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THE IMPACT OF THE WIND COMPONENT ON THE AIRCRAFT FUEL CONSUMPTION AND PRICING

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Abstract: The article deals with the wind component and fuel consumption and pricing differences. The article contains 2 main chapters - theoretical (general knowledge) and practical (simulated models - in different flight stages based on the dates from the AFM manual of the C560 XLS+ A/C type). The discussion evaluates the out coming data and shows the facts of how the fuel price can change. The article's topic is related to meteorology, A/C type performance, and economy. Every part of the mentioned topic is important for a safe, fluent, and economical flight.

Keywords: Aircraft, Fuel Consumption, Fuel Flow, Fuel Price, Headwind, Management, Tailwind, Wind Component, Zero Wind

1. INTRODUCTION

The article discusses the fuel consumption and fuel price ratio in different flight stages and wind components.
Similar articles in a journal [1], [2] discuss the fuel flow and consumption too, limited for just cruising but not including the actual price for the year 2023 and for other flight phases.

The fuel price is changeable, and every month differs from the actual price list and delivery companies. It is the main reason, why is unable to state the exact fuel consumption price for the whole flight in a long-term usage.
The wind component greatly affects the fuel consumption in every flight stage - take-off, climb, cruise, en-route, and descend.
Chapter 2 describes wind as a main meteorological factor in aviation calculation and safety.
It is a general introduction describing the wind component.
Chapter 3 is a practical simulation part of the wind and fuel consumption coherency. Based on the stage of flight, meteorological conditions, and wind components the fuel consumption will differ and change. The fuel price relates to the fuel consumption regarding the actual month, day, and delivery company.

Papers which influenced this research (related to my previous research) and article are the following:

- firstly regarding the impact of climate change on European aviation (included in the IREA journal) [3]
- the C560 XLS+ (the same A/C type) A/C landing distance variability according to temperature and wind component effect - this article is related to the meteorological factors and the same aircraft type operation performance [4]
- how can global climate change impact the C560 XLS+ A/C type´s selected parameters and performance - the civil aviation experience was used for the Air Force issue. [5]

Other papers, that engaged similar problems are:

- improving A/C performance using machine learning - it is a review, that deals with aerospace engineering, and new requirements related to ACARE Flightúath 2050, emission producing, alternative fuels, and CO_2 producing, and reducing [6]

- A/C performance model implementation for the estimation of aviation fuel burn and emission (APMI updating) [7]
- modeling global fuel consumption for commercial aviation - regarding computation efficiency and accuracy of fuel burn estimation, and CO2 emission production [8]
- estimation of A/C fuel consumption by modeling flight data from avionics systems [9]

The used values and dates in this article are from the OM and AFM manual of the C560XLS+ aircraft type [10].

The article includes graphs and tables for a better understanding of the text part.

2. WIND AS A METEOROLOGICAL ELEMENT

“The wind is air in horizontal motion. Wind direction is always given as the direction from which the wind is blowing. Wind speed is usually given in knots.” [11]

$$1\ kt = \frac{1\ nautical\ mile}{1\ hour}$$

A wind gust is a sudden, brief increase in the speed of the wind, or it is defined as a sudden speed and direction fluctuation. It is characterized by the ratio of the amplitude of wind speed fluctuation to the average wind speed value per certain time interval.

$$v_n = \frac{A_n}{v_{average}}$$

v_n- wind gust

A_n–the wind speed fluctuation amplitude, which defines the difference between the two following maximum and minimum speed

$v_{average}$ – the average value of the wind speed. [11]

In the meteorology exist two phrases:

- the wind veering = which is a change in wind direction in a clockwise direction

- the wind backing = which is an anti-clockwise direction change (Fig.1).

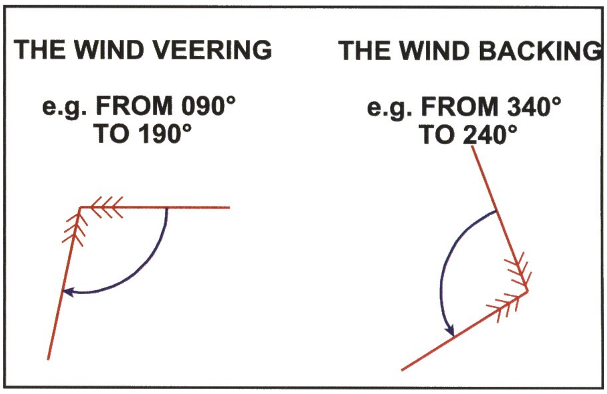


Figure 1 The wind veering and backing [11]

The wind has a big impact on the aircraft performance and fuel consumption. The headwind has a positive influence on the take-off and landing procedures, but negatively affects the en-route flight.

