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Safety considerations about hypersonic vehicles integration into ATM/HA

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In recent years, the development of new concepts of suborbital space vehicles for passenger and/or things transportation transiting through ATM and operating at High Altitudes has led to increasingly significant progress of technologies to ensure efficient and safe integration of hypersonic flights into controlled and non-controlled airspace. Airspace segregation ensures safety but is not sustainable for long-term operations.
Investigations are needed on regulating hypersonic vehicles for integration into managed and regulated airspace and at higher altitudes. Moreover, ATM must develop strategies for controlling hypersonic sub-orbital flights and enhancing systems to ensure ATCOs can handle them effectively.
The technological keystone of the European Commission's Single European Sky Initiative that aims to integrate new entrances in an innovative ATM is Single European Sky Air Traffic management (ATM) Research (SESAR) project. From ATM perspective, the trajectory-based operations requirements, developed in SESAR, can facilitate a robust ATM integration of such types of operations. In this direction, these new entrants can be considered as the conventional traffic in ATM scenarios. However, it remains to be analysed how the potential increase in traffic due to the integration of hypersonic operations and their different speed performances, characteristics and constraints can impact the current mandatory level of Safety.
This paper aims to provide an overview of potential ATM scenarios including suborbital vehicles, investigating on the potential effects that these new operations can have in terms of Safety on risk models currently applied by the SESAR safety methodology. Based on the identified safety impacts of hypersonic operations on the future ATM developments, a gaps analysis has been carried out to identify potential additional requirements for contributing to the quantification of the new safety criteria related to the hazard analysis of the Integrated Risk Picture (IRP) for ATM in causing or preventing accidents.

Keywords: Safety, ATM, hypersonic vehicles.

1. Introduction

Technological innovation has led to a rise in emerging airspace users, exploiting new commercial opportunities from very low to very high levels over the past decade. This includes drones and air taxis for Urban/Advanced Air Mobility, High Altitude Platform Systems (HAPS) for communication, surveillance and Earth observation, commercial space and suborbital vehicles for air-launching experimentation and space tourism. Other new entrants are expected in the coming years, such as intercontinental point to point supersonic, hypersonic and suborbital aircraft, and re-entry-from-orbit vehicles. The hypersonic vehicles, which travel at speeds greater than Mach 5 and altitude above FL550 (Higher Airspace Operations – HAO), typically within the atmosphere or re-entry from the space, could be adopted in several scenarios such as commercial space tourism, military operations, or high-speed transport of things and/or passengers. While the suborbital flight reaches outer space, (above the Kármán line, at 100 km altitude), but without reaching the speed necessary to enter orbit. After reaching a specific point, it returns to Earth with a curved trajectory.

Integrating hypersonic vehicles into Air Traffic Management (ATM) introduces a unique set of challenges, opportunities and considerations, particularly in terms of safety and how these vehicles would interact with existing air traffic. In particular, significant adaptations in current ATM structures and safety risk models, such as those developed by SESAR (Single European Sky ATM Research) are required.

This paper aims to provide an overview of ATM scenarios including hypersonic vehicles, to investigate the potential effects that these new operations can have in terms of safety on risk models currently applied by the SESAR safety methodology. Based on the identified safety concerns of hypersonic operations on ATM, a gap analysis has been carried out to identify potential additional requirements of the Integrated Risk Picture (IRP).

It is a safety analysis framework developed by EUROCONTROL, the European organization for air navigation safety providing a comprehensive and data-driven assessment of aviation safety risks within the European air traffic management (ATM) system. Since in Literature no risk model is available for hypersonic operations, and there are no data that evaluate possible risks and hazards unique to these missions, a preliminary and qualitative assessment is presented in this paper.

Specifically, HAZOP (Hazard and Operability Study) a structured and systematic risk assessment technique used to identify potential hazards and operational issues in complex systems, including aviation and air traffic management (ATM) is applied. It allows to identify gaps in current ATM risk models concerning the hypersonic operations. HAZOP can provide valuable data to the IRP framework by identifying potential risks in new comers (e.g. hypersonic flights). HAZOP findings can be incorporated into IRP's system-wide safety models. HAZOP outcomes can validate or refine risk scenarios within IRP.

