The influence of weight on fuel consumption and range for a turboprop medium courier aircraft

Marius-Alexandru VOICU*,[1], Ion FUIOREA[1]

*Corresponding author
[1]"POLITEHNICA" University of Bucharest,
Splaiul Independentei 313, 060042, Bucharest, Romania,
alex_voicu91@yahoo.com*, ifuiorea@yahoo.com

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Abstract: *Performance in the en route phase can be measured using the range and endurance parameters of the airplane. The range is a more useful performance parameter than endurance and one that aircraft designers are constantly trying to improve. While endurance refers to airborne time, the range is more concerned with distance covered and is therefore sometimes referred to as fuel mileage. In most cases, the trade-off between range and payload is achieved at the initial purchase of the aircraft and, subsequently during in-flight planning.*

Key Words: *aviation, fuel consumption, turboprop aircraft, range, endurance*

1. INTRODUCTION

There are two important factors in the calculation of the cruise flight, the range and the endurance. The first factor refers to the maximum distance that can be flown and the second to the maximum time that the aircraft can spend in the air, both depending on the amount of fuel on board [1], [2], [3].

Following the results of maintenance analysis for a medium courier turboprop aircraft, the components with the highest failure rate were identified and placed in the spare parts stock with which the aircraft should go on air transport missions.

In addition, maintenance manuals and tools needed to perform corrective maintenance work were included. All objects were organized into boxes so that the influence on the space, weight and balance of the aircraft was minimal, with a total weight of about 700 pounds.

The analysis refers to a military aircraft, in which case an integrated multinational logistical support system, similar to that used by civilian airlines, cannot be considered, so it is necessary to bring on board the materials needed to ensure the fulfillment of missions.

The technical team needed to carry out the corrective maintenance includes a number of four members, which leads to a weight gain of 800 pounds. In conclusion, it is considered an extra weight of about 1500 pounds.

Any extra weight loaded will reduce the maximum flight distance, so the purpose of this article is to check the influence of the extra weight on the range of the aircraft.

2. THE INFLUENCE OF THE ADDITIONAL WEIGHT GENERATED BY THE SPARE PARTS STOCK ON FUEL CONSUMPTION AND RANGE

The range is a function of fuel consumption and ground speed [4], [5]. Since fuel consumption increases with increasing power on the throttle levers (considering/given that the aircraft remains at the same weight and flight level), the maximum range cannot be reached at maximum speed [6], [7]. In other words, for a given mission, where fuel economy is more important than speed, the best result will be obtained by flying at a low power setting [8]. As a mathematical formula, the range is the distance represented in nautical miles divided by the amount of fuel, in kilograms.

$$Range = distance\ (NM) \div fuel(KG) \tag{1}$$

It can be deduced that the maximum range can be defined as the maximum distance that an aircraft can fly with a certain amount of fuel or the minimum amount of fuel consumed by an aircraft to fly a predetermined distance [9], [10]. Starting from the above formula, more useful and easier to use information can be obtained. In other words, if the distance is replaced by the distance/hour, resulting in true speed (TAS), and the fuel is replaced by fuel hour, resulting in consumption (FF), the formula of the specific range is obtained.

$$Specific\ range = TAS\ (NM/hour) \div FF(KG/hour) \tag{2}$$

It is noted that the specific range can be defined as the ratio between the true speed and the fuel consumption; in the case of turboprop aircraft, the range is influenced by the power applied to the engines. Fuel consumption (FF) can be calculated by multiplying the specific consumption (SFC) by the power coefficient applied to the engines (P) [11].

$$Specific\ range = TAS\ \div (SFC * \mathrm{P}) \tag{3}$$

Studying the formula, it becomes obvious that in order to maximize the specific range of an aircraft it is necessary to fly with high true speed and low fuel consumption. Below, the influence of the stock weight on fuel consumption and range, in different flight phases will be calculated. Figures 1, 2 and 3 show the graphs of fuel consumption obtained in three configurations: train and flap retracted, train retracted - flap 50%, train retracted - flap 100%, for flights performed at low altitudes (below 5000 feet).

The lower limit of the consumption curve in all cases corresponds to the stall speed, and the upper one corresponds to the structural and flap limitations. Figures 4 to 10 show graphs with specific range, from the sea level to 30,000 feet, at constant weight, as a function of the speed obtained with an engine setting of 100 percent. To calculate the influence of 1500 lbs. on the performance of the aircraft, the required flight data will first be set, in which, after the initial interpretation, the weights will be modified and the results compared.

1. Low altitude consumption with retracted train / flaps

Without spare parts stock (1)	With spare parts stock (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 140000 lbs.	Weight 141500 lbs.
ZFW = 107892 lbs.	ZFW = 109392 lbs.
Speed 230 knots	Speed 230 knots
Altitude 4000 feet	Altitude 4000 feet
Temperature - standard conditions	Temperature - standard conditions

