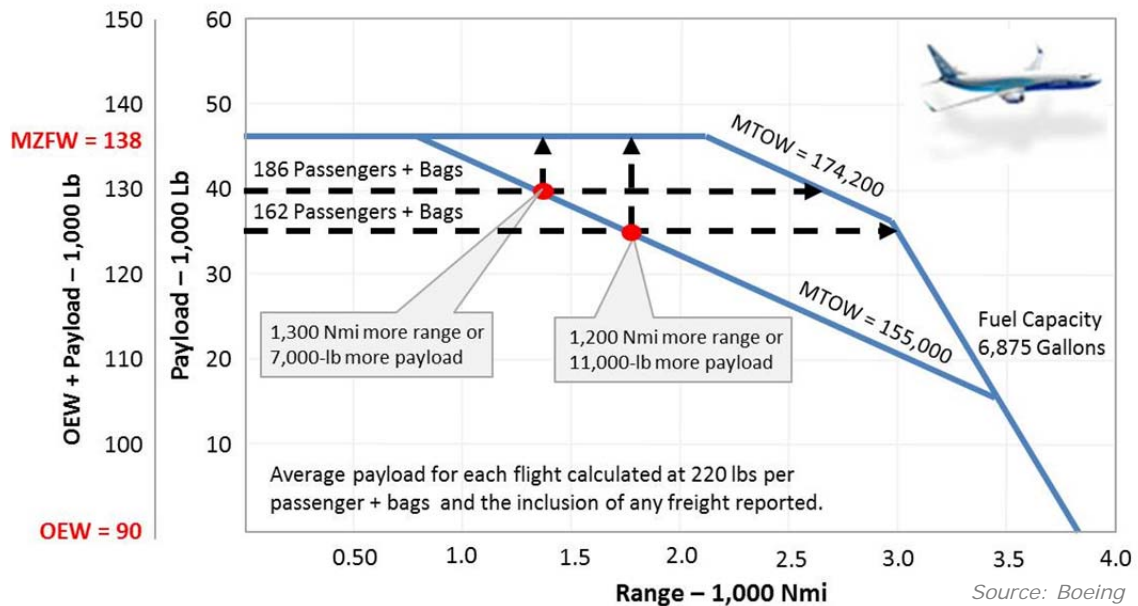
The above example illustrates how the **family concept** can assist airlines to better match an aircraft model (i.e., 737-700, 737-800, etc.) to particular parts of its network. Operational flexibility becomes especially important in fleet planning as future range and payload requirements can be adjusted more easily by selecting smaller and/or larger-sized variants of an aircraft type you already operate.

# Aircraft Payload-Range Analysis for Financiers

In similar practice where aircraft manufacturer's offer operators a family concept to meet operational flexibility, they also allow operators to select among a range of Maximum Takeoff Operating Weights (MTOWs) for a given aircraft model. In general, trading up to higher MTOWs translates into higher payload capacity as well as longer operating range. Thus, MTOW options allow airline's to better match the payload-range capability of an aircraft to its network and thus provide maximum economic benefits.

Figure 9 below compares the payload-range capabilities of the 737-800 models operating at two different authorized MTOWs and two payload scenarios. Relative to the lower spec'd variant (155,000 lb MTOW) a 737-800 spec'd at 174,200 lb MTOW with 162 passengers is capable of flying 1,200 nautical miles further while carry 11,000 lbs more payload. If the same higher MTOW aircraft is equipped to carry 186 passengers, it will be capable of flying approximately 1,300 nautical miles further and carrying an additional 7,000 lbs relative to the lower spec'd aircraft.

**FIGURE 9 – 737-800 PAYLOAD-DIAGRAM WITH MTOW ALTERNATIVES**



## Aircraft MTOW Performance Perspective

Throughout Europe most airports levy a separate landing fee to be paid to the airport operator. The fees cover the use of airport infrastructure and equipment necessary for landing, taking off and taxiing. Fees are primarily based on the aircraft's certified Maximum Takeoff Weight (MTOW).

Therefore, if an operator is serving airports where landing fees are relatively high, then it might pay to throw more emphasis on the weight of the aircraft in the performance evaluation. Some aircraft types have better unit-cost advantages in terms of weight than others.