2. Background

Civil aviation, particularly that related to hypersonic vehicles, is a fast-paced sector, with cutting-edge technology and capabilities, sitting at the forefront of innovation in the air domain. Since civil and hypersonic aircraft shall share the airspace for flight phases below FL600, updates to air traffic management systems to ensure efficient civil coordination to manage the airspace more dynamically, safely and efficiently are required. Based on different vehicle performances, flight planning systems must be able to handle the increased complexity of airspace and the need for more precise routing. Interoperability for data and information exchange will have to be further improved to guarantee a reliable air situation picture, allowing for the detection, identification and classification of any vehicle and intervention when needed. While drone regulation is well underway in Europe, regulation of high-altitude operations is still in the nascent phase. However, some States, like the UK and partly Italy, have developed their national regulations, benefiting from the FAA's experience in the US.

2.1. *European scenario*

In Europe, only in the recent past the EASA (European Aviation Safety Agency) has included Higher Airspace Operations (HAO), and specifically suborbital flights, in the various editions of the European Plan for Aviation Safety. After an initial attempt to set up a regulatory framework similar to the current aeronautical processes, it has been moved towards new modern approaches: operation-centric, risk-based and performance-based approaches that could be used as possible alternatives to the traditional full-certification when possible and deemed appropriate, (Di Antonio 2021). Regulating should consider the risks that operations pose to third parties on ground, in the air, in space, to people onboard and critical infrastructure, regardless of the approach. Currently, the traditional full-certification approach is based on a prescriptive regulation that allows operations only when the vehicle and any other element of the operation have obtained the relevant certification issued by a competent authority. However, with the introduction of new technologies, this approach is not applicable due to the lack of requirements in current standards that lead to a not certifiable aircraft. To overcome this issue, an operation-centric approach has been introduced giving the possibility of granting one single operational authorization to carry out one or more flights under the same: scenario, vehicle configuration, infrastructure and conditions without the need to authorize every single element separately. The authorization may be based upon the results of a comprehensive risk assessment that identifies a set of technical and operational mitigating measures, including flightworthiness design provisions, to control all foreseeable hazards related to design, maintenance, operational procedures, personnel licenses, and so on, up to an acceptable low-risk level compliant with the level of safety set by the regulator.

In terms of regulation, the most significant issue lies in defining adequate overall safety objectives and targets for onboard occupants, as well as for third-party users on ground, in the air, and in space, including other airspace and higher airspace users. The safety level will need to be determined based on the safety continuum principle (derived from traditional aviation), considering the various vehicle configurations with different levels of risk and different scope of operation. It is evident that a single safety level that matches current Commercial Air Transport (CAT) aircraft and operations may not be suitable for all the different types of HAO, even in the long term, (Di Antonio et al 2023). This could be overcome by addressing a performance-based approach, in which the regulator sets only qualitative safety objectives to comply with. It is not feasible for an airplane to comply with different regulations in each country where it should fly. Instead, it might be advisable to have a single risk-based regulation with common objective requirements that can be met in various situations using different technical and operational mitigation measures. Two levels could be utilized to implement this type of regulation. At the initial level, there could be a set of rules that is globally applicable for all operations: Higher Airspace Traffic Management (HATM), air navigation services, air and space collision avoidance and so on. The second level could have a modular structure by encompassing regulations for different categories of vehicles that concern design, production, maintenance etc, (Di Antonio 2021).

As it can be seen, several challenges need to be addressed within the HAO domain, in particular: coordination of air and space law; determining the division of responsibilities between the EU and its Member States; defining new air rules that take into account different vehicle performances; ensuring fair and equal access to higher airspace; determining appropriate safety levels for different types of vehicles and operational categories, taking into account the state of the art of technology; establishing effective interfaces and coordination between ATM and STM (Space Traffic Management) to prevent collisions with active space objects and space debris. More details regarding these safety perspectives are analysed and discussed in (Buzzo et al 2023).

Additionally, it is important to consider third-party liability and insurance, given the potentially higher risk of HAO compared to traditional aviation and its resemblance to space operations. A compromise between the aviation regime, which holds the operator liable, and the space regime, which holds the launch states liable, is necessary in this area.

Aviation and space institutions, research bodies and industry need to collaborate and cooperate to address all these challenges.

2.2. *Italian scenario*

Within Italy, the Italian Civil Aviation Authority - ENAC has set up a working group for the regulation of high-altitude operations and access to space, (Sandrucci 2022). The SASO Regulation has been issued and contains the requirements a vehicle system operator must comply with to be authorized to conduct suborbital operations or operations for access to space (e.g. Launching into orbit) or re-entry from orbit; it follows a risk-based and operation-centric approach as reported in (SASO 2023).

