A Strategy for Efficient Operations through Flight Planning and the use of the Cost Index Approach.

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***Abstract*— This work will show the importance of carefully planning flight operations and its impact on total costs of an airline or military base. Some concepts of efficient flight is introduced such as cost index, CG and weight management, control of drag index on external configurations and fuel loading with complete performance analysis comparing the difference with approximate methodologies. Practical examples using the Brazilian Air Force aircraft C-95 and C-130 will show the benefits and cost improvement with the adoption of some simple practices previous to flight. Finally it will be shown a mission performance assessment with a C-95 aircraft using the cost index methodology and traditional long range cruise flight proving the total cost reduction. It becomes clear that time invested in performance planning previous to flying is profitable.**

***Keywords*— Fuel Efficiency, Flight planning, Cost Index**

I. Introduction

Flight planning has achieved a large level of importance at military squadrons and civilian airlines mainly due to the increase of tight budgets, the rise of oil prices and labor costs and also the aging fleet and engines which requires expensive spare parts and maintenance downtime contributing to the aircraft low availability. Specially at the military flight community, the United States Air Force has invested in an energy strategic plan after realising the impact of its energy consumption at their federal government annual energy budget. In 2011, the Department of Defense (DOD) was responsible for 80% of the total energy consumed at the US government, 48% of this was due to the US Air Force operations, corresponding to approximately 2.5 billions gallons of aviation fuel each year [1].

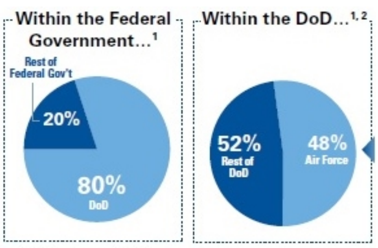

Fig. 1 - US Government and DOD energy consumption distribution [1].

Among USAF priorities and goals for reaching an energy efficient operation, it is worth pointing out here those which directly affects flight operations and fuel economy.

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- Improve aviation energy efficiency 10% by 2020 (2011 baseline);
- Develop and implement a plan to evaluate technologies for potential improvements in energy and operational efficiency;
- Share best practices with domestic and international partners for efficient fuel use.

Also towards improving energy efficiency at product and process, the academic and industrial community, represented by the International Organization for Standardization (ISO) has recently published the ISO 500001: *Energy Management Systems - Requirements with Guidance for Use*. This document provides guidance for energy monitoring and process improvement using traditional tools based on quality management methodologies that provides methods to organize an energy efficiency management culture inside any organization.

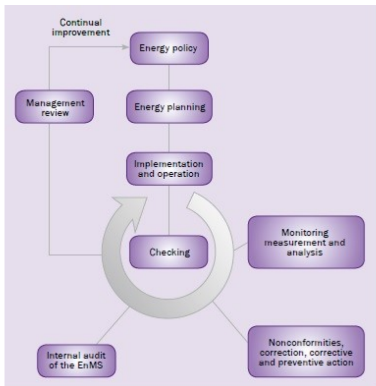


Fig. 2 - ISO energy management process [2].

Considering the above examples at the military and civilian community and also the economical crisis which enhances budget restrictions, it becomes urgent the need to think of alternatives to reduce operational costs without compromising missions accomplishments.

II. Military Flight Costs

In general, there are mainly two costs group associated with aircraft operations, the first is the total cost of fuel and oil necessary to operate and accomplish each mission and the second is the cost based on the total annually flight hours for each aircraft. The fuel and oil costs depends basically at the engine and aircraft aerodynamic deterioration state and flight profiles policy. Keeping the aircraft at good flight conditions with constant and efficient airframe and engine maintenance may reduce fuel and oil costs. Improving flight profiles, analysing the best cruise speed, flight route, trade-off between altitude and wind, among others are flight operations procedures that may also contribute to fuel and oil costs reduction. Costs such as maintenance labor, spare parts supplies, crew costs, consumed material and hangar fees are dependant on total flight hours, therefore it is a function of aircraft average flight speed, justifying the reason why optimizing flight planning and flight profile may also indirectly reduce these expenses. The Brazilian Air Force has a structured procedure to compile aircraft total logistical costs separating it into two categories: direct and indirect with the possibility of being variable or fixed costs [3]. These are divided in:

- Fuel and Oil;
- Maintenance and Supplies;
- Flight simulator development and operation;
- Avionics modernization;
- Aircraft Procurement;
- Aircraft modernization;

Therefore, following the Brazilian standard method, it is possible to calculate and separate fuel, oil and every other variable costs that is function of flight hours which will form the aircraft cost index.