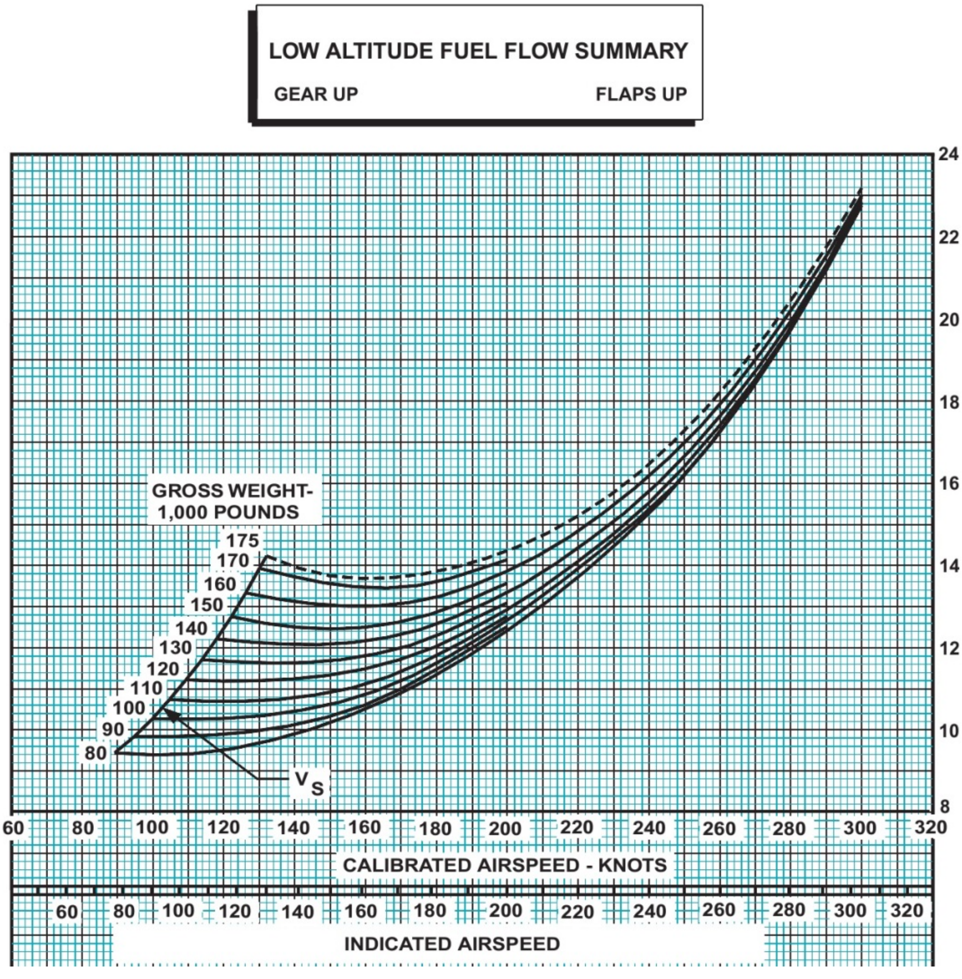

Fig. 1 Low altitude consumption with retracted train / flaps

As can be seen in the chart above, in the first situation, a consumption of approximately 1500 lbs. /hour is obtained, which leads to a total consumption of 6000 lbs. /hour.

In the case of the spare parts stock and the on-board personnel, hereinafter referred to as situation 2, a consumption of approximately 50 lbs. /hour higher is obtained, which leads to a total consumption of 200 lbs. /hour higher. There is an increase in consumption by 3.33%.

2. Low altitude consumption with retracted train, 50% flaps

Without spare parts stock (1)	With spare parts stock (2)
Retracted train - flaps 50%	Retracted train - flaps 50%
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs.	Weight 121500 lbs.
ZFW = 87892 lbs.	ZFW = 89392 lbs.
Speed 170 knots	Speed 170 knots
Altitude 2500 feet	Altitude 2500 feet
Temperature - standard conditions	Temperature - standard conditions