3. Adequacy assessment of current risk model for hypersonic operations

The EUROCONTROL Integrated Risk Picture (IRP) is the output of a "risk model", representing the risks of aviation accidents, with particular emphasis on ATM contributions. In order to ensure that the risk model reflects ATM as it develops in the future, the risk model is founded on an ATM model, describing the ATM system whose risks are to be modelled (EUROCONTROL, 2023). It is based on historical data and statistical analysis of air traffic accidents, near-misses, and operational incidents. To evaluate how the hypersonic operations can be integrated in ATM in terms of relations to the EUROCONTROL risk model, a gap assessment of the whole IPR model needs to be done.

The adequacy of the Integrated Risk Model (IRM) for suborbital operations integrating in Air Traffic Management (ATM), has been analysed in previous studies, (Errico et al. 2024). The goal was to analyse the adequacy of the Integrated Risk Model for Mid Air Collision En Route to suborbital flight CONOPS and apply a gap assessment to identify specific safety metrics. The Authors reported the identified gaps and the breakdown of key gaps when applying SESAR's risk model to suborbital missions to support an extension of the existing model to address the unique challenges posed by suborbital flights.

Whit a similar approach, integrating hypersonic vehicles into ATM needs to handle space management, surveillance, aerodynamic, environmental effect, and safety concerns. Such integration requires new technology development, regulatory frameworks, and enhanced safety measures to ensure that these vehicles can operate safely within the current air traffic.

3.1. *Key Factors for the adequacy assessment*

This sub-section identifies a non-exhaustive list of key differences, challenges, and areas for the adaptation are to be considered.

3.1.1. *Differences between hypersonic and conventional Aviation*

It is worth noting that Hypersonic flights could revolutionize air travel by cutting long-haul flight times from hours to minutes.

A New York-to-London flight could be reduced from 7 hours to about 1 hour. Intercontinental travel could become as fast as regional flights today. Furthermore they are strategic for military and defence applications. Hypersonic missiles & aircraft are nearly unstoppable due to their extreme speed and manoeuvrability.

They are harder to detect and intercept compared to traditional missiles and enable rapid response capabilities for military operations.

Hypersonic technologies could make spaceplanes a reality, reducing launch costs and enabling quick satellite deployment. Their potential for point-to-point suborbital travel, allowing near-instant delivery of cargo or personnel. Thus, they represent a strategic asset.

Hypersonic vehicles may have flight profiles that differ significantly from conventional commercial aircraft, with steep ascent and descent profiles, faster acceleration and deceleration, and higher Mach numbers, especially during cruise. The airspace usage for hypersonic operations is expected to be distinct from current commercial air traffic, potentially overlapping with military airspace, existing space operations, or commercial suborbital air routes. Furthermore, they may involve high-altitude or even trans-atmospheric flight paths that enter the lower edge of space.

The operational altitude range of hypersonic vehicles may overlap with airspace used by both commercial suborbital and high-altitude military aircraft, adding new complexity to collision risk management. Thus, the risk of collision in shared airspace increases dramatically, as relative velocities between aircraft would be far greater than in subsonic flight.

Another key difference from subsonic flights is the flight environment, considering the regimes that involve complex fluid dynamics and aero-thermodynamic challenges.

Also, the environmental considerations led to identify some significant environmental concerns regarding atmospheric chemistry (e.g., emissions affecting the ozone layer), due to hypersonic aircraft high speeds and altitude ranges.

3.1.2. *Key challenges for current risk models*

EUROCONTROL's existing risk model for conventional aviation is based on historical data, statistical analysis of operational safety, and established risk management practices tailored to subsonic air traffic. Several key challenges must be addressed to adapt this model to face with hypersonic operations. Among them there are:.

Data availability. There is a limited operational data on hypersonic incidents, near-misses, and accidents. The lack of sufficient data makes risk prediction and statistical modelling for these high-speed flight regimes challenging.

Collision avoidance and Detection. Existing air traffic control systems could not be adequate for the near-instantaneous detection and resolution of conflicts at hypersonic speeds. This limitation could lead to insufficient situational awareness and delayed conflict detection.

Airspace segregation. Hypersonic aircraft might need to operate with temporary airspace closures or restrictions considering additional procedures for de-conflicting hypersonic operations with commercial and military air traffic.

HA Operations. For hypersonic vehicles, which may enter space briefly or operate in near-space altitudes, there will be an increasing overlap with space traffic. It will be necessary to integrate Space Traffic Management (STM) principles. Also, managing the transition between subsonic, sub-orbital, and hypersonic regimes are relevant for airspaces regulated by different agencies and risk management frameworks.