III. Cost Index

The aircraft total flight costs at each mission depends on the block fuel BF and block time BT, which are functions of aircraft operational parameters such as take off weight, flight speed, altitude and engine performance and on the aircraft operational cost structure specially fuel and hourly costs (CF and CT).

$$Cost = BF \cdot CF + BT \cdot CT \qquad (1)$$

The cost index is basically the ratio of the variable costs of time and the costs of fuel and oil.

$$CI = \frac{CT\ [\$/h]}{CF\ [\$/kg]} \qquad (2)$$

Manipulating Eq.(1) and Eq. (2) it is possible to correlate flight performance index to mission total costs and arrive at a cost function that may be minimized at each flight phase [4].

$$J = \frac{1}{SR} + \frac{CI}{V_g} \qquad (3)$$

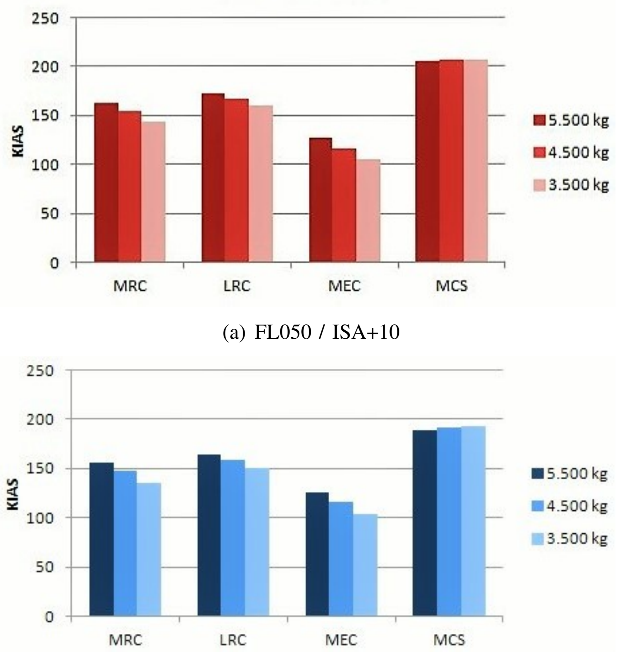
In Eq. (3), the flight mission total cost is a weighted balance by cost index of fuel costs represented by the aircraft specific range $SR_{[nm/kg]}$ and time related costs related to the ground speed V_g. Flight planning with cost index consists of minimizing the cost function J at each flight phase finding flight performance parameters like climb and descent schedules, cruise speed and flight altitude which reduces aircraft total mission costs.

IV. Cruise Flight Optimization

The cost of every flight mission depends on the fuel consumed and time spent at each flight segment. The majority of flights has its cruise as the predominant flight phase and its optimization must be the first step in mission cost reduction. Optimizing cruise flight is basically finding the best speed and altitude for the specified mission. Traditionally there are four cruise speeds used in flights.

- Maximum Endurance Cruise (MEC): Speed used for minimum fuel consumed for a fixed flight time;
- Maximum Range Speed (MRS): Speed corresponding to the maximum specific range [nm/kg], it is the speed for minimum fuel consumed for a fixed flight range;
- Long Range Speed (LRC): Highest speed that corresponds to 99 percent of the maximum specific range;
- Maximum Cruise Speed (MCS): Maximum flight speed limited by the engine available thrust;

All of these cruise speeds depends on aircraft weight, flight altitude, temperature and wind. Flight planning must determine for each aircraft and flight characteristics the best speed profile.



