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Integrating Air Traffic Management and Space Traffic Management: Concepts, Challenges, and Solutions for the Evolving Aerospace Landscape in Europe

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For decades, the airspace volume above today's commercial traffic at altitudes higher than 60,000 ft - referred to as Higher Airspace (HA) in Europe, Upper Class E in the U.S. or sometimes Near Space - had been largely reserved for specialized military operations, experimental flights, rare exploration missions, and only occasionally interrupted by rocket launches. However, advancements in aerospace technology, a growing demand for expanded air travel, novel airborne capabilities, and a surge of (commercial) rockets launched to sub-orbital and orbital destinations, let to identifying the need to develop concepts for a more closely interfacing and later-on integration between Air Traffic Management (ATM) and Space Traffic Management (STM). Reasons for this are manifold, but they all can be summed up to the fact that methods developed have been done so in different contexts and different times: Procedures to allow crossing of airspace to reach higher altitudes have long lead times that leave little flexibility to adjust launch times to weather conditions or other unforeseen events. Covering against risk from unscheduled failures often requires closing large regions of air space, which does not scale with the number of launches expected over the coming decades. Additionally, every-now-and-then occurring reentries of large objects together with the inherent uncertainties of their predictions lead to closures of airspace that are questionable when considering the probability of casualty causing events, yet understandable when looking at the risk of being responsible if something occurs, without clear procedures and risk description. As an example, the brief closure of Spanish airspace in November 2022 in reaction to a reentering Chinese launcher stage, lead to the delay of more than 300 commercial flights.

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I. Introduction

For the European region with its high complexity of multiple ATM systems currently deployed in the EUROCONTROL Network Manager (NM) area, the development of solutions to accommodate space operations - and in general new entrants' operations in HA - will need to consider both national and regional State responsibilities. With forecasted traffic exceeding 40,000 IFR (Instrument flight rules) flights for a busy summer day by 2030 [1] and ATFCM (Air Traffic Flow and Capacity Management) delays already reaching critical levels with current traffic, solutions need to be developed for enabling a seamless accommodation of new operational stakeholders without further jeopardizing the current ATC (Air Traffic Control) capacity limits. These solutions will need to provide a paradigm shift, moving away from the segregation of today's pioneering new entrants' operations to a more dynamic, automated and integrated mode of routine.

In fact, on a global scale, HAO (Higher Airspace Operations) represent one of the most profound changes to the aviation environment for many decades. It is unanimously agreed that the number of space operations and other types of HAO is set to steadily increase in the years ahead [2]. It is imperative that such operations continue to take place in a safe and efficient manner, without a disproportional impact on conventional air traffic operations. Change is needed to evolve from how we work today to fully support the new HAO and space activities so these operations can fully achieve their economical and societal benefits.

The focus of this paper is on the challenges, efforts and anticipated benefits concerning the close coordination of space activities with conventional air traffic, highlighting the global nature and the need for cross-border and even cross-regional coordination. Section II provides an introduction of objectives and targets developed in the European concept of operations developed for HAO within the ECHO SESAR 2020 funded project [3]. Additionally, key elements of its ongoing successor project ECHO2 are detailed, which will enhance the European Network Manager with real-time space mission monitoring and management capabilities, setting the scene for future more dynamic airspace management procedures [4]. Section III offers the STM perspective, describing current STM capabilities in support of launch and reentry missions and discusses its limitations and challenges. In Section IV, solutions, new capabilities and improved operating methods are discussed, which could be built on a fully developed and implemented ATM-STM interface. A special focus hereby is set on global scaling benefits, which may boost the aerospace landscape as a whole, if approached beyond the regional perspective, but with its global footprint in mind.

II. **The path to integrating air and space operations – The European ATM perspective**

A. The current European ATM environment

The management of the European ATM network has been built on strong cooperation between all stakeholders based on the Collaborative Decision-Making (CDM) principle [5] (e.g. airspace users, service providers, regulators, the EU and its agencies, international organizations, etc.). It has been supported and codified by a coherent set of EU regulations which confers clear responsibilities on all actors involved. Hence, the management of the network is an essential component of the European ATM system and by extension for HAO which are regarded as an integral part of network operations, with airspace itself seen as one single continuum.