The next chapter presents the impact of the wind component on the A/C fuel consumption.

3. THE IMPACT OF THE WIND COMPONENT ON THE A/C FUEL CONSUMPTION AND PRICE

The example regards to LCLK-LKTB route, where the direct distance is 1 166 NM, with the C560XLS + aircraft type.

3.1. Cruise climb

In this research, the cruise climb is a continuous direct climb to FL430. The take-off weight at the start of the climb is 19 000 LBS, the temperature is ISA+10, and the wind component is zero wind. The TAS is 250 kt. In the mentioned meteorological condition, the duration of the continuous direct climb is 28 minutes by a 278 FPM, and the fuel consumption is 866 LBS. The climb distance is 171 NM. The price of the JET A1 fuel in Larnaca airport is 2,057 USD/USG (USD per gallon) to date 09.10.2023. 1 USG is 6,7 lbs. 866 LBS will be 129,25 USG. The price for the 866 LBS (129,25 USG) is 265,87 USD, which is approximately 252,58€. It means that in Cyprus, the price of JET A1 fuel is 1,95€ for a USG or 3,8 liters.

This price only regards the given month and given fuel delivery company. [10]

3.2. Cruise

The cruise is in ISA condition at FL430. The RAT (Ram Air Temperature) is -37°C, and the weight of the airplane 18 000 LBS. In this meteorological condition, the RPM of the engine is 92,1 RPM, and the fuel flow is 1081 LBS/HR - which is 18,02 LBS/MIN. The TAS is 403 kt, which means, that the A/C flies 6,72 kt per minutes. [10]

The cruise distance is 861NM, the climb is 171NM, and the descent is 134 NM from the 1 166NM. The cruise takes 128,2 minutes = 2 hours 8 minutes and 24 seconds:

$$\frac{861\ NM}{6{,}72\ kt/min} - 128{,}2\ min$$

If on the track occur headwind, the fuel consumption will be greater than in the zero or tailwind condition. From the A/C operation manual, the aircraft operational parameters are the following (Fig. 2):

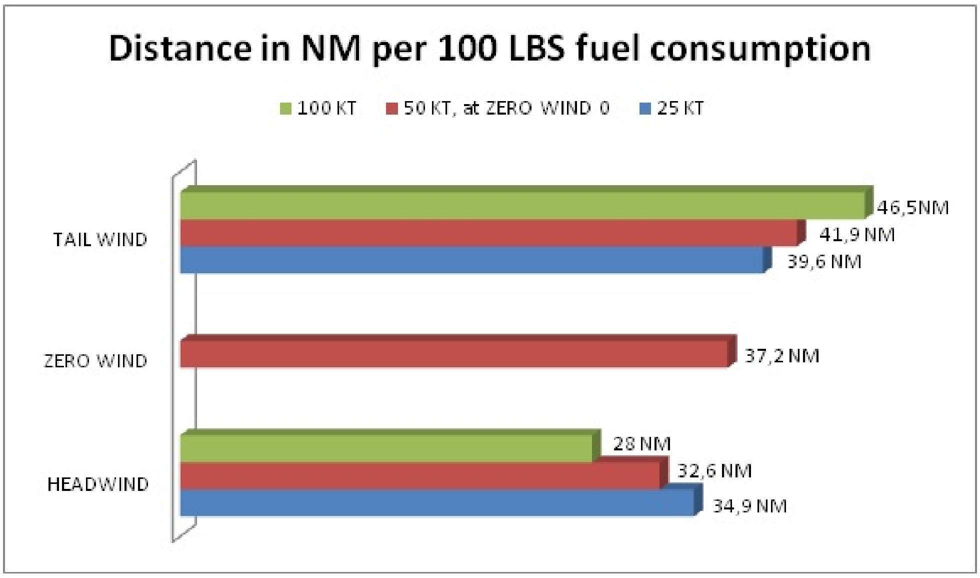
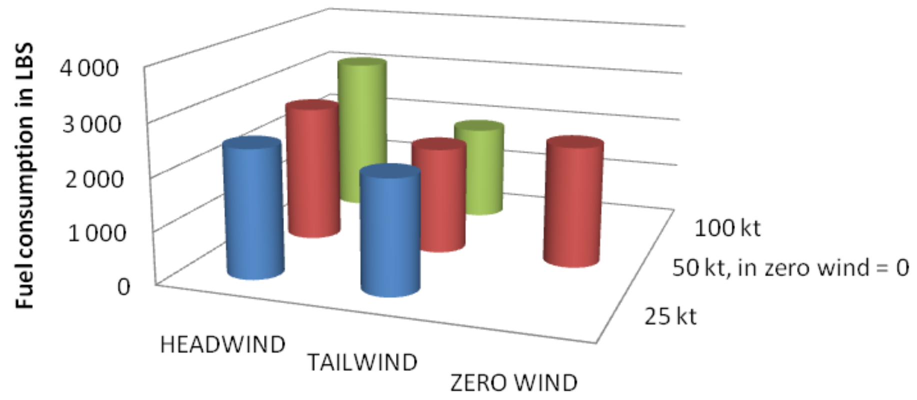