(a) FL050 / ISA+10

(b) FL100 / ISA+10

Fig. 3 - C95 Cruise Speeds [5]

The pitfall of using these speeds usually presented at flight manuals is that they do not consider the balance between fuel and time related costs. Maximum endurance, maximum range or long range speeds minimizes fuel consumed regardless the flight total block time. Maximum cruise speed although being the minimum flight time speed, penalizes the mission block fuel. The concept of cost index flying is to find the cruise speed that minimizes Eq. (3). This way, the cruise speed will be the one which minimizes total flight costs as it considers the balance between block fuel and block time. If fuel are the primary cost source inside the flight operations department, the cost index will approach 0 and flight speed will tend to the maximum range speed. If the costs of time are predominant, the cost index will be high and flight speed will be close to the maximum cruise speed in order to reduce total block time.

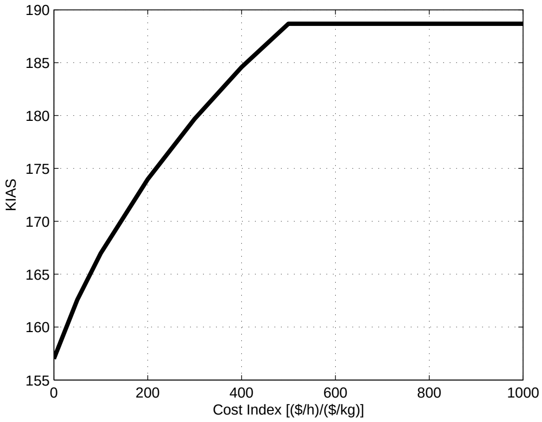


Fig. 4 - C95 Cost Index Speeds - FL100 / ISA+10 / 5.500 kg.

As shown in Fig. (4), depending on the aircraft operations cost structure, there will an ideal cruise speed for efficient flight. This speed varies along the cruise flight as it is dependent on aircraft weight and atmospheric properties such as altitude, temperature and winds.

V. Flight Planning

In summary, flight planning consists of defining the best flight profile for each segment, including best cruise speeds and altitudes, and also controlling the aircraft configuration in terms of CG location, take-off weight and total fuel used.

A. CG Position

The CG position affects directly the total fuel consumed as it changes the aircraft drag polar since its position is directly related to the aircraft trim drag. For conventional aircraft where the horizontal empennage is responsible for moment compensation, the aft CG results in lower trim drag since at this position the empennage will need less aerodynamic force to compensate the wing fuselage pitching moment. Therefore it is the responsibility of flight operation to guarantee the most aft CG position for each flight mission reducing fuel related costs.

Aircraft Type	Aft CG(35-37%)	Fwd CG(20%)
A300-600	+1.7%	-0.9%
A310	+1.8%	-1.8%
A330	+0.5%	-1.3%
A340	+0.6%	-0.9%

Fig. 5 - CG effect on specific range [6]

At Fig. (5) the reference CG for A300/A310 is 27% and aft CG is 35%, for the A330/A340, the reference is 28% and the aft position is 37%. It is shown an increase in specific range of up to 3.6% for the A310 from the fwd to the aft CG position justifying the importance of CG controlling toward efficient flight operations.

B. Take Off Weight and Configuration

Controlling the aircraft basic operational weight and also the external configuration are important steps towards flight efficiency. Extra and unnecessary weight have the consequence of increasing fuel burn due to the aircraft higher drag at heavier configurations.

$$TOW = BOW + FUEL + PAYLOAD \quad (4)$$

Each kg in excess at the basic operational weight corresponds directly to an increase on block fuel. Therefore, the difference on take-off weight is the sum of the BOW in excess and the additional necessary fuel for mission accomplishment. These extra fuel depends on the amount of excess weight, flight range and speed.

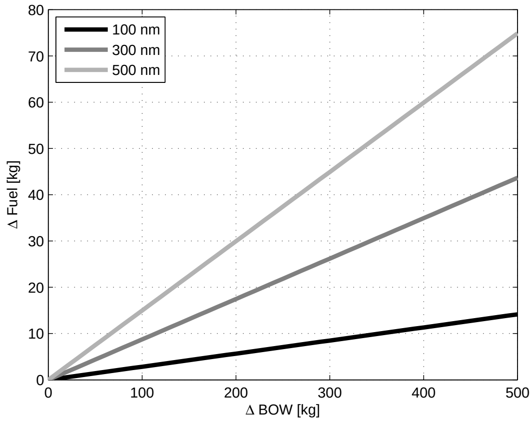


Fig. 6 - Effect of extra weight on block fuel at C95 flight profiles [7]

