

NATBLUE - A MODELLING TOOL FOR ASSESSING NORTH ATLANTIC AIR TRAFFIC MANAGEMENT CONCEPTS

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Abstract

The aviation sector is responsible for approximately 2 to 3% of global CO₂ emissions. New solutions must therefore be found to reduce this environmental footprint. One solution is the development of new technologies such as hydrogen-powered aircraft and the use of alternative fuels. The development and implementation of these solutions usually requires years or decades and high investments. Another solution is to optimize the current air traffic operations. This approach can provide short- to medium-term solutions to improve flight efficiency and reduce the overall aviation emissions. The North Atlantic (NAT) Air Traffic Management (ATM) system is largely based on the communication, navigation and surveillance (CNS) technologies of how it was decades ago. The upgrades have so far been limited to reduced vertical separation minima and in-trail climb procedures in some specific airspace. Over the NAT a track system is still being used, with large lateral separation minima to ensure safety. While ensuring safety, both this set-up as well as the underlying assumptions about CNS, severely reduce the effectiveness of the operations most of all in terms of sustainability of the operations as well as the capacity. Recent research has investigated possible improvements for the NAT ATM, such as climate-optimised routes and improved communication networks. However, there is no standardised and open-access simulation framework for comparing these different approaches. This study introduces the North Atlantic Modelling Tool – Bluesky (NATBlue), which is developed using the open ATM simulator BlueSky to fill this gap. NATBlue is a fast-time simulation framework tailored for the NAT ATM. It integrates several components, such as an aircraft performance model, a wind model, a conflict model, a logger and NAT specific components. This enables an assessment of different ATM solutions for the NAT airspace. The paper explains the general structure, the individual components and their functionalities in detail as well as ongoing developments are discussed. Finally, an exemplary usage with realistic traffic and wind data is used to illustrate the application of NATBlue. By providing an open-access modelling tool, NATBlue enables a comprehensive evaluation of different ATM strategies for the NAT ATM. This will support the effort to improve the efficiency and sustainability of NAT ATM.

Keywords

Air Traffic Management; North Atlantic; Fast Time Simulation

NOMENCLATURE

Abbreviations

ADS-B	Automatic Dependent Surveillance - Broadcast
AIS	Aeronautical Information Service
ANSP	Air Navigation Service Providers
ASAS	Airborne Separation Assurance System
ATM	Air Traffic Management
BADA	Base of Aircraft Data
CNS	Communication, Navigation, and Surveillance
CPDLC	Controller Pilot Data Link Communication

DHA	Dynamic Managed Hazard Areas
NAT	North Atlantic
OCA	Oceanic Control Areas
OpenAP	Open Aircraft Performance
OTS	Organized Track System

1. INTRODUCTION

Aviation is responsible for around 2–3% of global anthropogenic CO₂ emissions. This share is expected to rise with continued growth in air traffic demand [1]. Long-term solutions such as new aircraft technologies and alternative fuels are essential to tackle the emission reduction, but will take decades to implement and scale. In the meantime, operational



FIG 1. North Atlantic airspace (purple dashed line) and the six Oceanic Control Areas: BGGL, ENOB, BIRD, CZQX, EGGX, KZNY, LPPO

improvements in Air Traffic Management (ATM) offer a direct and effective way to reduce emissions in the short- to medium-term [2]. Even modest increases in efficiency can yield substantial environmental benefits, especially for long-haul flights. Long-haul flights contribute to more than half of aviation's emissions, although they only account for eight percentage of total flights [3]. As a result, optimizing ATM is a critical short-term lever for mitigating aviation's climate impact while technological transformations are still under development.

1.1. North Atlantic Air Traffic Management

The North Atlantic (NAT) airspace represents the busiest oceanic airspace in the world. It's build by six Oceanic Control Areas (OCAs), displayed in Figure 1. Over half a million flights per year are handled in NAT airspace with an estimated traffic growth of 4% yearly [4]. The traffic is characterised by two major traffic flows: westbound and eastbound flow. Those flows exists due to several factors, such as different time zones, passenger demand and the energetic nature of the NAT weather, such as the jet stream [5]. Unlike continental regions, ATM in the NAT faces challenges due to limited Communication, Navigation, and Surveillance (CNS) capabilities as there is no ground-based surveillance in the NAT. To ensure safety and efficiency, the Organized Track System (OTS) was established in the 1970s [4]. The OTS provides a structured set of tracks that help to navigate and separate across the NAT airspace. The OTS are published twice a day, once for westbound and once for eastbound traffic. Figure 2 shows the NAT airspace and an exemplary set of three westbound and eastbound tracks. Usually five to seven tracks are published for each direction, depending on the traffic demand. Longitudinal separation within the