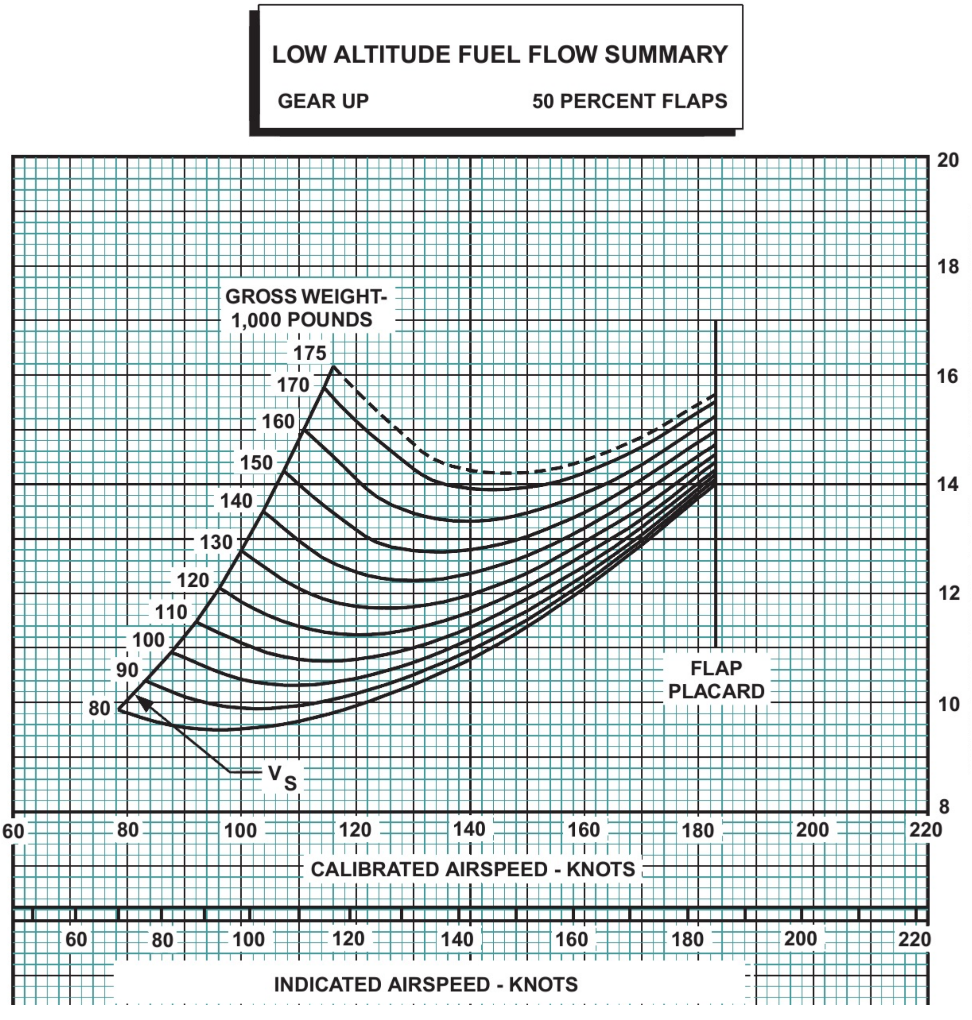

Fig. 2 Low altitude consumption with retracted train, flaps 50%

In the first situation a consumption of 1260 lbs. /hour per engine is obtained, which results in a total consumption of 5040 lbs. /hour, while in situation 2, the consumption increases by 30 lbs. /hour per engine, which leads to a consumption total of 5160 lbs. /hour. There is an increase in consumption by 2.38%.

3. Low altitude consumption with retracted train, flaps 100%

Without spare parts stock (1)	With spare parts stock (2)
Retracted train - flaps 100%	Retracted train - flaps 100%
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs.	Weight 121500 lbs.
ZFW = 87892 lbs.	ZFW=89392 lbs.
Speed 140 knots	Speed 140 knots
Altitude 1000 feet	Altitude 1000 feet
Temperature - standard conditions	Temperature - standard conditions

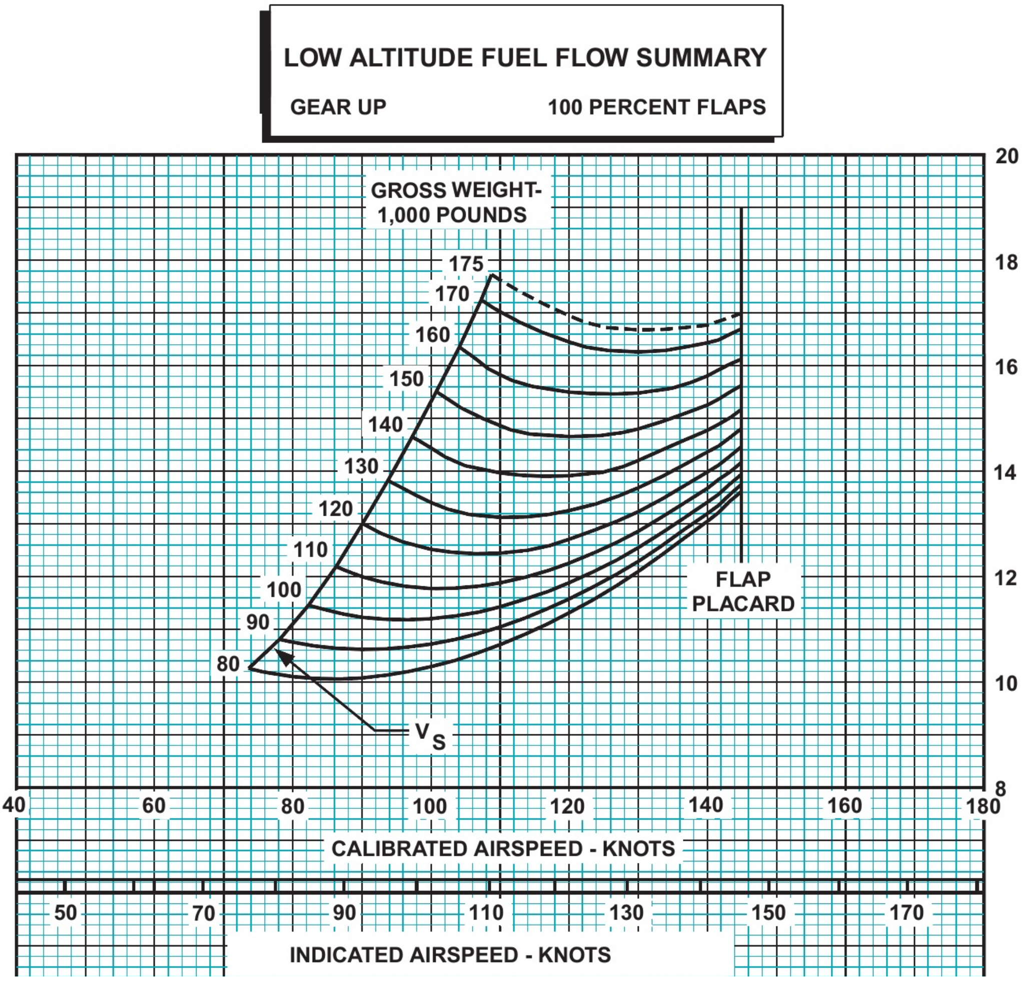

Fig. 3 Low altitude consumption with retracted train, 100% flaps

In the first situation a consumption of 1400 lbs. /hour per engine is obtained, which results in a total consumption of 5600 lbs. /hour, while in situation 2, the consumption increases by 60 lbs. /hour per engine, which leads to a consumption total of 5840 lbs. /hour. There is an increase in consumption by 4.28%.