# Aircraft Payload-Range Analysis for Financiers

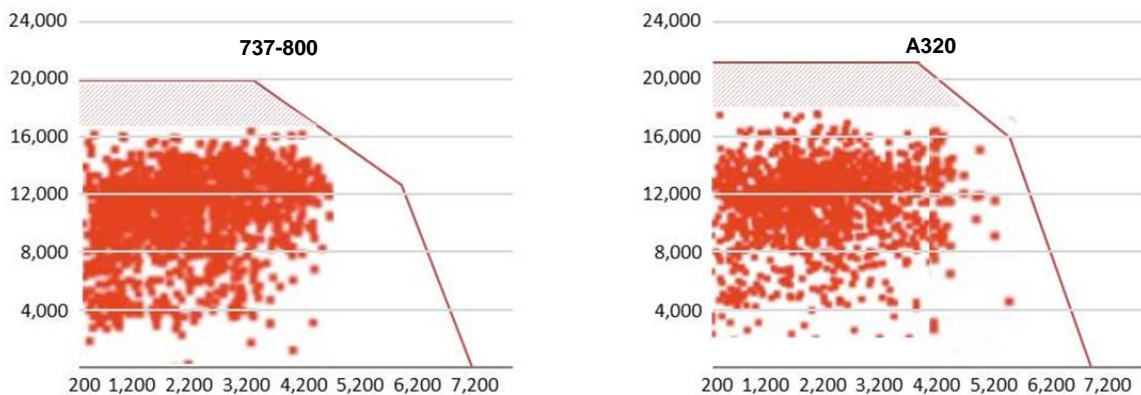
## 3.6 Limitations & Drawbacks of Payload-Range Diagrams

A note of caution about payload range diagrams is that they only apply to a given set of flight conditions; traditionally, they are only applicable to zero wind conditions, standard cruise speed, standard day conditions (e.g., standard atmosphere) and standard domestic fuel reserves. If any of these conditions changes then so does the payload-range diagram.

One general trend worth noting regards the notion that airlines are fully exploiting an aircraft's range and payload productivity potential. Recent studies have suggested that aircraft are rarely used near their maximum performance capabilities (particularly for range, but also payload), As illustrated in Figure 10, which distills A320 and 737-800 flights sourced from the Bureau of Transportation Statistics (BTS); no flights were operated at either limits of maximum payload and range, with essentially a void region for maximum payload operations.

FIGURE 10 – 737-800 AND A320 FLIGHT LISTINGS

Source: *Trends in Aircraft Efficiency and Design Parameters* - Zeinali, M, Ph.D. & Rutherford, D, Ph.D.

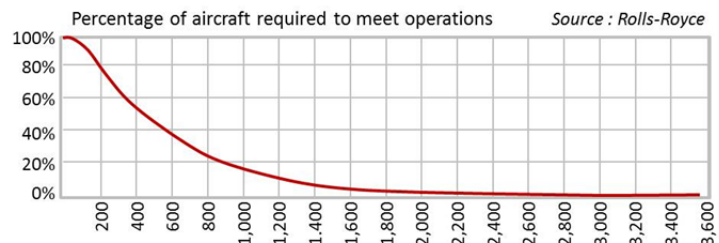


This reinforces the view that aircraft performance (i.e. payload & range performance) has become much less of a concern for airline fleet planners than it was in the past. Thus, airlines are keener to flexibly deploy aircraft on a variety of routes and missions in their networks versus consistently operating them at maximum capability.

### Aircraft Range Performance Perspective

In 2008, Rolls-Royce conducted a survey of the 100-200-seat aircraft to measure how aircraft missions were being operated. Their analysis found that:

- Less than 0.5% have ranges > 2,500 Nm
- Less than 2% have ranges > 2,000 Nm
- Less than 8% have ranges > 1,500 Nm



# Aircraft Payload-Range Analysis for Financiers

## 4. HOW DESIGN CHANGE AFFECT THE PAYLOAD-RANGE DIAGRAM

**4.1 Changing the MZFW limit** – Figure 11 illustrates the effects of increasing the Maximum Zero-Fuel Weight (MZFW). The maximum payload can be calculated as the MZFW minus the OEW (operational empty weight)