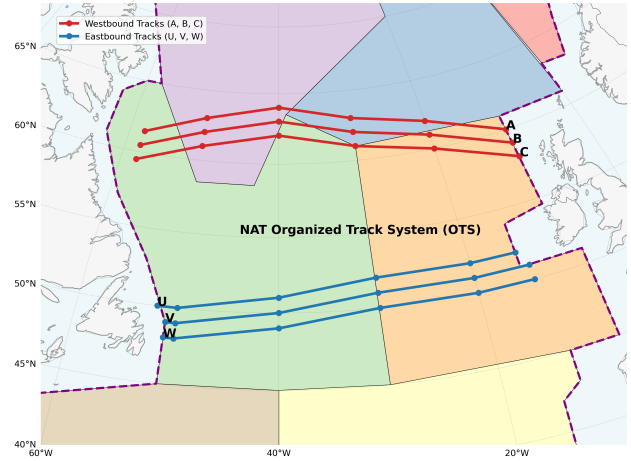


FIG 2. North Atlantic Airspace with exemplary westbound tracks A, B, C (red) and eastbound tracks U, V, W (blue) from the Organized Track System

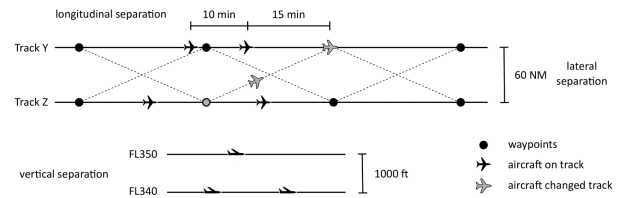


FIG 3. Organized Track System: separation standards and procedures along the tracks based on [4]

OTS is applied on a time-based scale, whereas lateral separation is carried out distance based, see Figure 3. While the OTS enables safe flight progress, it also restricts operational flexibility in the NAT airspace. This is reflected in the fact that often aircraft are prevented from flying at optimal flight levels. The reduction in aircraft mass due to progressive fuel consumption continuously changes the optimum flight level. Therefore, continuous climbing would be beneficial for fuel consumption. Additionally, optimising aircraft trajectories on a lateral domain, for example wind-optimal routes, could be beneficial too. The reasons for prevention of vertical and lateral optimisation are mainly the high separation minima and the static route environment. This reduces efficiency and increases flight fuel consumption, which highlights the need for improved ATM concepts for the NAT airspace with a growing traffic demand.

1.2. Current developments

Current developments in NAT ATM mainly target the improvement of the OTS. Several studies have proposed new track structures aligned with the jet stream to reduce flight times and fuel consumption [6,7]. Others have investigated the impact of reducing lateral and longitudinal separation standards [8], supported by new surveillance technologies such as Automatic Dependent Surveillance - Broadcast (ADS-B) over satellite. In parallel, concepts for free wind-optimal operations have been developed [9], allowing aircraft

to leave the rigid OTS and instead follow optimised trajectories through the NAT airspace. These operational improvements are increasingly supported by enhanced communication and navigation networks, such as Controller–Pilot Data Link Communication (CPDLC) and satellite-based CNS, which provide the infrastructure needed for more flexible and dynamic routing.

Most of these mentioned concepts have been tested with dedicated mathematical formulations or specialized simulation studies, each designed to validate a particular approach. While these studies demonstrate significant potential for the reduction of fuel consumption and emissions in NAT operations, their closed or proprietary methods limit comparability between different proposals. What is missing is a standardised, open-source simulation environment that enables the systematic evaluation of different concepts under consistent conditions. Such an approach would not only provide a basis for comparison but also accelerate the development of operationally feasible solutions or the combination of solutions for the NAT ATM.