4. Specific range at sea level

Without spare parts stock (1)	With spare parts stock (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs.	Weight 121500 lbs.
ZFW = 87892 lbs.	ZFW=89392 lbs.
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - sea level	Altitude - sea level
Temperature - standard conditions	Temperature - standard conditions

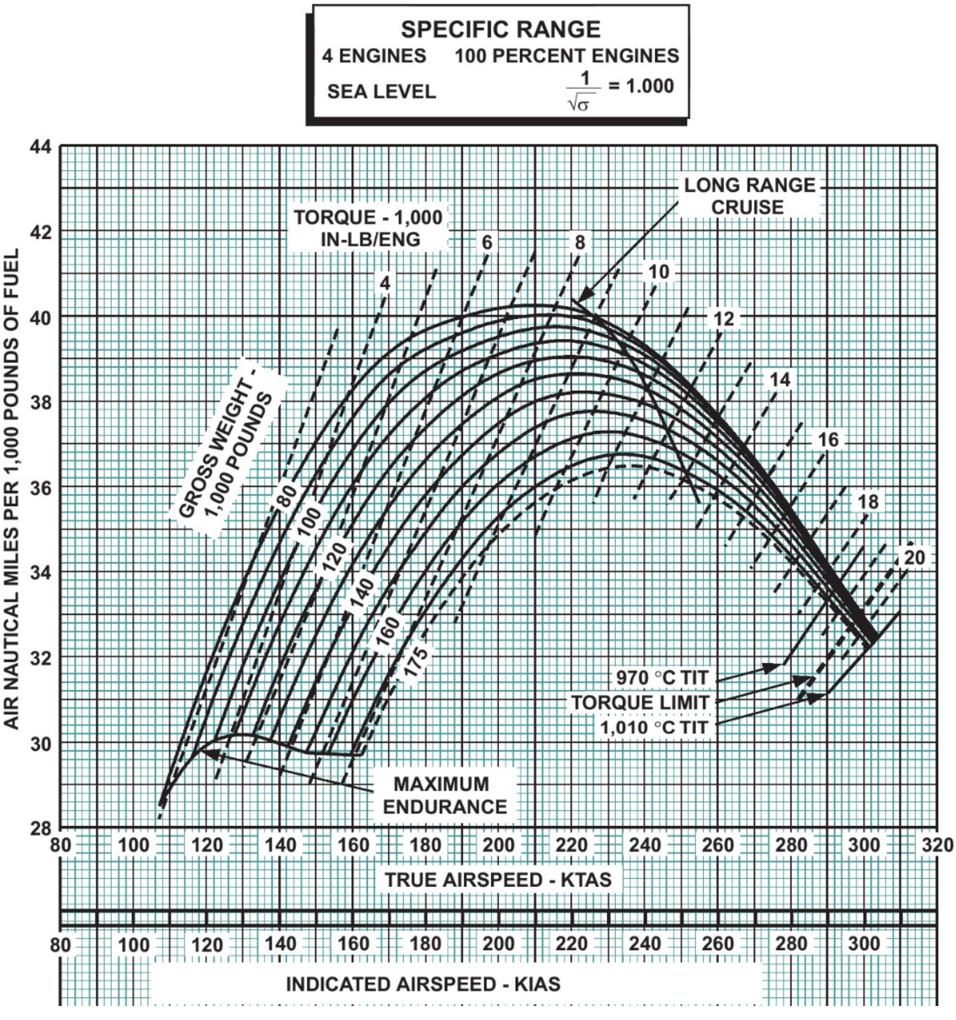

Fig. 4 Specific range at sea level

In the first situation, the obtained range is 37.4 nautical miles for 1000 lbs. of fuel consumed, while in situation 2, it will be reduced by 1.21, becoming 36.19. There is a decrease in the range by 3.23%.

5. Specific range at 5000FT

Without spare parts stock (1)	With spare parts stock (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs.	Weight 121500 lbs.
ZFW = 87892 lbs.	ZFW=89392 lbs.
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 5000FT	Altitude - 5000FT
Temperature - standard conditions	Temperature - standard conditions

