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AVIATION SECURITY IN CONFLICT ZONES: THE ROLE OF GDP PER CAPITA IN MITIGATING RISKS

The paper investigates the relationship between GDP per capita and the risk of aircraft shootdowns in conflict zones, revealing a strong correlation between economic stability and aviation security. With global air traffic recovering post-COVID-19, aviation security remains a critical challenge, particularly in conflict zones. The study quantifies this risk by analysing 178 shooting incidents and employing a Generalized Linear Model to predict the probability of aircraft being shot down. Findings show that lower GDP per capita increases the likelihood of such incidents. Incorporating economic data into security models can help improve risk assessment for future aviation operations.

The research underscores the importance of using GDP per capita as a key economic metric when assessing national and aviation security risks. By examining conflicts and flight operations data, the study shows that countries with stronger economies, as reflected by higher GDP per capita, are less likely to experience aviation security incidents.

The analysis uses variables such as the nature of the flight, conflict intensity, and type to create predictive models, suggesting that economic conditions play a vital role in mitigating security threats in civil aviation. This approach to aviation security analysis not only emphasizes the importance of GDP as a measure of national stability but also points to the broader use of quantitative methods in predicting and managing security risks. The inclusion of GDP data into risk models provides a more robust framework for understanding and mitigating the likelihood of civilian aircraft being shot down in conflict zones, offering valuable insights for policymakers and airline operators. Future research should explore additional economic and geopolitical factors to enhance these models further.

Keywords: *risk, aviation security, conflict zones, quantitative methods, economic indicators*

The problem statements. Steady growth of global passenger traffic in recent years demonstrates that aviation has recovered from the effects of COVID pandemic. In 2021 airlines transported over 2.3 billion passengers, in 2022 – 3.2 billion, in 2023 – 4.2 billion passengers that is only slightly less than in pre-pandemic 2019 – 4.5 billion passengers [1]. Civil aviation is experiencing significant growth and expansion nowadays along with few other sectors. It remains a highly popular means of transportations and considering this positive trend it is highly likely that passenger numbers of 2024 will be even higher than in pre-pandemic 2019.

At the same time, civil aviation is particularly susceptible to numerous security threats. The International Air Transport Association (IATA) identifies five key threats applicable to aviation:

- "Insider threats" present potential internal risks to airlines;
- Civil unrest that can endanger aircrew at their layovers away from home bases;
- Operations in the vicinity of airspace with conflict zones;
- Security breaches caused by lone-wolf attacks or terrorist incidents;
- Human trafficking, inadequately documented passengers and contraband [2].

As we see, operations over or in the vicinity of conflict zones are one of the five key threats to aviation. This threat is widely known mostly due to two most notable air accidents of the last decade – shooting down of Malaysian Airlines flight MH17 in 2014 and the Ukrainian International Airlines flight PS 752 in 2020. Besides these known accidents, there are more than 300 other events of shooting at passenger, cargo, humanitarian and other aircraft between 1946 and 2024 [3].

These incidents occurred across throughout a number of regions worldwide, resulted in different numbers of casualties, involved aircraft of various sizes and types. A broad range of weapons were utilized in these events, including small arms, anti-aircraft artillery, and surface-to-air missiles.

Despite the above variations, certain commonalities were observed: the majority of these incidents took place in areas experiencing some sort of war conflict or in countries facing economic hardship. European Union Aviation Safety Agency, EASA, currently acknowledges 13 active conflict zones worldwide [4]. Some of the zones are located at the areas with vital air ways, where air traffic is particularly busy, such as Iraq, Yemen, Israel, Lebanon, Afghanistan, Pakistan, areas in the vicinity of Ukrainian and Russian borders. This creates additional operational constrains on top of already congested airspace caused by post-pandemic growth of air traffic. Given the absence of a standardized industry methodology for risk management, airlines are responsible for managing risks themselves, leading to significantly different approaches when planning the same route (Fig. 1).