This paper introduces NATBlue, a fast-time simulation framework built on the open-source BlueSky simulator developed at TU Delft. NATBlue extends the simulator with dedicated plugins and functionalities tailored to the NAT. This enables the evaluation of different concepts specific to NAT ATM in a reproducible environment. The framework provides both the general simulation infrastructure and specialized components that capture the characteristics of NAT operations.

The paper is structured as follows: Section 2 provides a description of the overall architecture of NATBlue followed by a detailed explanation of its individual components/plugins as well as discusses ongoing developments and extensions. A case study illustrates the application of NATBlue in practices in Section 3, followed by a conclusion in Section 4.

2. NORTH ATLANTIC MODELLING TOOL - BLUESKY

In this section, the BlueSky simulator is briefly introduced, followed by a detailed description of the self contained NAT specific plugins and their functionalities in NATBlue. All plugins are written in Python. NATBlue is open-source and can be found on: <https://github.com/NilsAhr/NATblue>.

2.1. BlueSky

BlueSky is an open-source air traffic simulator developed at TU Delft to provide a transparent, flexible and shareable research environment [10]. Its architecture is modular, with core components for simulation control, traffic modelling, user interface and tools for navigation and aerodynamics. Scenarios are defined through a simple plain-text language (TrafScript), which is also used by NLR, DLR and NASA [10]. Generally, the

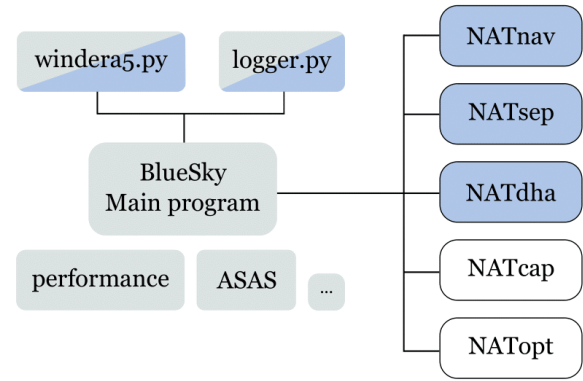


FIG 4. General architecture of NATBlue: BlueSky internal functionalities (gray), extended plugins (gray and blue), self-contained NATBlue plugins (blue), ongoing developments (white)

simulator is written in Python and distributed under the GNU GPL. This makes it easy to adapt and extend, while remaining platform-independent. The navigation database is based on published open data as part of the Aeronautical Information Service (AIS) by the authorities. Flight performance can be modelled using the Base of Aircraft Data (BADA) from EUROCONTROL or Open Aircraft Performance (OpenAP) model.

A key advantage of BlueSky is that it can simulate hundreds of aircraft in real-time or fast-time on a standard computer, comparable to commercial ATM simulators but without their licensing restrictions. This makes it particularly well-suited for developing and testing new ATM concepts. For more detailed information about BlueSky, please see [10].

Building on these features, this paper introduces NATBlue, an extension of BlueSky with dedicated plugins and functionalities tailored to the NAT, which will be explained in the next sections.

2.2. NATBlue plugins

The purpose of the plugins is to extend the BlueSky functionalities and enable faster validation of different ATM concepts for the NAT airspace. Figure 4 illustrates the general architecture. Gray boxes, such as performance and Airborne Separation Assurance System (ASAS), are BlueSky internal functionalities, for more details please see [10]. Gray and blue coloured boxes represent BlueSky internal plugins, which were extended with more functionalities and blue boxes show NATBlue specific plugins. White boxes depict ongoing developments and initiatives. All plugins functionalities will be explained in more detail in the following section. Possible use cases for those plugins will be then explained subsequently.

NATnav

The NATnav plugin provides the navigational basis for simulations in the NAT airspace. A function enables the load of oceanic tracks from the daily Organized

Track System (OTS), which is generated from publicly available information published by Air Navigation Service Providers (ANSP). Within the simulation, the OTS is implemented as predefined routes and displayed on the graphical interface. In addition, the NATnav plugin includes functions to import oceanic sector boundaries and NAT borders, which can be used both for filtering traffic and for evaluation purposes. Furthermore, oceanic entry and exit points can be imported by a function from a list as simulation waypoints. This is important since entry and exit points might be changed by the ANSPs over time.

NATsep

The NATsep plugin enables the simulation of separation standards specific to NAT airspace. Due to the above mentioned limited CNS capabilities, separation minima in the NAT differ from those applied in continental regions.