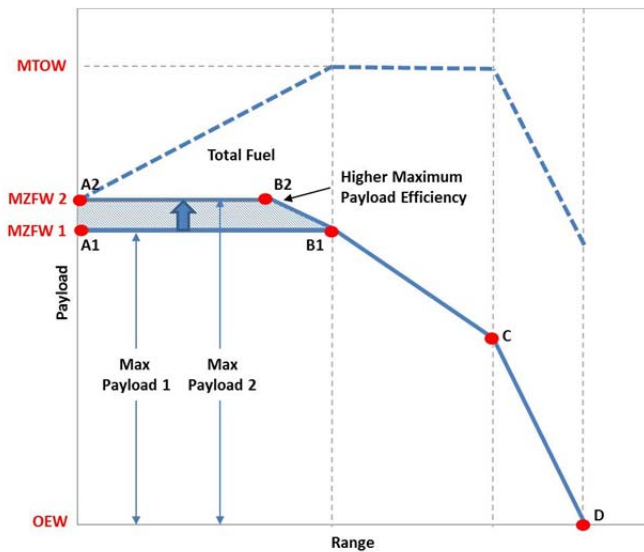
$$\text{Max Payload} = \text{MZFW} - \text{OEW}$$

If the manufacturer can improve this certificated value by demonstrating the structural integrity of the airframe, then more payload can be made available.

Boeing for example, offers customers of the 737NG aircraft the option to select from a range of MZFW alternatives, commencing with a baseline certified limit and capping out at a maximum design certified limit - the 737-800 currently has a baseline MZFW of 136,000 lb and a maximum certified design limit of 138,300 lb. The OEM offers operators the choice to purchase additional weight in 1,000 pound increments up to the maximum limit.

Another characteristic of increasing MZFW is that it generally does not result in an increase in the MTOW since this is a fixed, certified weight. Consequently, at the point of maximum payload efficiency the MZFW decreases linearly as the MTOW increases – as illustrated as segment along points B2 to B1.

FIGURE 11- PAYLOAD-RANGE AFFECTED BY CHANGES IN MZFW



# Aircraft Payload-Range Analysis for Financiers

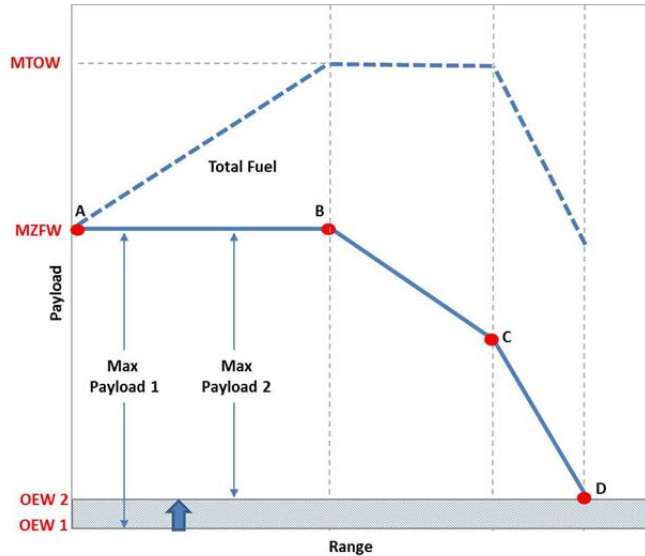
## 4.2 Changing the OEW limit –

Whereas the MZFW is a fixed value, the OWE varies according to the weight of the operator items, therefore actual OEWs and payloads will vary with airplane and airline configuration. All things being equal, the greater an airline increases an aircraft's OEW the less payload the aircraft can carry, and conversely the more OEW is lowered the more payload can be carried – Figure 12.

Although reducing an aircraft's OEW allows more payload to be carried, the primary reason why an airline would focus on reducing weight is to improve aircraft performance and save on fuel expense. Excess weight reduces the flight performance

of an airplane in almost every respect, including higher takeoff speeds, longer takeoff run, and reduced rate and angle of climb. Adding weight to an airplane requires a greater lifting force as it moves through the air - which also increases the drag.

FIGURE 12 - PAYLOAD-RANGE AFFECTED BY CHANGES IN OEW



## Aircraft OEW Perspective

In recent years, aircraft operators as well as manufacturers have been focusing on new ways to reduce the weight – primarily OEW - of the aircraft they operate. A new generation of lightweight but strong carbon-fiber based materials to replace traditional aluminum-alloy materials for interior systems and equipment has greatly reduced the weight.