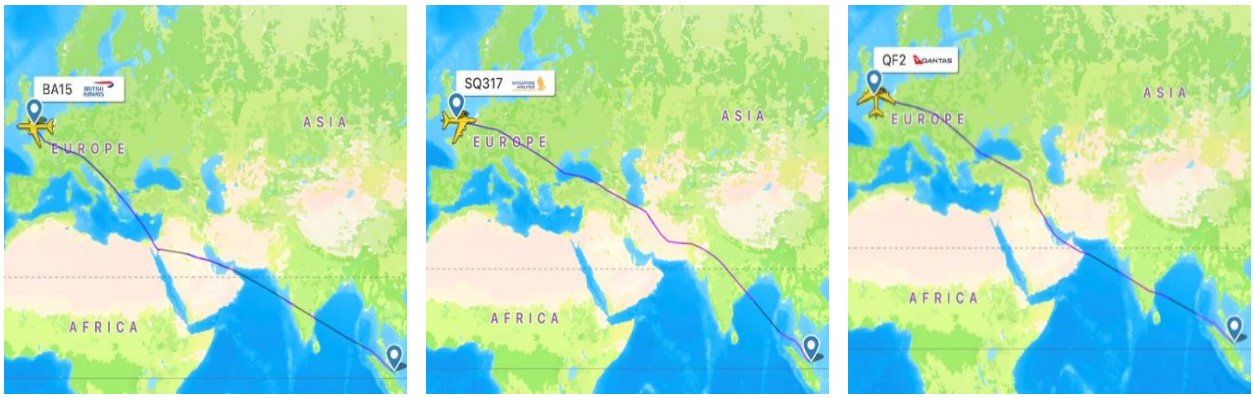

Fig 1. Flight paths of flight London-Singapore. Left to right: British Airways, Qantas, Singapore Airlines July 2024 (flightradar24.com)

Source: built by the author based on the source flightradar24.com

Literature review. The paper explored a number of sources covering aviation authorities' regulations and reports, such as ICAO's Safety Report" (2024) (ICAO, 2024 #1) and IATA's "What You Need to Know About Aviation Security" (2023) [2] that focus on global aviation safety protocols; EASA's "Conflict Zone Information Bulletin" (2024) [4] that highlights conflict-related risk zones; government reports and laws such as Gore's report to President Clinton (1997) [5] and the 107th Congress Homeland Security Act (2002) [6], that address foundational aviation and national security legislation. Our research also analyses papers by Luciani (1988) [7] and Humphreys (2003) [8] establishing links between economy and security and Bukhman et al. (2024) that use data-driven methods for risk assessment in conflict zones. This research also uses several datasets, such as Aviation Safety Network (2024) [3] that provides incident databases, examining shot-down incidents due to ground fire, Uppsala Conflict Data Program (2020) [9] that categorizes conflicts worldwide and World Bank's database of GDP per capita per country per year [10].

Purpose of the article. This paper aims to explore the relationship between economic indicators and levels of national and aviation security, focusing on how these connections can help mitigate the risk of aircraft being shot down over conflict zones. Comprehending these relationships is essential for formulating effective risk mitigation strategies to enhance security of civil aviation, reducing the likelihood of civilian aircraft shootdown incidents and improve the efficiency of flight planning and operation.

Results.

Economic indicators impacting the level of security

Undoubtfully, aviation security is an integral part of national security of any country with the developed aviation infrastructure. This was recognized and highlighted in the report of White House

Commission on Aviation Safety and Security [5], US Homeland Security Act [6], national security strategies of United Kingdom, Germany, Australia [11] [12, 13].

Threats to national and international security were categorised and summarised by the United Nations, UN, in their high-level panel "Report on Threats, Challenges and Change. A more secure world: our shared responsibility". These threats as follows:

1) Economic and social threats, poverty, infectious diseases, and environmental degradation;
2) Inter-state conflict;
3) Internal conflict, including civil war, genocide, and other large-scale crimes;
4) Nuclear, radiological, chemical, and biological weapons;
5) Terrorism; and
6) Transnational organised crime [14].