The NATsep plugin allows to define and manage this distinction by assigning dedicated separation minima directly to aircraft entering the NAT airspace by a stack command after the plugin is activated. This includes definition of lateral, longitudinal, and vertical separation minima. These can be configured to reflect current standards or adapted to test alternative scenarios. The NATsep plugin therefore provides a flexible framework to investigate the impact of reduced separation or advanced separation assurance systems such as Automatic Separation Assurance System (ASAS), and to quantify their potential benefits in terms of safety and efficiency.

NATdha

The NATdha plugin addresses the emerging challenge of space launch activities over the NAT airspace. The new space sector is growing and with it the impact on the NAT airspace. Current procedures declare the closure of large portions of airspace for the air traffic during launch events. This imposes significant disruption of transatlantic traffic. NATdha plugin was developed to test the new concept of dynamically managed hazard areas (DHA).

The NATdha plugin enables to model different polygons as DHA. The DHAs can be defined, activated, and deactivated within the simulation. Additionally, the NATdha plugin offers functions to capture the operational aspects. Three different evacuation strategies are implemented, which can be selected and activated during the simulation. In the event of a contingency, aircraft endangered by falling debris will be automatically evacuated from the DHA in respect to the selected evacuation method. This provides a plugin to assess the feasibility and efficiency of more dynamic airspace management solutions for mitigating the impact of space activities on NAT operations.

windera5 & logger

Two additional plugins extend BlueSky's internal capabilities to support environmental modeling and

systematic data collection. The windera5 plugin enables the integration of ERA5 reanalysis weather data into simulations [11]. It can automatically access ERA5 data through an API or alternatively load pre-downloaded datasets. For the API usage an user account and credentials are needed.

Update intervals can be defined to match the temporal resolution of the input data, which is particularly valuable for long-duration simulation runs. Complementing this, the logger plugin provides structured output for analysis. It generates two log files: a flight status log (FLST), which records aircraft states and parameters at user defined intervals, and a conflict log (CONF), which captures the number and parameters of conflicts as well as the involved aircraft. This is valuable for post processing of the simulation runs.

NATopt & NATcap

Two additional plugins are currently under development to extend the capabilities of NATBlue. The NATOpt plugin is intended as a real-time trajectory optimization tool that adapts flight trajectories based on aircraft position and weather data. It is designed to pursue different objectives, such as reducing fuel consumption and associated emissions or adjusting the trajectory according to non-CO₂ climate effects. Additionally, the user should be able to determine regular update intervals when trajectory recalculations should be performed during a simulation. This makes it particularly relevant for long-haul flights, where progressive adjustments to changing weather conditions could improve efficiency. The main limitation is currently the high computational demand needed, which makes real-time implementation challenging.

The NATcap plugin focuses on sector capacity estimation. It takes aircraft positions and sector boundaries as inputs and continuously calculates sector occupancy, either relative to a theoretical maximum or tracked over time. This allows changes in sector load to be monitored and compared to current operations, when changing operational procedures.

Although both plugins are still in development, they represent useful extensions of NATBlue toward trajectory optimization and capacity monitoring, providing tools that can support future research into environmental and operational performance in the NAT airspace.

The postprocessing scripts are developed to match the implemented NATBlue plugins. Currently, these scripts are outsourced due to computational intensity and can not yet be run in real-time. In the next section exemplary usage of NATBlue will be explained.

3. USAGE OF NATBLUE

In this section three short examples are shown to illustrate how the plugins have been used. For this purpose, only synthetic data is used, which is intended to give an impression of the contexts in which the

plugins can be used.

Example 1: windera5

In this example, the windera5 plugin was used to load pre-downloaded ERA5 weather data in order to reduce run-time during the simulation [11]. The goal was to analyse the impact of different temporal wind data granularities on flight fuel consumption.

The plugin imported the u (east) and v (north) components of the wind data, which directly influence the flight performance of each aircraft in the simulation [12]. Figure 5 shows the wind field as a calculated vector representation of the ERA5 u and v components for a selected region and time. For more details see [13].

Example 2: NATdha

The NATdha plugin was applied to model the DHA concept for three different space launches and integrate these into the simulation. Figure 6 illustrates the DHA and their activation times within the simulation. In combination with the logger plugin, the number of affected aircraft and the associated flight times were recorded.