Within European airspace, ATS (Air Traffic Services) are provided by more than 60 ACCs (Area Control Centers) and more than 30 ANSPs (Air Navigation Services Providers). An overview of the dense traffic flows across Europe is shown in Fig. 1. Regarding airspace classification, Class C airspace has been published from FL195 up to FL660. Above FL 660, in some States no classification is published, while some have published Class G airspace to unlimited and consequently a basic ATS should be provided (see Fig 2, e.g. FIS (Flight Information Service) and Alerting). It should be noted that today there is little or no surveillance and communication capability provided by ANSPs above FL660.

HAO offer a unique opportunity to promote an operational vision that, from the outset aims to address some of the structural elements that in the past have required significant time and effort to improve. Perhaps one of the most familiar examples, the airspace organization and structure across the NM area, has been subject to constant developments to reduce fragmentation and improve interoperability. Such improvements have required a bottom-up approach and several decades to be fully implemented across the network. The lessons learned from this experience should be taken into consideration and the development of HA should start with a new approach that would facilitate the global nature of these operations.

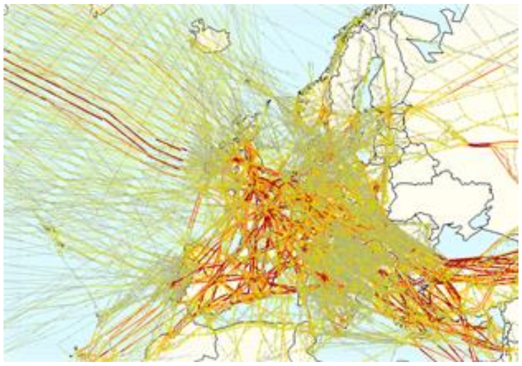

Fig. 1 Traffic Flows in Europe

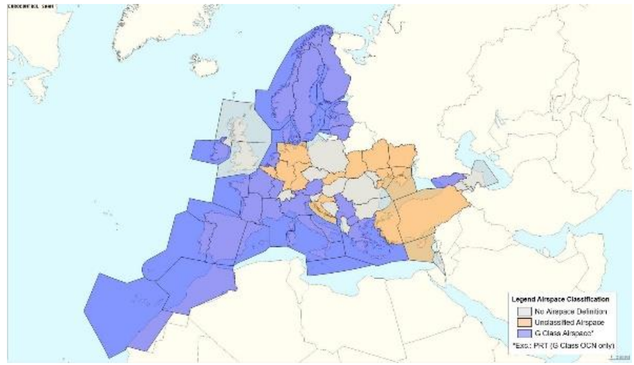

Fig. 2 Airspace Classification above FL 660

B. The demand for space activities in Europe

In the past, only suborbital operations were frequently conducted in the European network area in the form of sounding rocket launches almost exclusively in Scandinavia. However, a wave of new players is set to transform the European space landscape. Lead by technological innovation, the surge of commercial space associated with the advent of the so-called micro-launchers may lead to a rapid increase in demand for space operations launched from European soil in the coming years. At the same time, a large number of potential spaceport locations are proposed and developed, supporting different launch methods ranging from traditional vertical lift-off to air-launch supporting aerodromes, to offshore launch pad infrastructure. Additionally, demand for sub-orbital operations could also gain momentum, as commercial providers for A to A suborbital flights could find suitable spaceports located in the UK and Italy.

Orbital launch activities are expected to grow in Europe with multiple European launch providers progressing to start operative service soon. Scandinavia and the United Kingdom could host launch services in the short to medium term future. The first spaceport, Spaceport Cornwall (UK) has been certified and is operational since 2023, when the Virgin Orbit air-launched Launcher One on 9 January 2023.

Additionally, a variety of launch sites/spaceports are designated, with initial launch intentions already announced (e.g. SaxaVord Spaceport (UK), Andøya Spaceport (NO), German Offshore Spaceport (North Sea, international waters). Air-launch operations may also be possible at Grottaglie spaceport (IT). From orbit operations of the Space Rider could use Grottaglie in southern Italy as landing site in the future, Sierra Space Dream Chaser approaches into Cornwall and Italy are under consideration. An overview of proposed launch sites/spaceports for orbital operations in Europe is depicted in Fig. 3.