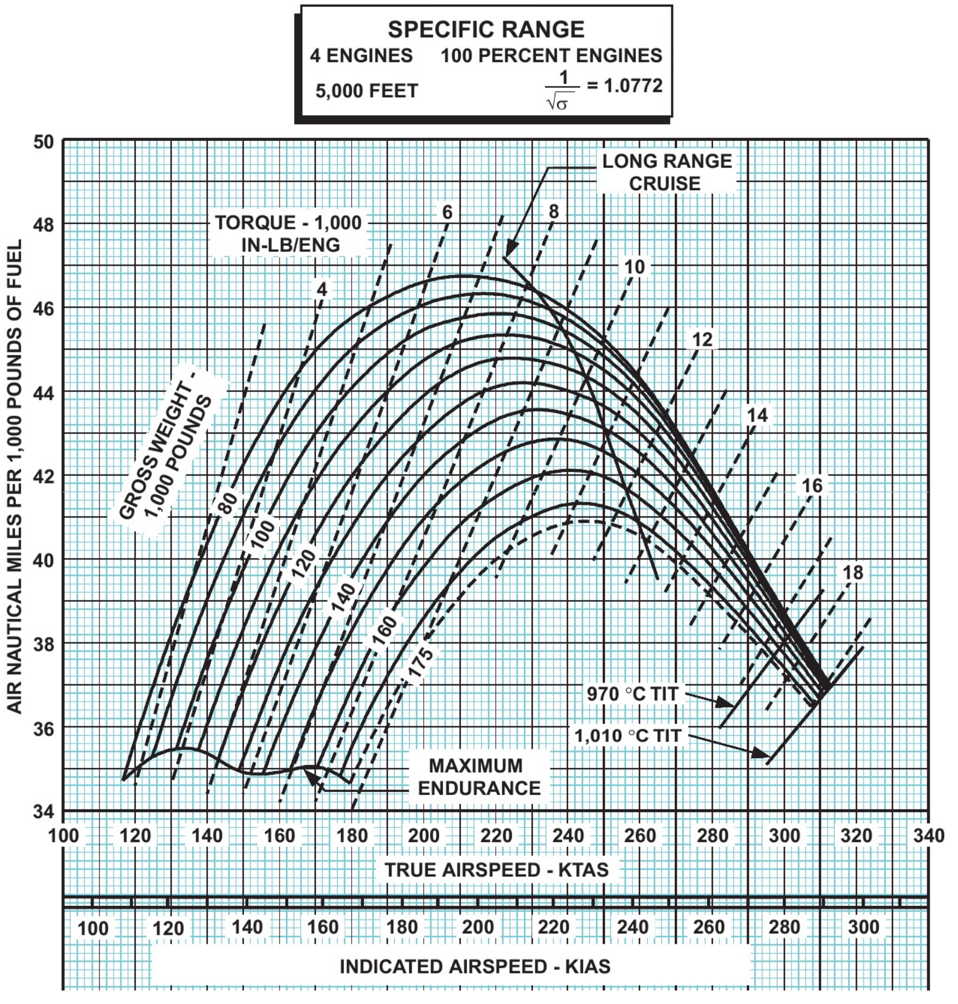

Fig. 5 Specific range at 5000FT

In the first situation, the obtained range is 43,4 nautical miles per 1000 lbs. of fuel consumed, while in situation 2, it will be reduced by 1.51, becoming 41,89. There is a decrease in the range by 3. 47%.

6. Specific range at 10000FT

Without spare parts stock (1)	With spare parts stock (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs.	Weight 121500 lbs.
ZFW = 87892 lbs.	ZFW=89392 lbs.
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 10000FT	Altitude - 10000FT
Temperature - standard conditions	Temperature - standard conditions

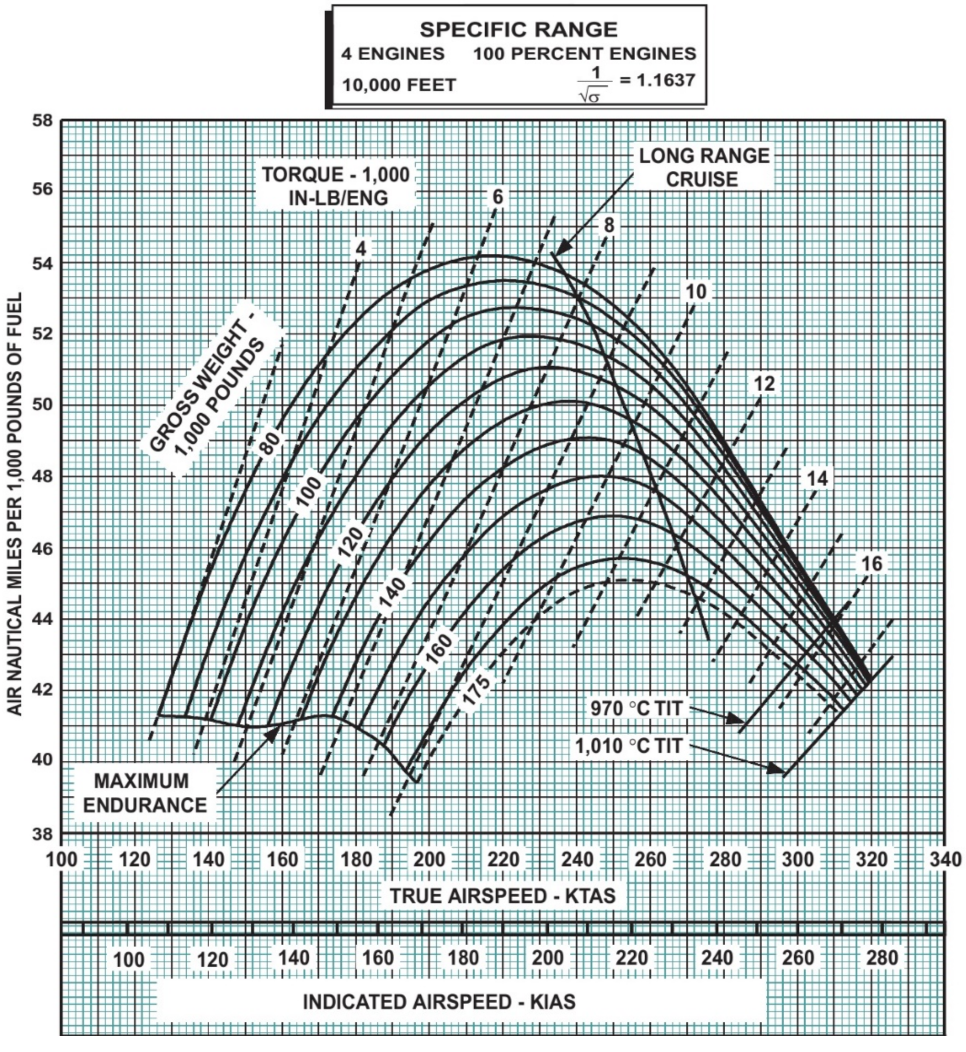

Fig. 6 Specific range at 10000FT

In the first situation, range obtained is 50 nautical miles per1000 lbs. of fuel consumed, while in situation 2, it will be reduced by 1.81, becoming 48,19. There is a decrease in the range by 3, 62 %.