Figure 2 Distance in NM per 100 LBS fuel consumption
[own processing, based on [10]]

Fig. 2 shows the fact that during cruise flight the tailwind component positively affects the fuel consumption. In FL 430 the flown track is increasing with the rising tailwind component. The flown track is:
- 34,9 NM per 100 LBS if the headwind speed is 25 kt
- 32,6 NM per 100 LBS in 50 kt headwind component
- only 28 NM per 100 LBS in 100 kt headwind.

In zero wind component, the flown track per 100 LBS is 37,2 NM. In the tailwind component the flown track per 100 LBS is:
- 39,6 NM if the wind speed is 25 kt
- 41,9 NM if the wind speed is 50 kt
- 46,5 NM in 100 kt wind speed.

From the Fig. 3 it is revealing that the fuel consumption is greater in headwind condition (Fig. 3) than in tailwind condition. [10]



	HEADWIND	TAILWIND	ZERO WIND
25 kt	2 467	2 174,30	
50 kt, in zero wind = 0	2 641	2 055	2 315
100 kt	3 075	1 852	

Figure 3 Fuel consumption in LBS during 861 NM distance track
[own processing, based on [10]]

The fuel consumption for the 861 NM long track in a headwind condition is 2 467 LBS (25 kt h), 2 641 LBS (50 kt headwind), and 3075 LBS (100 kt headwind).
The fuel consumption for the 861 NM long track in a tailwind condition is 2 174,3 LBS (25 kt tailwind), 2 055 LBS (50 kt tailwind), and 1 852 LBS (100 kt tailwind), and in a zero wind condition is 2 315 LBS. [10,12]

The prices of the fuel consumption in different meteorological conditions regarding wind components are stated in Tab. 1.

Table 1 Wind component vs Fuel price
[own processing, based on [10,12]]

Wind component / Fuel price	HEADWIND			TAILWIND			ZERO WIND
	25 kt	50 kt	100 kt	25 kt	50 kt	100 kt	-
Fuel price in USD	757,4	810,8	944	667,5	630,9	568,6	710,7
Fuel price in €	717,9	768,5	894,8	632,7	598	538,9	673,7

From the above mentioned, it is clear, that the fuel consumption price for the en-route flight depends on the wind component. The highest price is when the headwind is blowing 100 kt, it costs 895€. In tailwind with 100 kt speed, the fuel price is only 539€. The difference between the fuel price is 356 €. The price is 718 € when blowing a headwind with 25 kt, 177 € cheaper than in 100 kt headwind. In zero wind component, the fuel price is 674 €. The price difference is 221 € between zero wind and headwind (100 kt), and 135 € between zero wind and tailwind (100 kt).

From the above demonstrated it is clear, that the fuel consumption and the fuel price are greater in headwind and zero wind components. The fuel consumption decreases with the speed of the tailwind and increases with the speed of the headwind.

3.3. Descend

We expect CDA approach and descend from FL430 by normal descent (2000 fpm). The parameters are the following: anti-ice system off, gear and flaps up, and speed brakes retracted. KIAS is 200 kt. This information is from the C560 XLS+ AFM manual. The WT of the A/C is 1 600 LBS. We expect ISA condition. In descend and take-off performance the headwind has a positive impact on the aircraft. In this meteorological condition and operational parameters, the distance is 134 NM, and the descend time is 1,7 min. The fuel consumption is approximately 410 LBS.