The evacuation strategies implemented in NATdha were then used to evaluate their impact on flight times and fuel consumption. This setup provided insight into which approaches are operationally feasible and efficient. For more details see [14].

Example 3: post processing with logger

The logger plugin enables detailed analysis of flight and conflict data after a simulation run. For instance, flight status logs can be used to evaluate performance metrics such as fuel consumption under different scenarios, while conflict logs provide information on the frequency, location, and properties of conflicts. Figure 7 presents an example showing the spatial distribution of conflicts under varying operational conditions.

Ultimately, the use of plugins and the evaluation of data are very project-specific and cannot be standard-

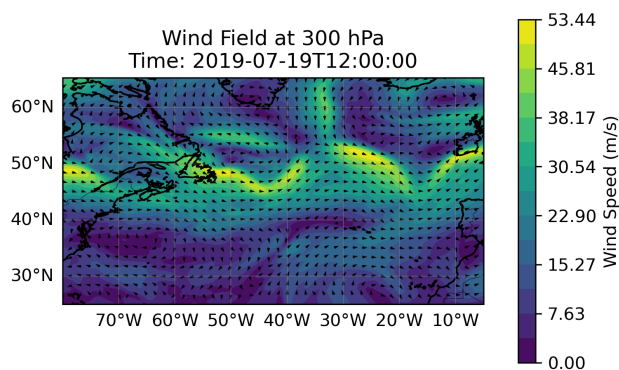


FIG 5. Implementation of ERA5 wind data for the NAT airspace within the simulation environment NATBlue using windera5.py plugin; wind speed (vector) is computed based on u and v wind component; for more details see [13]

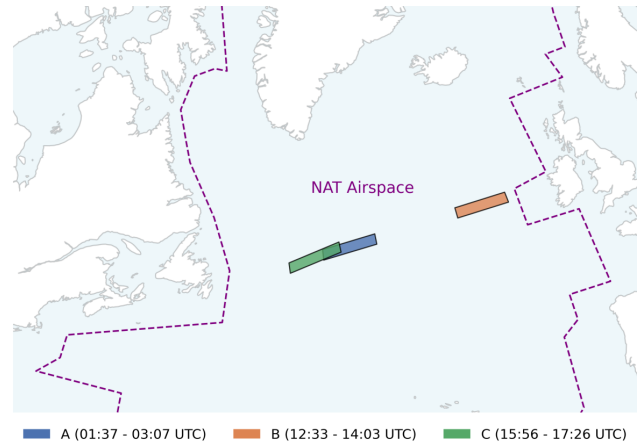


FIG 6. Modelling of DHA in NAT airspace within the simulation environment NATBlue using NATdha plugin; DHA are activated at closure times after contingency event; for more details see [14]

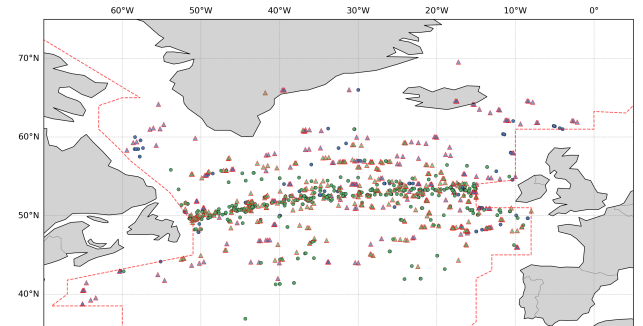


FIG 7. Spatial distribution of conflict (circle) and intrusion (triangle) under different conditions (blue and green) as a results of the logger file postprocessing

ised across the board.

4. CONCLUSION

The North Atlantic remains a unique and challenging airspace, but also one with considerable potential for operational improvements. Those could contribute to reducing aviation's environmental impact. A transparent and open-source simulation environment is required to compare different solutions and concepts in a consistent way.

With NATBlue, the open-source BlueSky simulator has been extended to incorporate North Atlantic-specific requirements. A set of dedicated plugins has been developed that can be adapted and applied to a wide range of research purposes. With continued development, NATBlue has the potential to serve as a shared platform for testing and evaluating new ATM concepts in the NAT, supporting both operational improvements and the broader research community.