7. Specific range at 15000FT

Without spare parts stock (1)	With spare parts stock (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs.	Weight 121500 lbs.
ZFW = 87892 lbs.	ZFW=89392 lbs.
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 15000FT	Altitude - 15000FT
Temperature - standard conditions	Temperature - standard conditions

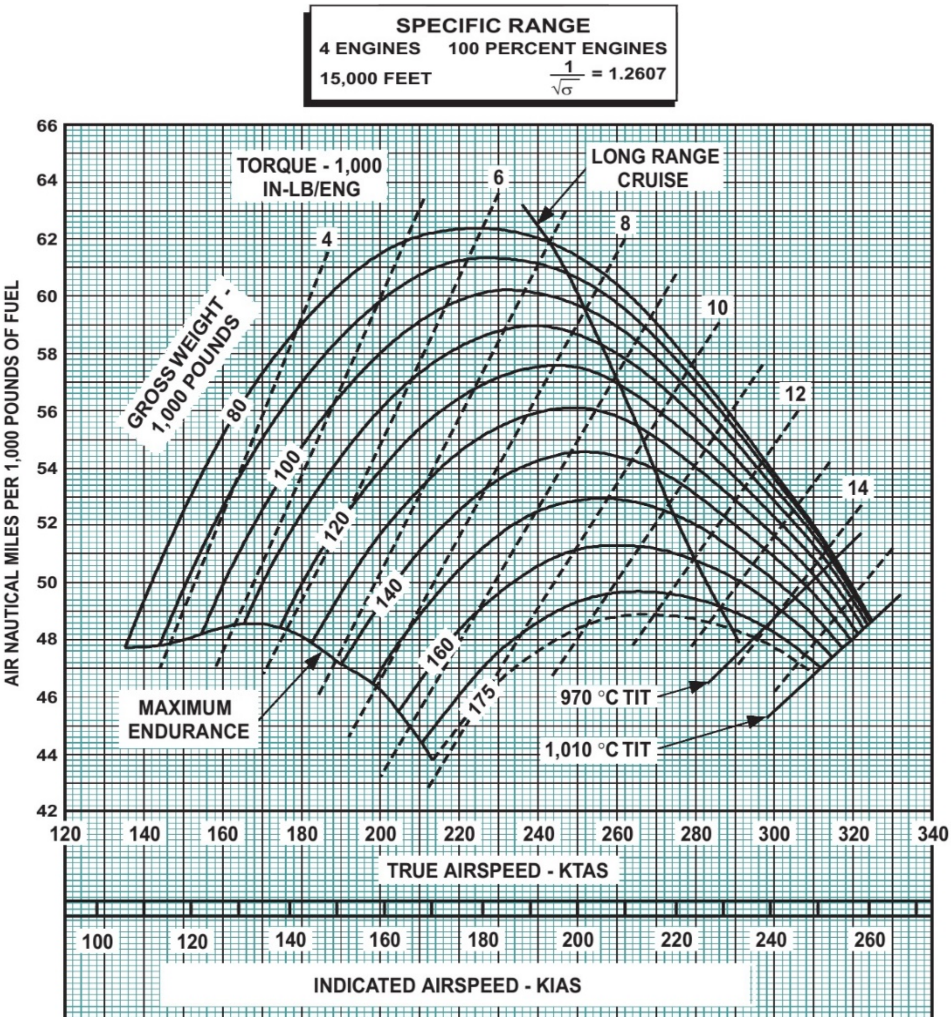

Fig. 7 Specific range at 15000FT

In the first situation, the obtained range is 56,9 nautical miles per 1000 lbs. of fuel consumed, while in situation 2, it will be reduced by 2,42, becoming 54,48. There is a decrease in the range by 4, 25%.

8. Specific range at 20000FT

Without spare parts stock (1)	With spare parts stock (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs.	Weight 121500 lbs.
ZFW = 87892 lbs.	ZFW=89392 lbs.
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 20000FT	Altitude - 20000FT
Temperature - standard conditions	Temperature - standard conditions