Up in the cockpit, Delta is studying whether it is feasible to divide the heavy pilot manuals required on each flight between the captain and first officer, so pilots are not toting duplicate sets. Eventually, the airline wants to eliminate printed manuals and display the information on computer screens, a step that would require government approval.

Passengers might notice other changes. Airlines including Delta are swapping heavier seats for models weighing about 5 pounds, or 2.3 kilograms, less. Air France plans to phase in a new seat on short-haul flights that is 9.9 pounds lighter.

American is replacing its bulky drink carts with ones that are 17 pounds lighter. The airline said that change will help save 1.9 million gallons of fuel a year, on top of the 96 million gallons it is saving through other means.

Water is another target. Northwest is putting 25 percent less water for bathroom faucets and toilets on its international flights, McGraw said. Most planes had been returning from long flights with their tanks half full, an unneeded expense given that water weighs 8.3 pounds a gallon and a gallon of jet fuel weighs 6.8 pounds. "Every 25 pounds we remove, we save \$440,000 a year," McGraw said.



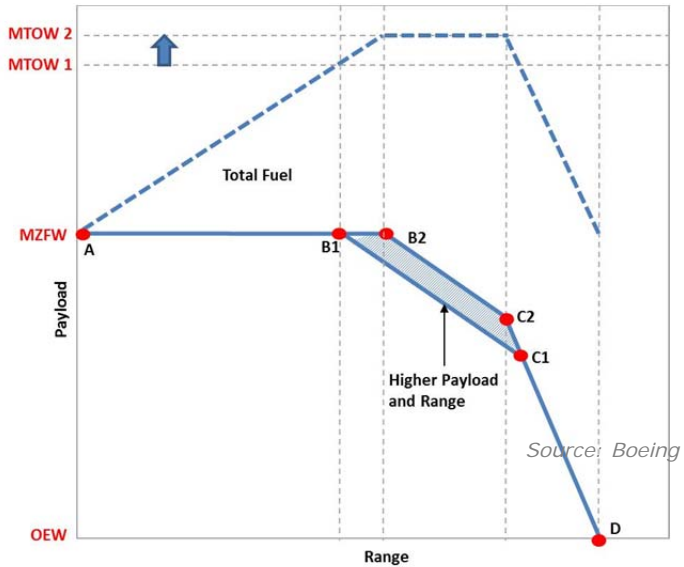
# Aircraft Payload-Range Analysis for Financiers

**4.3 Changing the MTOW limit** – Figure 13 illustrates the effects of increasing the Maximum Take-off Weight (MTOW). Operators who need additional performance capabilities of an aircraft can increase their certified MTOW (up to the maximum design limit) in an effort to either carry more payload at a given range, or fly further a given payload, or a combination of both.

All things being equal, if the manufacturer can improve this certificated value by demonstrating the structural integrity of the airframe, then more payload-range can be made available. As previously discussed, while higher MTOWs enhance an aircraft's utility, airframe manufacturers routinely charge premiums for these higher design weights.

The 737-800, for example, has Maximum Takeoff Weight (MTOW) options ranging from 155,000 lbs up to 174,000 lbs. For a new aircraft, the value differential between the lower and higher MTOW alternatives is approximately \$1.4 - \$1.5 million.

FIGURE 13- PAYLOAD-RANGE AFFECTED BY CHANGES IN MTOW



## Aircraft MTOW Perspective

It is common for first generation of an aircraft type to be offered with conservative certified weights. This is largely due to the need to validate the structural efficiency of the airframe. As an airframe accumulates operating experience (i.e. FH, FC, etc.), design engineers will analyze data sampled from structural checks to validate increasing the maximum design weights.

As an example, the original A330-300 Maximum Take-Off Weight (MTOW) was 467,460lbs, which has been increased three times, to 507,000 lb, 513,765 lb and 533,518 lb. The latter three are High Gross Weight (HGW) options, which have helped boost payload & range offerings. And while the lower MTOW options still exist as certified options, all recent orders have been for the HGW option.