Fig. 3 Proposed spaceports in Europe

C. The European Concept for Higher Airspace Operations – From accommodation to integration of space operations

The European concept of operations (ConOps) develops and outlines a desirable and aspirational state as the target for the long-term integration of all types of HAO – which includes space activities too – in the European environment. Individual target concept elements which directly relate to space operations are summarized in this section. [3]

Managing HAO in the European ATM network will be based on the principles of collaborative decision-making which includes cooperative air situation awareness and strategic cooperative de-confliction which forms part of trajectory-based operations (TBO). The concept will be applied across all types of operations, ranging from individual vehicles, flying according to their agreed trajectories, to operating volumes, which are called 4D operating zones. A 4D operating zone is understood to be a volume of airspace typically used by vehicles associated with higher levels of uncertainties for their movements. It is allocated to one or several specific vehicle(s) and separated from other airspace users, meaning there will be a 4D volume of airspace moving alongside a 4D trajectory profile. Inside the 4D operating zone, vehicle(s) are free to operate as required as long as they stay inside the 4D operating zone.

The European concept aims to set out operational means and approaches on how to enable managing operations with a large variety of velocity and trajectory profiles in an already highly congested airspace environment, building upon the established strategic, pre-tactical and tactical ATM planning phases.

First of all, it has to be determined if a vehicle will require airspace segregation or if it can be handled by its 4D-trajectory. This assessment may change over time, as reliability as well as technology especially regarding navigational performance and surveillance may improve. If airspace segregation is determined to be needed, this might be either a static airspace volume activated at a specific time and duration or a dynamic airspace volume representing the amount of uncertainty associated with this specific type of operation.

Specific HA vehicles such as space vehicles during launch or re-entry may require efficient segregation procedures, protecting other airspace users. Areas along their flight trajectory, for which sufficient levels of safety cannot be assured by other means, will be segregated as the vehicle moves along its trajectory through this airspace region. Further along its flight trajectory, the vehicle is separated from other airspace users by operating within a 4D operating zone which also considers the level of uncertainty associated with the individual type of operation. Below their flight trajectory, airspace regions that would be endangered in case of non-nominal situations, but which can be cleared of other airspace users on time to prevent any collision with resulting debris are protected by dynamic aircraft hazard areas (AHA) using real-time monitoring and data-processing capabilities. Dynamic AHA complements the use of 4D operating zones and DMAs (Dynamic Mobile Areas) to separate the operational volume of the vehicle itself. The use of 4D operating zones covering the space vehicle in real-time minimizes the need for static airspace segregation. This is achieved based on the real-time provision of all necessary information to all involved stakeholders allowing dynamic adaptation to non-nominal events, supported by higher levels of automation.

Strategic de-confliction is applied as far as possible to ensure conflict-free flight execution of HAO already through the planning phase. This includes a variety of airspace route structures such as entry/exit routes for hypersonic flights, launch/re-entry structures for space operations or dynamic airspace volumes for HAPS (High-Altitude Platform Systems). To maintain consistent situational awareness and predictability of operations, operators share changes to their intent, enrich surveillance information where necessary by additional information like telemetry data, maintain awareness of their operational environment and flight intent of other operators and participate in collaborative coordination measures.

When the operational profile of an HA vehicle and the flight intent of its operator result in a trajectory extending beyond HA and entering the space domain, it requires not only separation from other operating vehicles in ATS airspace and HA, but also from active and passive space objects. During the planning phase, the operator extends the coordination of its intended trajectory beyond ATS airspace and HA, using services provided by STM or other additional service providers. The planning of the re-entry of a vehicle from space takes place as part of the flight-planning process. The re-entry of a space vehicle may already be part of the initially planned flight trajectory. However, the re-entry of an orbital or interplanetary mission can also take place after a considerable time; its exact time can be determined only in the course of the mission. Planning of re-entry operations considers the aspect of limiting unnecessary interactions and impairment of other traffic participants and is thereupon likewise reviewed and coordinated with the NM. It is considered that the flight phase of the re-entry is irreversible after it has been initiated and that the resulting flight phase can be associated with the need for prioritized execution.

Within the execution phase, deviations from the planned trajectory must be checked for their impact in both domains and appropriate measures must be initiated with the help of the respective processes of ATM and STM. STM service providers maintain situational awareness and support the vehicle operator through means of SSA (Space Situational Awareness).