Environment. Hypersonic flights might also raise concerns about their impact on the atmosphere (e.g., carbon emissions, ozone layer depletion). These environmental risks would need to be integrated into broader safety and risk management strategies.

3.1.3. *Areas for the adequacy assessment*

To assess the adequacy of the EUROCONTROL's risk model for hypersonic aircraft, several key adaptations are required as reported in the following.

Data-Driven Risk Assessment aims at collaborating with aerospace manufacturers and operators to collect detailed data on supersonic and hypersonic flight risks, and using simulations and advanced modelling tools to predict risks in high-speed regimes.

ATM and Separation Standards should be redefined (i.e. much larger separation distances, due to the speed and unpredictability of hypersonic trajectories). Conflict detection and time to collision prediction should consider the much shorter reaction time. It is crucial to increase the manoeuvrability of the air vehicle representing the complex interplay of design, engineering, and control systems that determine how quickly and effectively the hypersonic air vehicle can adjust its flight path.

Collaboration with Space Traffic Management (STM) is necessary to integrate spaceflight-related risks and requirements into the air traffic management framework.

Operational Procedures and Human Factors should consider specialized training.

Dynamic Risk Assessment allows the new model to incorporate high-fidelity simulations and predictive tools. Furthermore, the current model would need to integrate real-time monitoring of various parameters (e.g., pressure, temperature, speed) to dynamically adjust risk assessments and provide timely warnings.

Regulatory and Safety should consider new different safety margins, incorporating both known safety practices from high-speed aviation and novel methodologies to account for the risks that cannot be mitigated in the same way as traditional aircraft. Also, EUROCONTROL's risk model need to adapt to the evolving regulatory framework, considering novel testing protocols, certification procedures, and the validation of risk management strategies specific to hypersonic vehicles.

Aircraft Performance and Reliability should incorporate factors related to hypersonic domain into the risk assessment process, possibly using predictive analytics to estimate failure rates and system degradation over time.

4. Proposal for risk assessment tailored to hypersonic operations

The gap analysis between the existing risk models and a new concept of risk model integrating hypersonic operations, can be conducted by tools assessing safety hazards, identifying risks, and comparing how both existing risk model and new integrated risk model handle risk factors in different operational contexts. This study adopts the HAZOP (Hazard and Operability Study) approach, which is used to systematically find potential risks while hypersonic vehicle is operating and interacting within ATM. The process is structured in Matlab/Simulink® environment. The Table 1 reports the high-level workflow.

Table 1. High-level process for computing the gap analysis.

STEP	PROCESS	OUTPUT
1. Define the Risk Scenarios.	Identify the primary hazard categories.	List of hazards.
2. Define Deviation Parameters.	Identify failure modes.	Differences in identified causes of hazards.
3. Identify: Causes, Consequences, and safety measures.	Determine the causes, consequences, and safety measures.	Differences in potential consequences.
4. Gap Analysis.	Assess current risk model and identify gaps in the models when hypersonic vehicles are integrated into the airspace.	Recommendations for risk mitigation.

4.1. *HAZOP Methodology for ATM Risk Model*

A HAZOP is a structured and systematic technique used to identify potential hazards and operational issues in a complex system by analysing each component or process in detail. In the context of ATM systems integrating hypersonic operations, a HAZOP support the identification of risks and ensuring that safety measures are adequate for managing these new, high-speed vehicles in shared airspace. A HAZOP tailored to the integration of hypersonic operations into the ATM risk model, focuses on hazard identification, potential operability issues, and safety management.

4.1.1. *Framework*

The hypersonic vehicles perform their flight paths very differently from traditional aircraft. The flight trajectory is here simulated by using typical parameters for hypersonic speed and altitude. The scenario focuses on a hypersonic commercial flight operating in HA and the airspace as conventional subsonic aircraft, based on predefined flight plans, with no dedicated flight corridors. The development of flight trajectories simulations and explanation of methods including separation from other aircraft and emergency scenarios are out of scope for this paper.

The primary objective for this study is to identify gaps in current ATM models in relation to hypersonic operations, focusing on risk factors, methodologies, and predictions.