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References

- [1] David S Lee, Giovanni Pitari, Volker Grewe, K Gierens, Joyce E Penner, Andreas Petzold, MJ Prather, Ulrich Schumann, A Bais, T Berntsen, et al. Transport impacts on atmosphere and climate: Aviation. *Atmospheric environment*, 44(37):4678–4734, 2010.
- [2] Volker Grewe, Sigrun Matthes, Christine Frömming, Sabine Brinkop, Patrick Jöckel, Klaus Gierens, Thierry Champougny, Jan Fuglestvedt, Amund Haslerud, Emma Irvine, et al. Feasibility of climate-optimized air traffic routing for transatlantic flights. *Environmental Research Letters*, 12(3):034003, 2017.
- [3] EUROCONTROL. Think paper #22 – long-haul decarbonisation. Think Paper 22, EUROCONTROL, Oct. 2024. Accessed: September 25, 2025.
- [4] ICAO European and North Atlantic Office on behalf of the North Atlantic Systems Planning Group (NAT SPG). NORTH ATLANTIC OPERATIONS AND AIRSPACE MANUAL - NAT DOC 007. International Civil Aviation Organization (ICAO), v.2024, and 4 edition.
- [5] Imen Dhief, Nour Houda Dougui, Daniel Delahaye, and Nouredine Hamdi. Conflict resolution of North Atlantic air traffic with speed regulation. *Transportation Research Procedia*, 27:1242–1249, 2017. ISSN: 2352-1465. DOI: 10.1016/j.trpro.2017.12.155.
- [6] Imen Dhief, Nour Elhouda Dougui, Daniel Delahaye, and Nouredine Hamdi. Strategic planning of North Atlantic Oceanic air traffic based on a new wind-optimal route structure. In *ATM Seminar, 12th USA/Europe Air Traffic Management R&D Seminar*, Seattle, United States, June 2017.
- [7] Banavar Sridhar, Neil Y Chen, K Ng Hok, Olga Rodionova, Daniel Delahaye, and Florian Linke. Strategic Planning of Efficient Oceanic Flights. In *ATM seminar 2015, 11th USA/EUROPE Air Traffic Management R&D Seminar*, Lisboa, Portugal, June 2015. FAA & Eurocontrol.
- [8] Daniel Delahaye Marcel Mongeau Olga Rodionova, Mohammed Sbihi. Optimization of aircraft trajectories in North Atlantic oceanic airspace. In *5th International Conference on Research in Air Transportation, ICRAT2012*, Berkeley, United States, May 2012. ICRAT.
- [9] J.M. Hoekstra, R.N.H.W van Gent, and R.C.J Ruigrok. Designing for safety: the ‘free flight’ air traffic management concept. *Reliability Engineering & System Safety*, 75(2):215–232, feb 2002. DOI: 10.1016/S0951-8320(01)00096-5.
- [10] Jacco Hoekstra and Joost Ellerbroek. Bluesky ATC Simulator Project An Open Data and Open Source Approach. In *7th International Conference on Research in Air Transportation*, volume 131, p. 132, Washington, DC, USA, 2016. FAA/EUROCONTROL.
- [11] et al. H. Hersbach. Era5 hourly data on pressure levels from 1940 to present. Technical report, Copernicus Climate Change Service (C3S) Climate Data Store (CDS), 2023. DOI: 10.24381/cds.bd0915c6.
- [12] Anabelle Menochet. Era5: How to calculate wind speed and wind direction from u and v components of the wind? ECMWF / Copernicus Knowledge Base (Confluence Wiki), Mar. 2024. Last modified: Mar 26, 2024. Accessed: September 25, 2025. <https://confluence.ecmwf.int/pages/viewpage.action?pageId=133262398>.
- [13] Nils Ahrenhold, Dirk Kügler, Jacco M Hoekstra, and Joost Ellerbroek. Optimisation of the north atlantic air traffic management to mitigate environmental impact: A simulation-based study on the impact of wind data granularity. In *ATRD Symposium 2025, 1st USA/EUROPE Air Transportation Research Development Symposium*, Praha, June 2025. FAA & Eurocontrol.
- [14] Nils Ahrenhold, Tobias Rabus, Lorenz Losensky, and Annette Temme. Assessing the impact of space launches on north atlantic air traffic management: A simulation-based approach. In *44th Digital Avionics Systems Conference DASC*, Montreal, Canada, Sept. 2025. IEEE & AIAA.