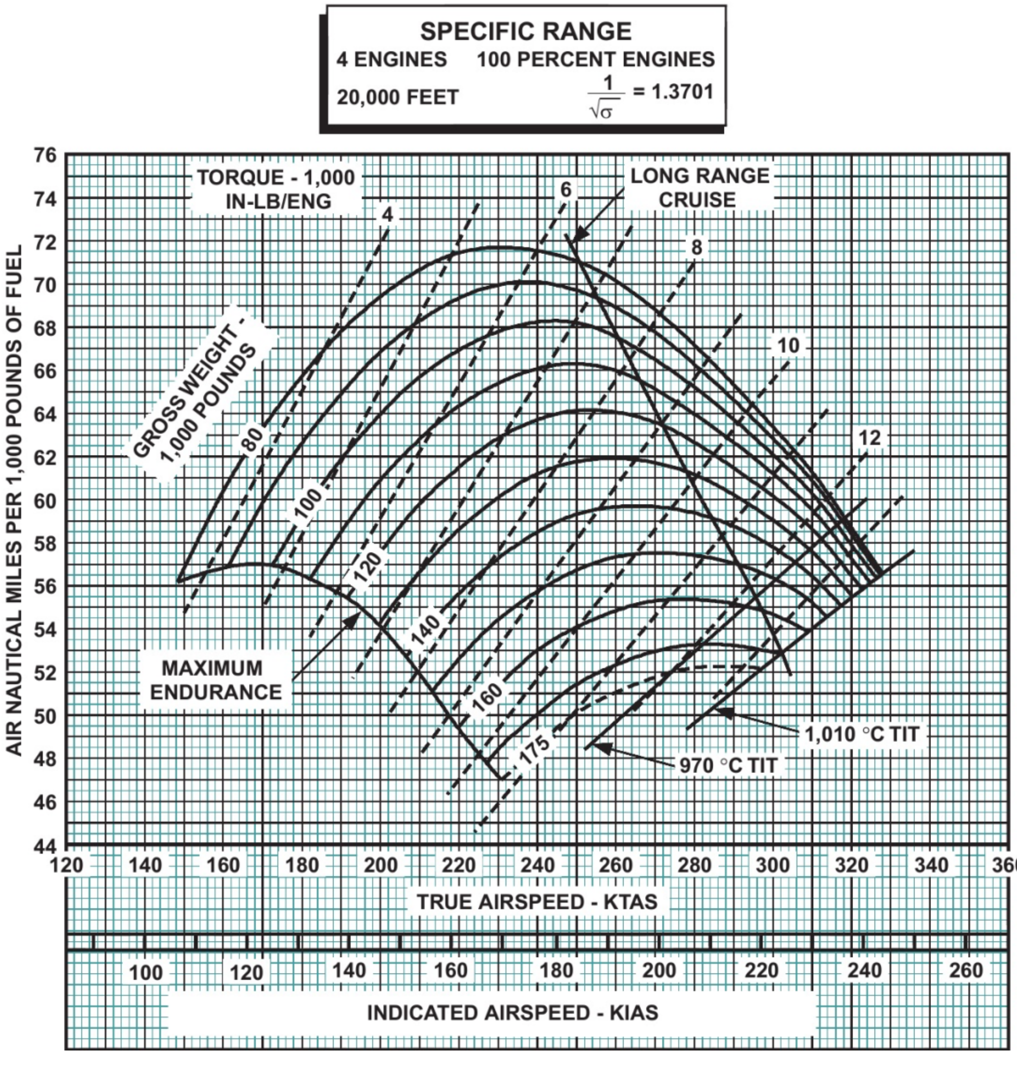

Fig. 8 Specific range at 20000FT

In the first situation, the obtained range is 64 nautical miles per 1000 lbs of fuel consumed, while in situation 2, it will be reduced by 3,15, becoming 60,85. There is a decrease in the range by 4, 92 %.

9. Specific range at 25000FT

Without spare parts stock (1)	With spare parts stock (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs.	Weight 121500 lbs.
ZFW = 87892 lbs.	ZFW=89392 lbs.
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 25000FT	Altitude - 25000FT
Temperature - standard conditions	Temperature - standard conditions

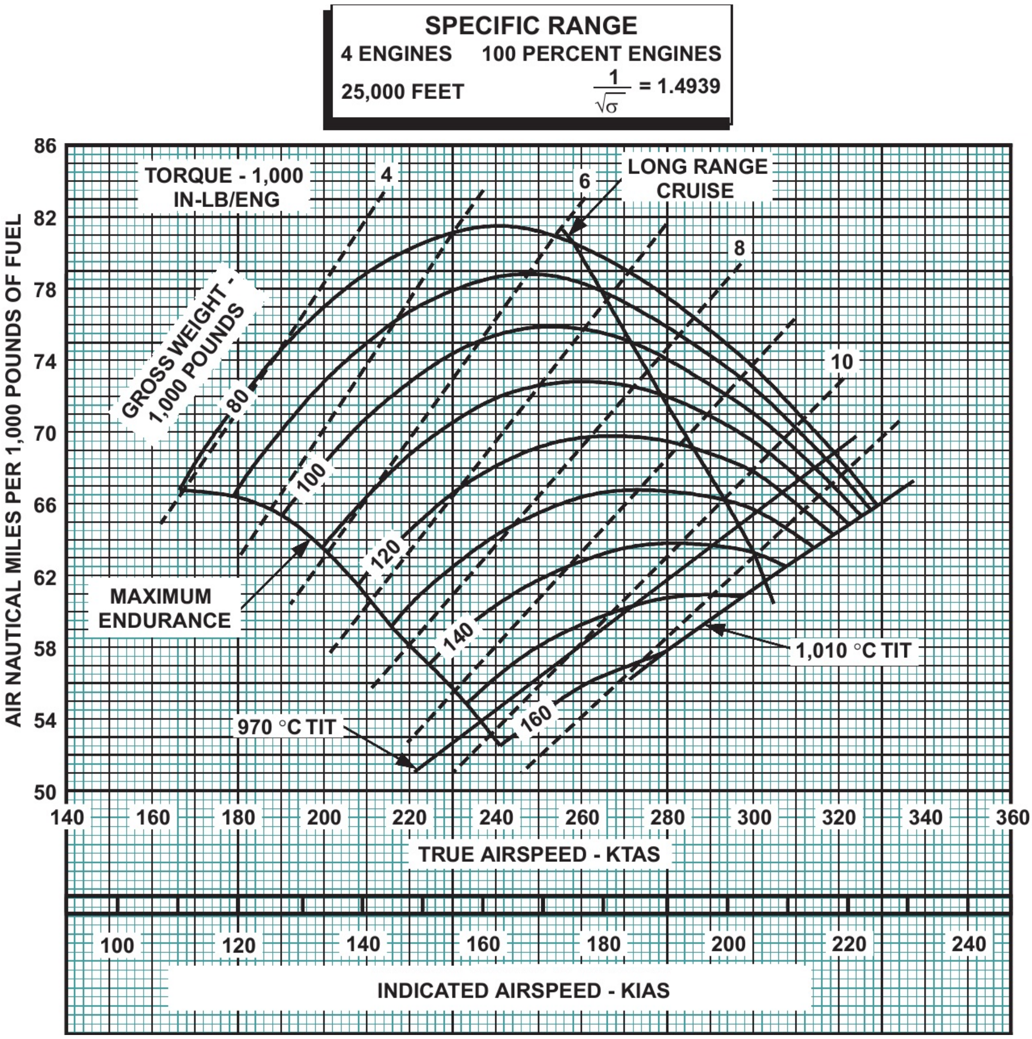

Fig. 9 Specific range at 25000FT

In the first situation, the obtained range is 69,5 nautical miles per 1000 lbs. of fuel consumed, while in situation 2, it will be reduced by 4,5, becoming 65. There is a decrease in the range by 6. 47%.