The fuel price for the 3 segments of the flight is approximately 125,87 USD, which means 119,31€. [12]

3.4. Holding

When a microburst or turbulent condition occurs near the RWY, the APP and landing procedure is impossible. In this situation, the reason is to choose an alternative airport or a holding procedure. When the A/C is in a holding in FL250 (25 000 ft) with the following operational parameters: anti-ice system off, gear and flaps up, speed brakes retracted, WT of A/C is 16 000 LBS, KIAS is 180 kt the total fuel consumption per hour is 853 LBS.

If the holding takes only 10 minutes, the fuel consumption in the mentioned meteorological condition and operational parameters is 143 LBS, which costs approximately 43,901 USD and 41,613€.

The 30 min holding costs 131,703 USD and 124,839€ (429 LBS). [12]

4. DISCUSSION

Chapter 2 discusses the fact, that the weather condition greatly impacts the aircraft operational parameters, fuel consumption, and pricing. The headwind positively impacts the A/C take-off and landing stage, but negatively the en-route flight stage. The Fig. 4 demonstrates the fuel price differences depending on the flight and meteorological conditions.

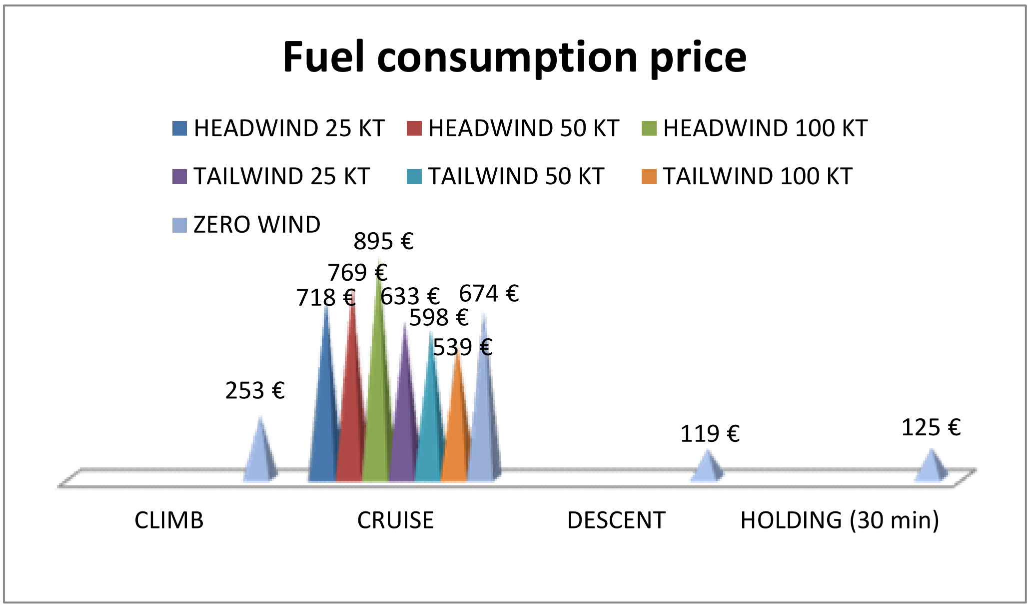


Figure 4 Fuel consumption price in EURO
[own processing, based on [10]]

From Fig. 4 it is clear, that the whole flight fuel consumption (including climb, cruise, and descent with holding) costs approximately:
- 1 171€ in a zero wind en-route condition
- 1 392€ if the en-route flight is in the headwind (100 kt) condition
- 1 036€ if the en-route flight is in the tailwind condition (100 kt). The climb and descent are in zero wind components because the wind minimally impacts the fuel consumption (from AFM manual). [10,12]

The 30-minute holding fuel price is 125 € in ISA meteorological conditions and at 25 000 ft.
In this paper, the mentioned values are from the AFM manual, and the price of the JET A1 fuel is concerned with the exact month and fuel delivery company.

The data are for the simulation from the tested and analyzed models because of the safety and security preservation.

5. METHODOLOGY

The initiative of the research came from the operation in the aviation business jet company and flight school. In these companies, the everyday work duty contained the following activities:
- modeling and calculating the fuel consumption in different meteorological conditions for different routes and ways to different destinations
- calculating the fuel price based on the given monthly price, fuel delivery companies, planned tracks (airways or FRA, A/C type, fuel consumption based on the tracks, and meteorological conditions...)
- calculating the economic outcomes.

The modeling and analysis of the whole flight (within the flight tracks, fuel consumption, A/C load and PAX information, actual meteorological condition,...) was provided in the given system NAV extended with the flight planning, maps function from the Eurocontrol and Vario system.