# Aircraft Payload-Range Analysis for Financiers

**4.4 Changing the MFC limit** – Figure 14 illustrates the effects of increasing the Maximum Fuel Capacity. What typically happens under this circumstance is the aircraft manufacturer will make available the option to add fuel tank(s) allowing the aircraft to fly longer ranges.

Although optional auxiliary fuel tanks increases range capability there are some disadvantages to this alternative as illustrated in Figure 15 below, which highlights the optional fuel tank capabilities of the 737-900ER.

Firstly, since the tanks itself adds weight to the aircraft, this leads to an increase in the Manufacturer's Empty Weight (MEW), which leads to a corresponding increase in OEW. The net effect is a decrease in maximum payload available.

Secondly, the addition of cargo tanks will often reduce space available that might otherwise be used for cargo. And thirdly, the range improvements are only available where the payload exceeds the point on the envelope where range would otherwise have been limited by MFC – as illustrated by the shaded envelope are in Figure 14.

FIGURE 14 - PAYLOAD-RANGE AFFECTED BY CHANGES IN MFC

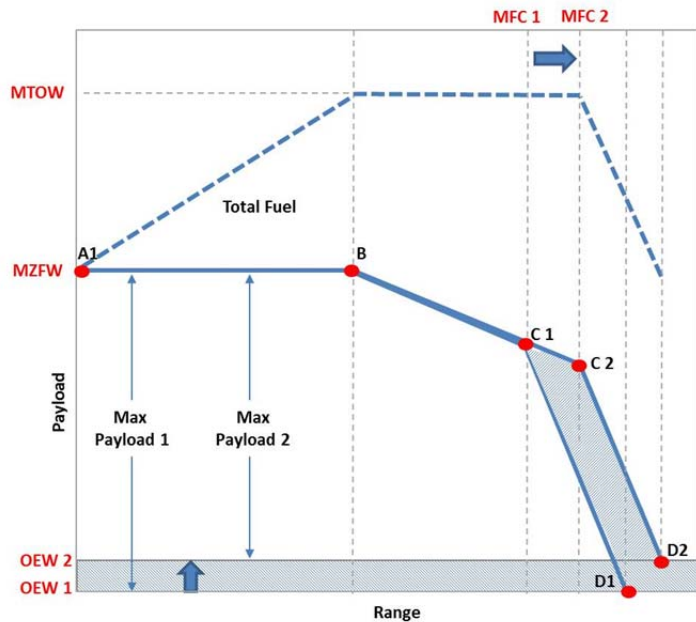
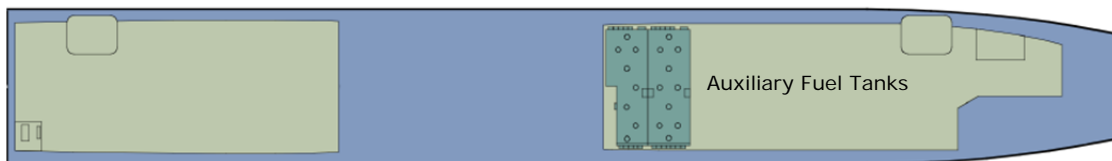