Similarly to the above, the United Nations Development Program, UNDP, the UN agency dedicated to economic assistance to the developing countries, suggests that proper security level can be achieved by protecting people and fundamental freedoms from critical threats, such as war and violent conflicts and by reducing poverty and achieving economic growth; the latter two factors also positively influencing national security [15].

According to Luciani [7], national security is the ability to withstand external aggression, where aggression is defined as an active use of force by an invading army occupying a part of national territory. In narrower definition, territorial integrity and possession of the land are key interests of national security and are essential for the wellbeing of the nation. At the same time, wider context of national security is strongly linked to economic prosperity. Under the broad definition, economic prosperity is a key element to national consensus and political stability, while deterioration of the economy can be considered as a threat to national security and, in extreme cases, be equal to aggression [7].

Humphreys [8] further develops this areas arguing that low level of GDP per capita can serve as a predictor of civil war: for example, nations with GDP per capita of 250 USD have a 0.15 probability of civil war, while nations with GDP per capita of 2,500 USD have a less than 0.01 probability of civil war [8] . The definition of GDP per capita as per the Cambridge dictionary is the following: "The total value of all the goods and services produced by a country in a particular year, divided by the number of people living there". US Bureau of Economic Analysis also considers GDP per capita as an important parameter of economic performance and an indicator of economic wellbeing [16].

As a result of the aforementioned points, it becomes clear that:

1) aviation security is an integral part of the national security;
2) the level of national security is strongly linked with economic stability and nation wellbeing;
3) GDP per capita can serve as a key metric for assessing economic stability and overall well-being of a country.

Therefore, a robust economy, as reflected by GDP per capita, is likely to enhance national security, which in turn strengthens aviation security. Thus, we can conclude that GDP per capita of the state is a significant economic metric that should be correlated with the likelihood of civilian aircraft being shot down.

Assessing the relationship between GDP per capita and civil aircraft shootdown risk

Our previous research aimed to quantify risks of aircraft shootdown and assess the probability of such event. To achieve this goal, we analysed 178 shooting incidents between 1961 and 2018 along with the quantitative data about conflicts [9], data of GDP per capita [10], types of commercial air operations [3] and number of flights departing from the affected countries [17]. The data was quantified, and following independent variables developed (table 1). The dependent variable was probability of the shooting attack. The regression model was bult with the help of SPSS Statistics software package.

Table 1. Independent variables

	Variable	Variable description and type	Variable code	Source (dataset)
1	GDP per capita	GDP per capita in the given country in given year, thousands of USD, scale variable. The variable is introduced as a descriptor of economic wealth and stability that influences the level of national security. Scale variable	*GDP_PC_1000*	The World Bank national accounts data
2	Intensity of the conflict	Intensity of the conflict where 1 and 2 represents minor conflict and war, respectively. Presence of the conflict and its intensity are factors significantly affecting the national security. Categorical nominal variable	*Conflict_Intensity*	Uppsala Conflict Data Program
3	Type of the conflict	Type of the conflict, where 1, 2, 3 and 4 represents extra-systemic conflict, interstate, internal and internationalised internal conflict, respectively. For the prediction of the risk of shooting down civilian aircraft it is important to consider what kind of conflict was registered in the area. Categorical nominal variable	*Conflict_Type*	Uppsala Conflict Data Program
4	Nature of the flight	Nature of the flight, where 1-8 represents scheduled flights, other passenger, cargo, military, aerial works, other, special flights, and non-scheduled flights, respectively. The variable is introduced to capture possible relation of type of commercial operations and probability of shooting down the flight. Similar relation exists in air safety. Categorical nominal variable	*Nature_Of_Flight*	Aviation Safety Network

Source: formed by the author based on the source [3, 9, 10].