10. Specific range at 30000FT

Without spare parts stock (1)	With spare parts stock (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs.	Weight 121500 lbs.
ZFW = 87892 lbs.	ZFW=89392 lbs.
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 30000FT	Altitude - 30000FT
Temperature - standard conditions	Temperature - standard conditions

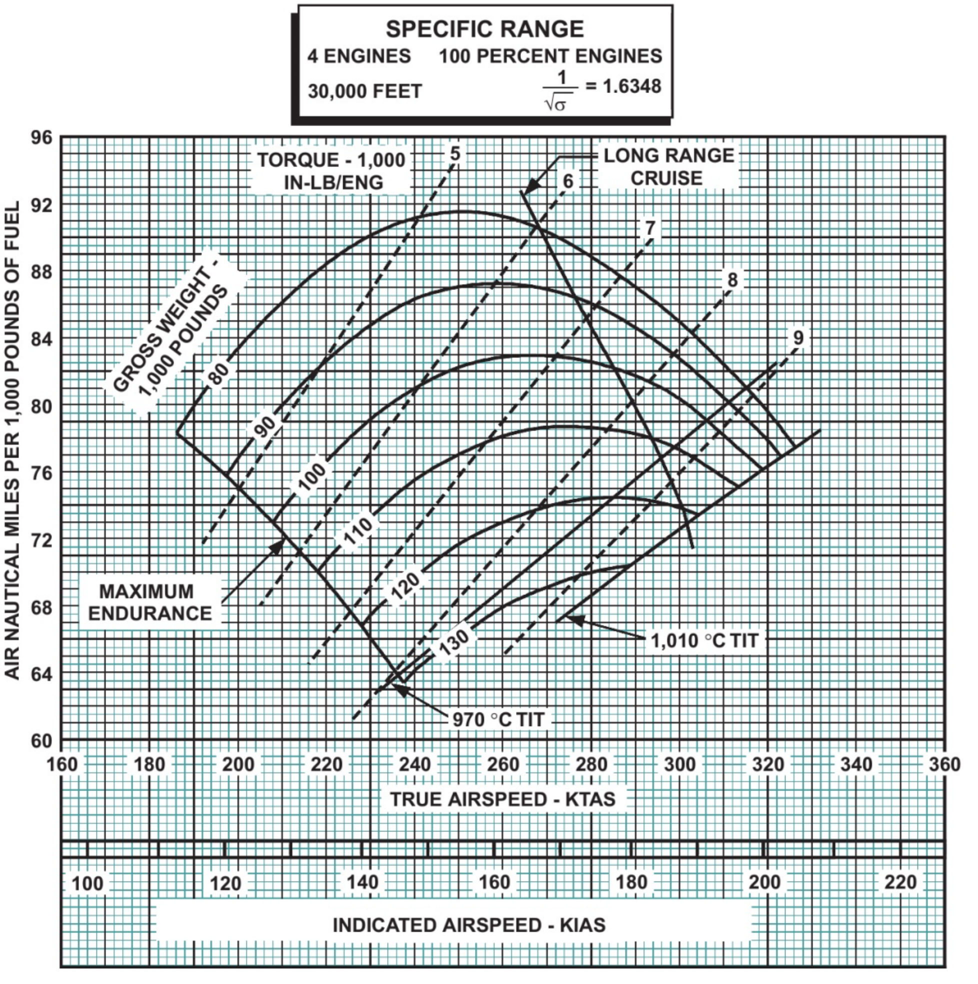

Fig. 10 Specific range at 30000FT

In the first situation, the obtained range is 74,5 nautical miles per 1000 lbs. of fuel consumed, while in situation 2, it will be reduced by 5,25, becoming 69,25. There is a decrease in the range by 3. 47%.

3. CONCLUSIONS

The purpose of this paper was to calculate the influence of the additional weight, generated by the spare parts stock and the technical team needed to perform the corrective maintenance work. The best way to find out this influence is to find out the increase in consumption generated by the extra weight and to calculate the autonomy.

In terms of low altitude consumption, for a takeoff weight of 120,000 lbs., calculated in different configurations, there was an average increase of 3.3 percent.

As it is already known, any extra weight loaded reduces the maximum flight distance, so this increase in consumption was also reflected in the range of the aircraft, an average decrease of about 4.71 percent being obtained.

These calculations are valid if the load of the aircraft is not so high as to increase the take-off weight to the maximum value. Precisely for this reason, the performance calculations were made for a weight of 120,000 lbs. As the aircraft is loaded at the maximum payload, the amount of fuel is limited by the maximum take-off weight, in this case the range being limited by the amount of fuel on board.

Therefore, the exchange will be made between the load and the amount of fuel, from which it can be deduced that the stock will not affect the range but will lead to a decrease in the amount of cargo that can be transported. An acceptable exchange, as long as the flight will be performed safely and the chances that the aircraft and crew will remain immobilized at a stopover, at an alternate airport or in the theater of operations will be almost non-existent.

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