D. Enabling real-time mission monitoring and management of space operations for the European Network Manager

Traditionally, large airspace volumes would be reserved for a considerable time to enable a launch or return from orbit to take place safely, preventing other traffic to utilize this airspace leading to flight inefficiencies or even cancelations. However, with the increasing number of expected launches, their impact on the European aviation network will significantly grow as the frequency of operations could be even daily by 2040, while commercial traffic is also expected to continue to grow. Therefore, an expansion of existing operational interfaces and tools, supplemented by newly developed data exchange capabilities between the aviation and space domains is critically required. New processes and procedures at European network level are essential to mitigate the impact of such launches, reducing the need for segregation, and to prepare for both planned and unplanned events. The operational interface between aviation and space requires a new approach that combines national, regional, and global perspectives to deliver the intended solutions for the future when the sharing of airspace becomes critical. The interface between the ATM domain and space traffic management domain (STM) will be determined using elements related to planning, contingency management and traffic management and will need to take all key factors into consideration.

Especially the accommodation of very high-speed operations, such as space operations or hypersonic flights, will require cross-border procedures and system capabilities that are able to deal with non-nominal events that may extend even outside a regional monitoring area. Matching the operational requirements from those new entrants with the specificities of the (European) ATM environment is therefore now essential.

A decisive factor, which will enable the new operating method integrating space operations into the European ATM, is the current development of a "Spacedesk" working position for the Network Manager Operations Center (NMOC) [4]. In its core, this development builds on the elements of the European ConOps for HAO which are specific to the integration of space operations. The new concept will focus on developing a new service accompanied by a new set of tailored procedures – which will be developed from the existing airspace management procedures, contingency management, NM flight and flow management and local ATSU procedures – using real-time data provision for ATSUs and NM, taking as orientation prototypes such as the Space Data Integrator (SDI) [6] and DLR Real time Mission Monitor (RMM) [7]. This will provide improved situational awareness and enable a more dynamic airspace management and support timely release of airspace restrictions when no longer required, plus provide real-time information in case of non-nominal events to those actors concerned. Real-time monitoring of mission-critical parameters and the utilization of safety-relevant information in non-nominal situations will be incorporated in the concept and adapted for the European network. This support will optimize the integration of space events into ATM during the strategic, pre-tactical, tactical and follow-up phases. The prototypes will be adapted to support the NM related integration tasks and will be compatible with the development related to the future NM system.

III. Integrating Air and Space Traffic Management – the space domain perspective

A. Space as an operational environment

Space differs significantly from the operational constraints as they apply to airspace. There are no borders and national territories to be considered. Outer space can be freely explored, and no nation or State can restrict another State's lawful access to outer space for peaceful purposes. The Outer Space Treaty is the basic international treaty defining the framework under which operations in space should be performed. As there is no state sovereignty in space, the Convention on Registration of Outer Space Objects has the effect of establishing a crucial component of state sovereignty. A State's right to exercise sovereignty over space objects is dependent on that State entering its launched objects in a national registry. Additionally, States are absolutely liable for damage their space launches cause on the surface of the ground, or damage to aircraft in flight.

Global space activity has experienced a massive growth since 2013. 10,625 spacecraft were launched between 2012 and 2023, which 2675 of those being in 2023 while only 110 spacecraft were launched in average per year between 2000 and 2012 [8]. The launch of so-called "mega-constellations", starting in 2019 with several operators, is expected to bring launch activity and satellites disposal to another level. Forecasts suggest that the deployment of mega-constellations, which have already started, will contribute to an even bigger increase in global space activity in the coming years.

B. Current Space Traffic Management capabilities, limitations and challenges

Falling prices for satellite manufacturing and launch, coupled with the popularity of large constellations, have recently led to a rapid increase in the number of objects orbiting Earth. While satellites were once operated primarily by a few organizations, mostly governments, today hundreds of private organizations also fly their own satellites [9]. This increase in traffic has resulted in numerous close approaches, or conjunctions, between active satellites. In the past, some conjunctions have even resulted in collisions, destroying both objects and creating thousands of pieces of debris, which themselves pose further risks [10]. Although the topic is still in its early stages, there clearly is a need for STM to keep the space surrounding Earth safe and accessible.