As a flight operations philosophy, an aircraft should be carried with only the minimum necessary payload and fuel for any flight mission respecting reasonable safety levels. Regarding aircraft external configuration, the use of the aircraft may induce additional drag [8] as:

- Control surfaces misrigging;
- Absence of seals;
- Mismatched doors;
- Consequences of structure repairs;
- Surface roughness;

These may be mitigated through a maintenance and inspection schedule planned through constant aircraft performance monitoring. Besides these aerodynamic defects which are natural to any aircraft,the external stores, loads, fuel tanks and every other optional configuration must be only installed and used in flight if it is strictly necessary, otherwise it will become an extra weight and additional drag to the aircraft.

Fig. 7 - External tanks on C-130 wings

The C-130 external fuel tanks, if mounted on the aircraft's wings will increase its basic operational weight and the aircraft total aerodynamic drag, reducing mission effectiveness.

TABLE I
IMPACT OF EXTERNAL TANK ON C-130 FLIGHT PERFORMANCE [9]

C-130 PERFORMANCE ESTIMATION					
	Weight [lb]	Hp [ft]	Drag Index	SR [nm/lb]	LRC [ktas]
With Tanks	120000	FL200	0	0.065	265
Without Tanks	120000	FL200	-18	0.067	270

Considering a scenario where a typical flight leg for a C-130 operation is 1000 nm, the fuel cost is $1.00/kg and variable hourly based costs are $6.000/h, if flying without external tanks, the aircraft will burn approximately $200kg$ less fuel and fly almost 2% faster, generating a total economy of $620.00 for every 1000 nm flight leg.

TABLE II
C-130 OPERATIONAL COSTS

C-130 TOTAL COSTS COMPARISON				
	Range [nm]	Block Fuel [kg]	Block Time [h]	Costs [$]
With Tanks	1000	6978.4	3.77	29619.93
Without Tanks	1000	6770.1	3.70	28992.33

C. Total Fuel Loading

It is the flight planning department responsibility to calculate the total volume of fuel to load the aircraft before each mission. Generally speaking, there are three ways of estimating the total amount of fuel on board [10].

- Calculate the fuel weight based on average historical fuel flow values considering alternate airport and additional fuel reserves;
- Calculate the fuel based on performance analysis of each flight segment considering aircraft instant speed, weight and altitude plus an alternative landing airport and a fixed reserve fuel;
- Calculate the fuel based on performance analysis of each flight segment considering aircraft instant speed, weight and altitude plus a alternative landing airport, a fixed reserve fuel and an additional contingency fuel based on a percentage of mission block time or block fuel;

Usually it is common at the Brazilian Air Force to calculate the total amount of fuel to load at C-95 missions using a historical average of 600 lb/h of fuel based on aircraft flight manual and performance monitoring. The advantage of these methodology is its simplicity as it only multiplies the average fuel flow with the estimate of flight block time. The great disadvantage is that this method does not distinguishes different flight altitudes and speeds, differences at atmospheric temperature and the actual aircraft weight. All of these parameters affects directly the aircraft fuel flow and using the average of 600 lb/h tends to be over conservative resulting at an overweight at the aircraft and consequent fuel penalty.

TABLE III
C-95 FLIGHT MISSION

FLIGHT MISSION		
Range	300	nm
Payload	1500	kg
Hp	12000	ft
V Climb	130	KIAS
V Descent	175	KIAS
ROD max	1000	ft/min
Cruise	LRC	
Alternate	100	nm
Reserve	45	min

Using this flight example it will be shown the benefits of using a more precise calculation procedure to estimate total fuel loading instead of using only average fuel flow values. The first approach is calculating the total fuel by analysing the entire flight and considering weight, altitude and speed variations.