The methodology of this article started with the initiative of the idea. Process in short (in this paper) one part of the briefing preparation for the pilots - provided by the operation department (flight dispatchers).
The used methods in this article were:

- brainstorming
- statistics methods, calculation, figures, graphs
- information gathering and collecting during work duty
- analyzation and evaluation of the data
- process the dates in a cohesive whole
- made the model with the help of the mentioned systems and AFM and OM manuals
- take care of the security.

The final result was evaluated. Based on the analysis and evaluation the article brings information from the praxis, and information about fuel consumption, price, and economic situation, which is important for the air companies.

6. CONCLUSION

The article deals with the topic "The impact of wind components on aircraft fuel consumption and pricing". Based on the simulation models, it gives information about the fuel consumption of the A/C type - Cessna Citation 560 XLS+ in different flight stages, wind components, and conditions. Consequently, it shows the actual fuel price regarding the simulated models. The fuel price differs in every meteorological condition, wind component, and flight stage. But not only the weather conditions change, but the fuel price too.

The models confirm the following facts:

- the highest fuel consumption during cruise flight (it is the longest flight stage) is in the headwind component
- the lowest fuel consumption during cruise flight is in the tailwind component.

The models also show how the fuel price changes depending on the flight stages, wind components, A/C types, and parameters - the price is the greatest in headwind components during en-route flight.
The models not only confirm the facts but also show economic price differences and changes. It is important from both sides - management (including economy) and A/C performance (including safety and security too).

Similar topics also appear in Scopus and Web of Science journals too, like [1], [2]. In [2] the authors focus on the fuel flow only in the cruise phase. The other articles with similar issues are mentioned in the part of Introduction.

REFERENCES

Journals:

[1] Hassan, T.H.; Sobaih, A.E.E.; Salem, A.E. Factors Affecting the Rate of Fuel Consumption in Aircrafts. Sustainability 2021, 13, 8066. https://doi.org/10.3390/ su13148066

[2] Enis .T. Turgut, Mustafa Cavcar, et.al. Fuel flow analysis for the cruise phase of commercial aircraft on domestic routes. Aerospace Science and Technology. Vol. 37, August 2014, pages 1-9. https://doi.org/10.1016/j.ast.2014.04.012

[3] Némethová, H. Švec, M., Kandráč, P. The Influence of Global Climate Change on the European Aviation. International Journal on Engineering Applications (IREA), Vol. 6, N.6, November 2018

[4] Némethová, H., Neštrák, D., Fábry, Ľ., Rozenberg, R. The C560 XLS+ Aircrafts Landing Distance Variability According to Temperature and Wind Component Effect. 978-1-7281-4079-7/19 IEEE 2019

[5] Némethová, H., Petríček, P., et al. Civil Aviation Experience for the Air Force: The Impact of Global Climate Change on the Selected Parameters of the Cessna Citation XLS+. International Conference on Military Technologies (ICMT) 2019. Brno, Czech Republic. 978-1-7281-4593-8/19. 2019 IEEE.

[6] Soledad Le Clainche, Esteban Ferrer, Sam Gibson, et. al. Improving aircraft performance using machine learning: A review. Aerospace Science and Technology, Vol. 138, July 2023. https://doi.org/10.1016/j.ast.2023.108354

[7] D.K. Wasiuk, M.H. Lowenberg, D.E. Shallcross. An Aircraft performance model implementation for the estimation of global and regional commercial aviation fuel burn and emission. Transportation Research Pert D: Transport and Environment, Vol. 35, March 2015. https://doi.org/10.1016/j.trd.2014.11.022

[8] K. Seymour, M. Held, G. Georges, K. Boulouchos. Fuel Estimation in Air Transportation: Modeling global fuel consumption for commercial aviation. Transportation Research Pert D: Transport and Environment, Vol. 88, November 2020. https://doi.org/10.1016/j.trd.2020.102528

[9] Chenyu Huang, Xiaoyue Cheng. Estimation of aircraft fuel consumption by modeling flight data from avionics systems. Journal of Air Transport Management, Vol. 99, March 2022. https://doi.org/10.1016/j.jairtraman.2022.102181

Books:

[10] FAA Approved Airplane Flight Manual Citation XLS+, Model 560XLS 560-6001 and on.

[11] CAE Oxford Aviation Academy. Meteorology ATPL Ground Training Series. Limited 2014. Printed in Singapore by KHL Printing Co. Pte Ltd.

Online:

[12] https://jet-a1-fuel.com/price/cyprus

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