Firstly, HAZOP helps to evaluate the potential hazards and operability issues arising from the integration of hypersonic operations into the ATM system. This includes understanding how hypersonic vehicles can interact with traditional aircraft and the ATM infrastructure in terms of: Safety, Collision avoidance, Airspace management, Communication and surveillance, Operational continuity. A key element of the HAZOP process is breaking down the ATM system into discrete components, or "nodes", and systematically analysing deviations from the normal operation. In the first step, the tool combines a matrix of nodes and deviation including the effects of each deviation and the existing risk mitigations or actions for reducing identified risks. Once the components of HAZOP have been identified, and the needed adaptations have been defined by considering the unique characteristics of hypersonic flight that are not present in conventional ATM risk models, this study proposes to implement the HAZOP tool to identify significant gaps in current ATM risk models, especially with regard to the unique challenges posed by hypersonic operations. The process combines the structured hazard analysis with qualitative or quantitative risk assessments and data-driven insights to ensure that ATM systems are adapted to the high-speed, dynamic nature of hypersonic aircraft, as shown in Figure 1.

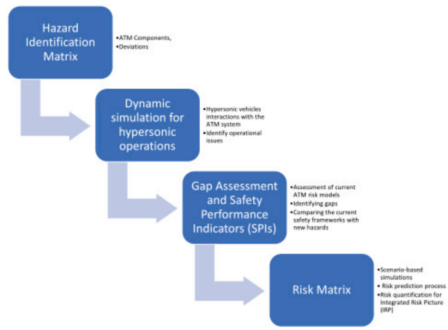

Fig. 1. HAZOP process for hypersonic operations integrating in ATM.

4.2. *Case Study: Application of the Risk Model to hypersonic operations*

The scope of this case study is to analyse the adequacy of the IRM for Mid Air Collision (MAC) en route to a hypersonic flight and derive a gap assessment. In the following the results obtained by applying the HAZOP process to the case study are presented.

Step1: The hazards identification matrix is reported in Table 2.

Step2: The simulations for hypersonic operations emphasis on flight trajectories, separation from other aircraft, and emergency scenarios. Such simulations can be based on predefined flight plans or real-time dynamic scenarios. The Matlab/Simulink® tools can simulate how hypersonic vehicles interact with the ATM system and identify operational issues useful for gaps assessment. Authors used a trajectory simplified model in this paper.

Step3: The gaps have been identified for IRM by combining the hazards matrix and analysis of discrepancies from current ATM, as shown in Table 3. The integration of hypersonic vehicles impacts several Safety Performance Indicators (SPIs) as reported below.

Accident Rate. Estimate the increased likelihood of accidents due to high-speed flight dynamics and potential collisions.

Mitigation Effectiveness. Evaluate the effectiveness of risk mitigations (e.g., real-time separation tools, communication systems) in reducing identified hazards and impacts.

Separation Minima Violations (SMVs). The number of instances where the minimum required separation is violated.

Conflict alert frequency. The number of conflict alerts triggered by ATC systems when two aircraft are projected to violate separation minima.

Some recommendations reported can be adopted in order to address the identified gaps.

Development of specialized risk models. Incorporate high-speed, high-altitude specific risk models that account for unique hypersonic risks.

Advanced communication systems. Invest in next-generation communication systems that allow for seamless, global connectivity for hypersonic vehicles.

Collaborative ATM framework. Develop protocols that allow for real-time data exchange and coordination among different air traffic control authorities to manage hypersonic traffic in an integrated and dynamic manner.

Integration of AI and Machine Learning. Utilize AI for predictive analytics in risk management, capable of processing large datasets in real time to anticipate and mitigate potential hazards during hypersonic operations.

International Standards development. Work toward international consensus on standards and regulations for hypersonic aircraft operations, ensuring safety and regulatory compliance across borders.

New Safety protocols. Research and implement new collision avoidance, emergency response, and safety measures that can handle the unique characteristics of hypersonic flight.

Step4: Different operational scenarios need to be modelled to assess risk effectively. The use of the probabilistic formula that combines the likelihood of the event and its consequence severity (Risk = Likelihood x Severity) resulted problematic in defining quantitative likelihood factors based on historical data, simulations, or expert judgment for each deviation. Data-driven techniques can improve the risk prediction process. The use of data-driven predictive models can help to assess risk factors dynamically in real-time during hypersonic operations, ensuring the ATM model adapts to changing conditions. The Authors used here Monte Carlo simulations for predicting failure rates under uncertain conditions, based on random deviations in speed and altitude and simplified model for collision risk. However, as such a vehicle introduce highly complex and scenario-specific risks for different conditions (e.g., during emergency manoeuvres, failure scenarios), the lack of historical operational data and the lack of sufficient scenario modelling for hypersonic operations within the existing ATM risk framework remains one of the crucial gaps identified in this analysis. The future work will deal with it in order to assess the adapted technics for the risk quantification.