The foundation of all STM services is a well-maintained catalog of space objects, their characteristics, and their orbits. Such a catalog is built by measuring the positions and velocities of space objects via radars, telescopes, laser-ranging, RF-ranging, and on-board GNSS receivers. From the determined orbits, positions can be predicted for a limited time into the future with sufficient accuracy. However, the accuracy of these predictions degrades over time due to errors in the physical force models. The possible prediction duration depends on the required accuracy and the orbit of the object. Typically, it ranges from a few days to weeks. To counteract this degradation, measurements need to be continuously made to keep the catalog current [11].

Based on the catalog, STM providers offer various services, like conjunction screening, collision avoidance, fragmentation detection, and re-entry prediction. One of the most important is the screening of the orbits of active satellites against all other objects. This allows for the detection of conjunctions and potential collisions in advance. Conjunctions then need to be assessed to estimate the probability of a collision [12]. Some providers also calculate maneuvers that satellites can perform to safely avoid these collisions. If both satellites in a conjunction are active and maneuverable, STM providers can facilitate communication and provide recommendations on which satellite should move out of the way. Another service of high interest is predicting when and where defunct satellites and space debris will re-enter Earth's atmosphere [11]. Although it is recommended to dispose of satellites and rocket stages at the end of their lifetimes in a controlled manner, this is often not done for various reasons. Unpredictable fluctuations in the density of the high atmosphere make this task especially complex. Re-entry predictions therefore have very high uncertainties, and narrowing down the time and place of re-entry is only possible a few hours in advance [13].

Today, basic STM services are provided by the U.S. Department of Commerce, mainly via Space Track (space-track.org). They maintain the most complete catalog in existence. Other entities, both public and private, are operating their own sensor networks and have started building their own catalogs to provide similar services. For example. The European Union has created a partnership to provide basic SST services to both satellite operators but also the general public, called EU SST. These services consist of free-of-charge collision avoidance services, fragmentation detection, and re-entry predictions. For the latter, the main purpose is to be aware of the re-entry of large objects to avoid accidents related to surviving fragments both on ground and in air-traffic.

As of this writing, the use of STM services and adherence to guidelines and recommendations is not mandatory [14]. Some organizations, like the European Space Agency (ESA) [15], have imposed regulations on their own missions, and some countries and supranational organizations have started drafting space laws that could define best practices for behavior in the event of a conjunction, acceptable risk thresholds, and reliability of disposal.

C. Benefits of integration from the STM perspective

The launch phase is one of the most critical stages of any space mission, particularly from a Space Traffic Management (STM) perspective. Initial data on the orbit of a launched object is often sparse and less accurate, and the final orbit can differ from the planned trajectory. During the early stages of the mission, satellites may require time to come online and might lack maneuvering capabilities. Access to comprehensive information can significantly improve data quality and help avoid critical conjunctions at this stage [16].

Launch operators are required to provide trajectory information prior to launch to the STM entity responsible. The UK for example mandated this data sharing as a prerequisite for receiving launch permission [17]. The trajectories of all objects expected to exceed 150 kilometers in altitude, including deployed satellites and all stages of the launcher, are screened against the existing catalog of space objects. This screening is conducted one week before the planned launch and repeated in the following days. A key focus of this screening is to ensure sufficient separation from active satellites and crewed spacecraft, such as the International Space Station. If the screening confirms no potential conjunctions, the STM entity can approve the desired launch window. At this point, all objects expected to achieve a stable orbit are registered [18]. With information on the planned trajectory and launched objects, STM providers can better allocate resources such as sensor time and manpower to monitor the launch. When determining the launch window, however, not only the requirements of the launch operator and the satellite operator with regard to the safe launch orbit must be considered. From an ATM perspective, the impact on air traffic on the launch day and for the possible launch time is also examined. Safety and capacity considerations can lead to the exclusion of specific launch days and periods during the course of a traffic day. These interactions can already be coordinated during the planning phase by comparing and synchronizing the requirements from both ATM and STM perspective.