We found out that Generalized Linear Model (GLM) Gamma with log link was then most appropriate regression model for the prediction of the risks [18]. Using the regression formula (1) from this research we can find the relation between GDP per capita and risk of the aircraft being shot down:

$$\ln(P_{Attack}) = -6.21 + (-0.589)\,Conflict\_Intensity\_1 + (-0.560)Conflict\_Type\_2 +$$
$$(-0.668)Conflict\_Typ\_3 + (-1.19)Nature\_Of\_Flight\_1 + (-0.911)Nature\_Of\_Flight\_2 +$$
$$(-0.906)Nature\_Of\_Flight\_3 + (-0.570)Nature\_Of\_Flight\_4 +$$

$$(-1.91)Nature\_Of\_Flight\_5 + (-3.32)Nature\_Of\_Flight\_6 + (-0.556)Nature\_Of\_Flight\_7 + (-0.354)GDP\_PC\_1000 \quad (1)$$

Consequently, the probability of an aircraft being shot down over country C P_{Attack} is reflected in following formula (2):

$$P_{Attack}\,(C, Y) = e^{\ln\,(P_{Attack})} \quad (2)$$

Using the above formulas, we can establish the relationship between the probability of an aircraft shooting incident and country GDP per capita.

For this analysis we assume the conflict intensity is classified as 'war' (variable *Conflict_Intensity=2),* and the as 'internationalized internal' (variable *Conflict_Intensity=4).* Additionally, we consider two types of commercial air operations: scheduled *(Nature_Of_Flight=1*) and non-scheduled *(Nature_Of_Flight=8).*

The resulting probabilities are presented in Table 2 and visualised at Figure 2.

Table 2. Probability of civil aircraft shootdown depending on GDP per capita

	Probability of shootdown of civil aircraft	
GDP per capita, USD	Scheduled flight	Non-scheduled flight
1	0.03%	0.11%
2	0.03%	0.11%
4	0.03%	0.11%
8	0.03%	0.11%
16	0.03%	0.11%
32	0.03%	0.11%
64	0.03%	0.11%
128	0.03%	0.11%
256	0.03%	0.10%
512	0.03%	0.09%
1024	0.02%	0.08%
2048	0.02%	0.05%
4096	0.01%	0.03%
8192	0.00%	0.01%
16384	0.00%	0.00%

Source: calculated by the author

The above Table 2 and Figure 2 demonstrates relation between a country's GDP per capita and the likelihood of civilian aircraft being targeted in conflict zones. Lower GDP per capita is associated with higher probability and higher GDP demonstrates lower probability of shootdown incidents.

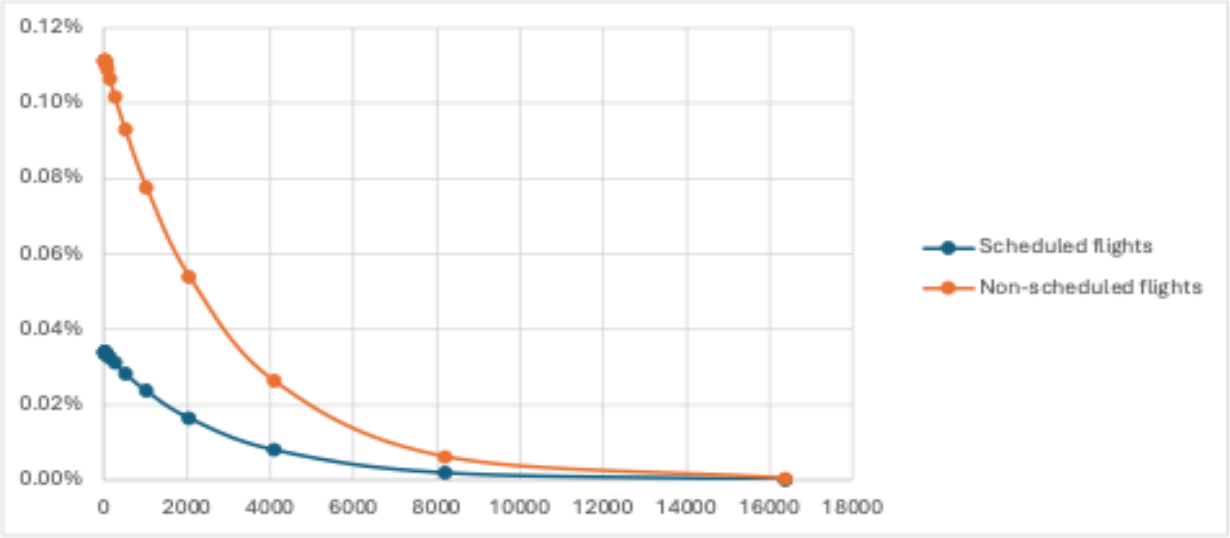

Fig. 2. Dependency of probability of aircraft shootdown from GDP per capita in the country
Source: calculated and built by the author