FIGURE 15 – 737-900ER OPTIONAL AUXILIARY FUEL TANKS & RANGE CAPABILITIES

Source: Boeing



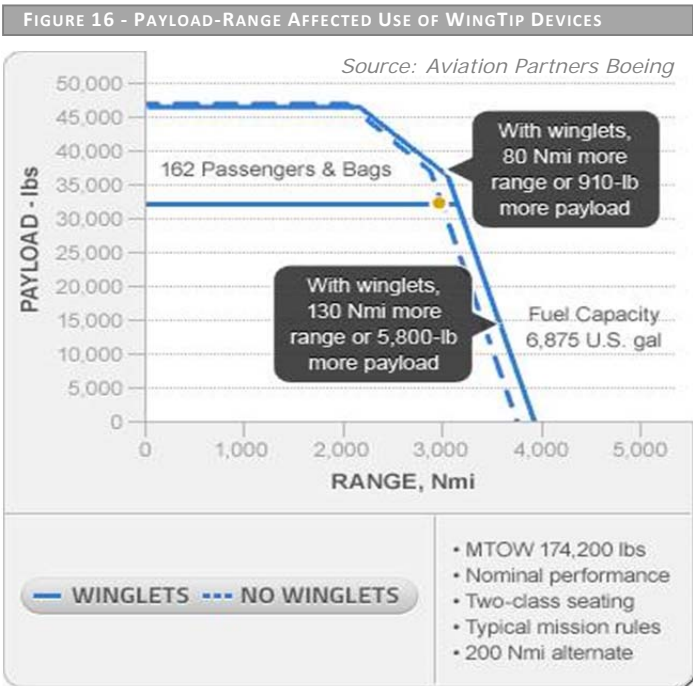
Optional Tanks	Range,* nmi (km)	Fuel, liters (gal)	OEW, kg (lb)	Cargo volume, m <sup>3</sup> (ft <sup>3</sup> )
0	2,845 (5,265)	26,020 (6,875)	43,890 (96,780)	51.7 (1,824)
1	3,045 (5,635) +200 (+370)	27,970 (7,390) +1,950 (515)	44,520 (98,170) +630 (1,390)	47.4 (1,674) -4.3 (150)
2	3,230 (5,980) +385 (+715)	29,660 (7,837) +3,640 (962)	44,680 (98,510) +790 (1,730)	44.9 (1,585) -6.8 (239)

# Aircraft Payload-Range Analysis for Financiers

## 4.5 Use of Wingtip Devices – Figure 16

From an engineering point of view – and ultimately that of mission capability and operating economics – the main purpose and direct benefit of winglets are reduced airplane drag.

Winglets can also extend an airplane’s range and enable additional payload capability depending on the operator’s needs. Figure 16 illustrates the payload-range diagram 737-800 equipped with blended winglets. The 8-ft. carbon graphite winglets allow an airplane to extend its range by as much as 80 nm and carry an additional 910 lb more payload at the airplane’s design range. According to Boeing, the fuel burn improvement with blended winglets at the airplane’s design range is 4 to 5 percent.



# Aircraft Payload-Range Analysis for Financiers

## REFERENCES

1. **Buying the Big Jets.** *Fleet Planning for Airlines*, Clark, P. *Second Edition*, 2007. ISBN: 978-07546-7091-9
2. **737 Airplane Characteristics for Airplane Planning.** Boeing Commercial Airplanes, Document Number D6-58325-6, March, 2011
3. **Rationalizing Aircraft Performance Dynamic Modeling in Airplane Fleet Planning Decisions** Fouris, T, Ph.D (2010). Macrothink Institute
4. **Beginners Guide to Aviation Efficiency.** Reference Version, June 2010. Air Transport Action Group
5. **Analysis of Air Transportation Systems.** Fundamentals of Aircraft Performance (1). Trani, A Dr. (2006). Virginia Tech – Air Transportation Systems Laboratory
6. **Trends in Aircraft Efficiency and Design Parameters.** Zeinali, M, Ph.D. & Rutherford, D. Ph.D – International Council on Clean Transportation (ICCT)
7. **Approaches to Representing Aircraft Fuel Efficiency Performance for the Purpose of a Commercial Aircraft Certification Standard.** Yutko, B. & Hansman, J. – Report No ICAT-2011-05, May 2011, MIT International Center for Air Transportation (ICAT)
8. **Fuel Efficiency at the Lufthansa Group – Cutting Cost & Protecting the Environment.** Climate and Environmental Responsibility, Balance 2012
9. **Aviation International News** ([www.ainonline.com](http://www.ainonline.com)) . New Airline Demands for Range and Payload Prompt Boeing to Optimize Fleet. Polek, G. July 9, 2012

About the author:



Shannon Ackert is currently Senior Vice President of Commercial Operations at Jackson Square Aviation where he has responsibility of the firm's commercial activities including technical services, contract development & negotiation, and asset selection & valuation. Prior to joining Jackson Square, Shannon spent over ten years working in the aircraft leasing industry where he presided over technical asset management roles as well as identifying and quantifying the expected risk and return of aircraft investments. Shannon started his career in aviation as a flight test engineer for McDonnell Douglas working on the MD-87/88 certification programs, and later worked for United Airlines as systems engineer in the airlines 757/767 engineering organization. He has published numerous industry reports dealing with aircraft maintenance economics and market analysis, and is a frequent guest speaker at aviation conferences. Shannon received his B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University and MBA from the University of San Francisco.