Even when the planned trajectory is shared with STM operators beforehand, inaccuracies in the insertion or off-nominal performance of the launcher can result in deviations from the planned orbit. In such cases, prompt communication between the launch operator and the STM operator can initiate the orbit determination process. Telemetry data from the launcher post-orbital insertion can serve as a more accurate starting point for orbit determination. With this information, STM operators can confirm proper orbital insertion and assist satellite operators in locating and establishing contact with their satellites, enabling the resumption of regular STM operations. Sharing information needed both to protect air traffic from the potential effects of a rocket launch and to improve the accuracy of inertial orbit determination provides an additional link between ATM and STM capabilities.

Another crucial mission phase is the re-entry of a spacecraft. Like the launch and any other major maneuver, a controlled re-entry should be communicated to the STM operator. Regular screening for close approaches is based on the assumption that no maneuvers are performed. When a maneuver is planned, it should be communicated so that the correct trajectory can be screened, ensuring it causes no dangerous conjunctions. If the spacecraft can share real-time GNSS data, STM can also take responsibility for confirming a successful maneuver and detecting if the desired re-entry trajectory is achieved.

For unplanned re-entries, predicting the time and place of impact is significantly more challenging. Several STM operators monitor objects that are about to re-enter and regularly issue warnings for upcoming events. The uncertainty of these predictions is high. In the days leading up to re-entry, the uncertainty can be narrowed down to a few orbital revolutions, limiting the possible point of impact to a relatively thin line circling the Earth. Hours before re-entry, this can be further narrowed to a ground track of hundreds of kilometers in length and tens of kilometers in width [13]. For example, as the consequence of an uncontrolled re-entry of a Chinese rocket body, the Spanish air was partially closed in 2022 [19]. Although the rocket body re-entered safely over the Pacific Ocean, the Spanish airspace was closed for 40 minutes in this case due to the large uncertainty in the re-entry prediction. Even the last available prediction, issues just minutes before the re-entry, had an uncertainty of 30 minutes and a ground track spanning a third of the globe [20]. While improving the accuracy of forecasts is a major and difficult challenge, linking the management systems from the space and aviation domains can open up the possibility of continuously updating information about the expected impact area and - if possible - generating timely warnings for air traffic. In this way, improvements in forecasting quality, where it is likely that only very short warning periods can be achieved in the foreseeable future, could be processed via real-time capable information systems and used to increase traffic safety.

IV. Conclusion: Opportunities of a fully integrated ATM-STM interface – A global perspective

As explained, STM is essential for maintaining the safety and accessibility of Earth's orbit, particularly as the number of satellites is increasing. STM providers offer crucial services like conjunction screening, collision avoidance, fragmentation detection, and re-entry prediction. These services are vital during all mission phases, from launch, where initial trajectory data is often sparse and less accurate, to re-entry, where predicting the time and place of impact can be challenging. Despite its importance, the use of STM services and adherence to its guidelines lack clear rules, although some organizations and countries are beginning to implement regulations.

Close cooperation with launch and satellite operators can greatly improve the quality of STM services in the future. Enhancing and accelerating the sharing of telemetry data can lead to earlier identification and tracking of satellites after launch, helping to close the coverage gap between the launch phase and regular operations. Better automation and communication with STM providers can also facilitate more regular screening of planned trajectories for launches, re-entries, and regular operations, increasing flexibility. Finally, improvements in the number of measurements, models, and methods used in STM can enhance the accuracy of re-entry predictions.

From the ATM perspective, an integrated interface and a resulting close coordination with STM through all phases ranging from pre-mission planning to post-mission analysis will help to enhance airspace management procedures to the benefit of both air and space domain users. As an example, to incorporate more flexible launch window changes into the daily routine could ease both the need for planning overhead for launch operators, as it will also increase airspace capacity, if a timely (de-)activation of the needed operational volumes is possible. Additionally, improving the data availability through accessing up-to-date space data will offer opportunities for future collaborative capabilities like more effective contingency management or an efficient handling of uncontrolled reentries.

ATM, and more specific the (regional) network management level, is the ideal intermediary with its inherent need to collaborate both with aviation stakeholders, as well as STM and launch and reentry operators (LROs) in order to ensure efficient operations. To build an ATM-STM interface, which is future-proof, interoperable and cross-border/regional, is an opportunity, operational stakeholders should recognize, as it will benefit all users of this one shared resource, which is the single airspace continuum.

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