5. Conclusions

Integrating hypersonic vehicles into the ATM and HA presents several safety considerations that must be addressed to ensure safe operations. The application of EUROCONTROL IRM is not fully adequate to the case of HA operations. Modifications or extensions of the existing model are needed to address the unique challenges posed by hypersonic operations. The proposed approach identifies key differences, challenges, and areas for the adaptation to drive the identification of new hazards and risks when the hypersonic flight operates in ATM. Then, the paper provides a gap analysis mainly for ATM in order to set up the Extended Integrated Risk Model (EIRM). The approach highlights the need of implementing a dynamic airspace management that continuously adapts to the presence of hypersonic vehicles and considering crucial issues coming from the safety considerations about reaction time, the manoeuvrability of the air vehicle, safety buffer and separation. Recommendations can be adopted in order to address gaps ensuring that future ATM systems are capable of safely managing these high-speed aircraft alongside traditional traffic. Furthermore, HAZOP tool to identify gaps in current ATM risk models with respect to the hypersonic operations in terms of risk variables, methodology, and prediction has been applied in this study. Since in Literature no risk model is available for hypersonic operations, and there are no data that for modelling scenario integrating hypersonic operations within the existing ATM, a preliminary and qualitative assessment is presented in this paper. The future work will assess different technics for the risk quantification, and provide a specific risk framework for evaluating possible risks and hazards unique to these missions.

ATM Components	Deviation	Cause	Consequence	Safety measure/Action
Airspace Management	Hypersonic vehicle enters airspace without appropriate coordination or planning.	Inadequate real-time airspace management systems.	Risk of collision or near-miss.	Implement dynamic airspace management. Use AI trajectory prediction and conflict detection systems for re-routing in real time.
Surveillance	Hypersonic vehicles are not tracked accurately.	Current radar and satellite technologies could not accurately track high-speed vehicles	Inability to detect and manage conflicts, leading to a collision risk. Mid-Air Collision (MAC)	New surveillance technologies, including space-based radar, satellite tracking, and high-frequency radar.
Communication	Loss of communication between hypersonic vehicle and ATM or ground control.	Communication shutdowns due to hypersonic flight speeds or altitude.	Loss of situational awareness, delayed responses to potential emergencies, and coordination issues.	Advanced communication systems, such as satellite-based communication that can handle the high-speed nature of hypersonic operations.
Separation	Insufficient separation between hypersonic and conventional aircraft.	Traditional separation minima do not apply effectively to high-speed vehicles.	Increased risk of collision or close calls between hypersonic vehicles and slower, conventional aircraft. Mid-Air Collision (MAC).	New dynamic separation standards specific to hypersonic operations. Collision avoidance systems that adapt in real-time based on relative speed, altitude, and trajectory.
Environmental hazards	Impact of wake turbulence or sonic boom from hypersonic vehicles on aircraft or communities.	Shockwaves and high-speed turbulence affect neighboring air traffic or ground infrastructure.	Structural damage to nearby aircraft, harm to ground-based infrastructure, and potential public safety risks.	Sonic boom mitigation technologies. Use wake vortex detection systems to avoid conflicts with slower-moving aircraft.

Table 3. Gaps for hypersonic operations.

Gap	Description
Risk identification and assessment.	Current IRM may not be designed to assess the full spectrum of risks for hypersonic operations.
Communication limitations.	Traditional communication protocols may not be suitable for high-speed, high-altitude hypersonic vehicles. Advanced communication systems could involve satellite-based communication.
Data exchange.	IRM may lack efficient data exchange protocols between different sectors of ATM, and coordinate hypersonic operations across multiple airspace jurisdictions could be difficult.
Predictive and real-time risk management.	Existing ATM systems do not predict or manage real-time risks associated with hypersonic operations, such as rapidly changing flight conditions, vehicle performance issues, or the influence of the shockwave.
Collision avoidance protocols.	Given their extreme speed and the limited time for reaction, hypersonic vehicles necessitate innovative collision avoidance technologies.
Safety Standards and Regulations.	Gap in the existing regulatory framework for hypersonic flight, which needs to evolve in line with the development of new technologies and operational procedures. Safety standards for hypersonic flight are still emerging.

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