Conclusions. Over the years, a number of tragic incidents involving passenger aircraft being shot down by surface-to-air missiles have occurred, highlighting existing risks faced by civil aviation in conflict zones. As geopolitical tensions continue to persist in various regions globally, the threat remains significant. This emphasizes the need for innovative, data-driven methodologies that can better predict and assess the risks of such attacks. These approaches would not only enhance the safety of commercial aviation but also support more informed decision-making in route planning and operational strategies.

A limitation of the approach described above is its reliance on national boundaries, which may not provide an accurate picture of risk in larger countries where security conditions can vary widely across regions. While some areas may be stable, others may face localized conflicts or unrest. In such cases, GDP per capita at the national level may not be the best indicator. To improve the model's accuracy, additional regional factors and indicators should be integrated. This would allow for more precise risk assessments and better aviation safety strategies.

The above analysis has demonstrated that there is a clear correlation between a country's GDP per capita and the probability of civilian aircraft being shot down. As GDP per capita reflects economic stability and national security, lower values often reflect underlying socio-political tensions and economic challenges, while higher values suggest a more stable economy. Although GDP per capita is a significant economic indicator, further research could explore additional factors contributing to the relationship between socio-economic conditions and a threat of an aircraft shootdown. This research also highlights that a quantitative, data-driven approach to measuring security risks presents significant opportunities for applying regression and machine learning methods. By incorporating values like GDP per into the model more accurate and reliable predictions can be made. The accessibility of relevant data will further enhance the precision of these models and their prognostic capabilities.

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БУХМАН СТАНІСЛАВ ЄВГЕНІЙОВИЧ. АВІАЦІЙНА БЕЗПЕКА В ЗОНАХ КОНФЛІКТУ: РОЛЬ ВВП НА ДУШУ НАСЕЛЕННЯ В ЗНИЖЕННІ РИЗИКІВ. *Стаття досліджує взаємозв'язок між ВВП на душу населення та ризиком збиття повітряних суден у зонах конфліктів, виявляючи сильну кореляцію між економічною стабільністю та авіаційною безпекою. У зв'язку з відновленням світового авіасполучення після пандемії COVID-19 авіаційна безпека залишається критичною проблемою, особливо в зонах конфлікту. Дослідження кількісно оцінює цей ризик шляхом аналізу 178 випадків збиття повітряних суден та використання узагальненої лінійної моделі (Generalized Linear Model, GLM) для прогнозування ймовірності збиття літака. Висновки показують, що нижчий ВВП на душу населення збільшує ймовірність таких інцидентів. Дослідження підкреслює важливість використання ВВП на душу населення як ключового економічного показника при оцінці національних ризиків та ризиків авіаційної безпеки. Вивчаючи дані про конфлікти та польоти, дослідження показує, що країни з більш стабільною економікою, про що свідчить вищий ВВП на душу населення, рідше стикаються з інцидентами авіаційної безпеки. Цей підхід до аналізу авіаційної безпеки не тільки підкреслює важливість ВВП як показника національної стабільності, але також вказує на необхідність більш широкого використання кількісних методів у прогнозуванні та управлінні ризиками безпеки. Включення даних про ВВП у моделі ризиків забезпечує більш надійну основу для розуміння та зменшення ймовірності збиття цивільних повітряних суден у зонах конфлікту, пропонуючи цінну інформацію для регуляторів, авіаційних адміністрацій та операторів авіакомпаній.*

Ключові слова: *ризик, авіаційна безпека, конфліктні зони, кількісні методи, економічні показники*