TABLE IV
C-95 PERFORMANCE ANALYSIS

PERFORMANCE ANALYSIS AT A C-95 FLIGHT MISSION			
Flight Phase	Time [h]	Fuel [kg]	Distance [nm]
Climb	0.14	48.87	20.86
Cruise	1.25	269.45	244.65
Descent	0.17	26.87	34.48

It becomes clear the differences at fuel flow and specific range when considering different flight phases such as climb, cruise and descent. At climb flight the average calculated fuel flow is 740 lb/h while at cruise is 473 lb/h and at descent flight it is 338.5 lb/h. Those are the calculated average fuel flow at each flight segment and are all different from the historical value of 600 lb/h used as an approximation.

TABLE V
PLANNING RESULTS

MISSION PLANNING RESULTS			
	Block Fuel	Reserve Fuel	Total Fuel
Complete Analysis	345 kg	262 kg	607 kg
Average of 600 lb/h	426 kg	344 kg	770 kg

The excess of 163 kg when loading the aircraft with the average fuel flow methodology will correspond to a fuel penalty of around 15 kg for this 300 nm flight Fig. (6).

VI. Cost Index Flight Planning

Using the cost index in flight planning has the advantage of reducing the mission total costs. The consideration of the costs of time [$/h] will define climb and descent schedules along with cruise speeds that will result in lower operational costs. If an airline has a total variable costs of $2000/h and if this value is used in mission performance optimization, the final flight costs will be lower when comparing, for example, with the traditional long range flight.

TABLE VI
FLIGHT PLANNING WITH COST INDEX

	Time [h]	Fuel [kg]	Time Costs	Fuel Costs	Total Costs
Cost Index	1.33	418.2	$ 2660	$ 418.2	$ 3078.2
LRC	1.56	346.6	$ 3120	$ 346.6	$ 3466.6

Comparing both results, the first row regarding the use of the cost index with a $2000/h of time related costs and $1.00/kg of fuel and the second row with traditional long range cruise flight, it is clear the almost $400,00 saving even though the total block fuel is higher at this cost index. This increase in fuel consumed is compensated with the lower block time which reduced considerably time related costs.

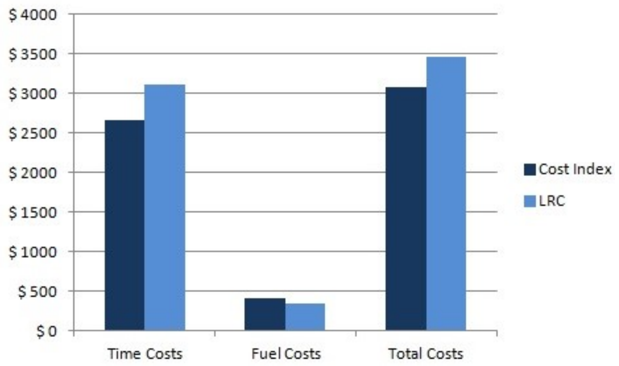


Fig. 8 - Mission Costs

VII. Conclusion

The flight planning and operations department plays an important row at the total costs of any airline or military base. Carefully planning every flight with time invested at considering complete performance calculations, not only average fuel flow values, accounting for time related variable costs and fuel price when determining best flight profiles and also managing aircraft configuration and weight are initiatives proved to be effective on providing general costs reduction culminating at increased aircraft availability and budget boundaries.

References

[1] U.S. Air Force, *U.S Air Force Energy Strategic Plan*, 2013.
[2] ISO, "Win the Energy Challenge with ISO 50001," International Organization for Standardization, Geneve Switzerland, 2011.
[3] Comando da Aeronautica, *ICA 400-2 Custo Logistico da Hora de Voo*, 2010.
[4] Flight Operations Support and Line Assistance, Airbus, *Getting to Grips with Cost Index*, 1998.
[5] Embraer, *Manual de Voo C-95B*.
[6] Flight Operations Support and Line Assistance, Airbus, *Getting To Grips With Fuel Economy*, 2004.
[7] Deo, V. A., "An Analysis of the Benefits of the Tankering Strategy Considering Cost Index Flying and Optional Refuelling Intermediate Stops," Tech. rep., ITA, 2016.
[8] Flight Operations Support and Line Assistance, Airbus, *Getting Hands On Experience Aerodynamic Deteriorations*, 2001.
[9] USAF, *C-130 Flight Manual - Performance Data*.
[10] Flight Operations Support and Line Assistance, Airbus, *Getting to Grips with Aircraft Performance*, 2002.