Homework 4: NFTs for space

Solidity and Smart Contract Development — Dauphine - PSL

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Abstract

In this homework, we will explore the possible use cases of NFTs in the New Space, more possible for its applications to the component-for-space supply chain. We firstly delve into a market research on the Space Industry, emphasizing on the case of France as a dominant player in the European market, to then analyze the ecosystem as a whole. We then go on to propose a detailed token white-paper.

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1 Exercise 1: Market Research of the Space Industry

In order to better understand the current state of the New Space, more specifically the dominant position France is currently in, we ought to go back in time. As a matter of fact, we have to go back to the end of World War II. At the time, the French government was intrigued by the development that had been made by Germany on the V2, which was the world's first long-range ballistic missile, developed by the Nazis. Of course, it seemed like a matter of national security as all countries at the time wanted to collect as much information as possible on the matter. This wish is perfectly embedded in a very specific and tense geopolitical context. The Cold War was the general scene on which the entire process was taking place (Giaccio 2024). Countries understood the general frictions that were already established and felt even more the need for national security. As one could say, after the war, your allies can become your adversaries in a bat of an eye. One of the big materializations of the war was the space conquest. This all led Charles de Gaulle and his collaborators to subsequently create the "Comité de Recherches Spatiales" (CRS) in 1959, the "Société pour l'étude et la réalisation d'engins balistiques" in the same year, and finally, the "Centre Nationale d'Études Spatiales" (CNES) in 1961. For the next 20 years, the CNES would be at the heart of the development of the European Space industry (Wikipédia 2025b). One of the embodiment of the dominance of France in the European Space industry can be seen through the fact that the headquarters of ESA are in Paris, and the primary spaceport is in French Guyana. This critical role in the ESA is even more important as the latter was one of the first structure to allow for the development of environmentally used satellites (Wikipédia 2025a). From the 80s onward, the agency has been internationally recognized, creating and expanding spatial missions projects. Even though a big chunk of the national budget has been allocated towards the European Space Agency, some very important projects were led, especially in collaboration with American and Russian agencies (namely Argos, a global environmental tracking and monitoring system, and TOPEX / Poseidon, a joint satellite altimeter aiming at mapping ocean surface topography).

In fact, the CNES played an instrumental role in the development of major tools and missions. To have a better grasp of these dimensions, here is a timeline of the history of the agency's space missions:

- 1965: French Diamant, that we touched upon before
- 1973: Ariane program
- 1978: Argos, tracking to study the impacts of climate change
- 1982: Cospas-Sarsat, saving lives and essential for the transport industry
- 1986: SPOT, with SPOT-1 being the first high-resolution civil Earth imaging satellite. Today, it is Pléiades
- 1995: Helios, for military purposes
- 2016: Galileo, Europe's first own GPS
- 2021: James Webb, launched by Ariane 5

- 2024: Ariane 6
- And many more...

(CNES 2025)

This all brings us to the present time. The 5 main programs of the agency right now are: Space exploration through their launchers, Sustainable development, climate change and the protection of the environment, Telecommunication, Research, and Security and defense.
We could quickly compare the CNES to the German Aerospace Center (DLR). The latter, also called the National Center for aerospace, energy and transportation in Germany, was founded in 1969. Whereas in France the CNES was institutionalized through one main entity, the DLR came as a combination of about 9 different space programs. The history can be traced back to the very beginning of the XXth century, more precisely 1907, when the oldest ancestor of the DLR was founded by Ludwig Prandtl. These different organizations were more oriented towards the development of military equipments as well as automotive engines, whereas the CNES was set up in order to organize space missions. Nowadays, the DLR is committed to the development of the exploration of Earth and the solar system taking into account environmental concerns. In addition to that, mobility, communications and security are also important parts of its growth (Wikipedia contributors 2025). We can see that the CNES and the DLR do share similar visions now, even though their origins differ both in terms of administrative evolution as well as initial vision.

We can see that France mainly established its dominance in the European Space industry through a big budget. As a matter of fact, the CNES had a budget of about 2.78 billion euros in 2020 (compared to the 1.348 billion euros in 2020 for the DLR, less than half of the budget of the CNES). It is the biggest budget in Europe (logically being the biggest contributor to the ESA), and the second biggest in the world in terms of Space Industry. Combined with that, there was an important campaign to push the use of its Ariane launchers for the ESA's space missions. Also, the political part of things seems to be essential as the headquarters of the ESA are in Paris.

Building on this historical background, the current landscape of the space industry reveals a clear trajectory from state-driven ambition to a more diversified and commercially oriented market. France's journey from post-war reconstruction to becoming the pivot of European space activities is marked by consistent state investment, robust industrial alliances, and a willingness to take calculated risks in technology development. The French approach has relied on long-term, well-funded programs that integrate both civil and defense objectives, thereby ensuring a dual-use capability that strengthens national security while promoting scientific advancement.

France's Strategic Investments and Institutional Leadership

The establishment and growth of CNES have been central to France's space policy. From the launch of the Diamant rocket in 1965 to the development of the Ariane series, France has invested in critical infrastructures that guarantee independent access to space. The Guiana Space Centre, strategically located near the equator, not only offers technical advantages for orbital launches but also symbolizes France's commitment to sustaining a sovereign launch capability. This dedication is evident in the successive generations of launch vehicles, each designed to secure both operational autonomy and a competitive edge in the global market.

Government support for CNES is deeply embedded in the national budget, reflecting a clear policy choice to prioritize space as a cornerstone of economic and security policy. The substantial allocation of funds—exceeding that of other European counterparts—has enabled CNES to undertake ambitious projects such as Galileo, a flagship initiative in satellite navigation, and multiple Earth observation missions that serve both civilian and military purposes. The persistent financial backing ensures that France not only meets its strategic objectives but also retains a dominant voice within the European Space Agency. In doing so, France has effectively turned political influence and financial muscle into technical and industrial leadership.

Germany's Strategic Focus and National Contributions

Germany's space strategy, embodied by DLR, reflects a distinct yet complementary approach to that of France. Established in 1969 through the merger of several research institutions, DLR has grown into Germany's national center for aerospace research while embracing a multidisciplinary structure that covers aeronautics, energy, and transportation. This broad remit enables DLR to foster cross-domain innovation and to collaborate extensively with major industrial players such as Airbus Defence & Space and OHB. Although its national budget for space projects is lower than that of CNES, DLR's decentralized model emphasizes scientific excellence and technological development. It plays a pivotal role in shaping international partnerships through its significant contributions to ESA, thereby enhancing Germany's influence in joint research and collaborative ventures. This strategic focus on diversified research and coordinated industrial support has ensured that DLR remains a key contributor to Europe's robust space ecosystem.

The Complementary Roles of CNES and DLR

A comparative analysis of CNES and the German Aerospace Center (DLR) provides insight into differing national approaches that ultimately converge in their mutual support of Europe's space agenda. While CNES operates as a focused, dedicated space agency with a singular mandate, DLR functions within a broader framework that encompasses aeronautics, energy, and transportation. Germany's emphasis on integrating space research with other high-tech domains reflects its multidisciplinary innovation policy; however, this breadth has traditionally meant that Germany's investments in space-specific projects remain lower in magnitude compared to France's targeted spending. Despite these structural differences, both agencies have evolved to support similar objectives—ensuring independent access to space, fostering scientific innovation, and strengthening national security—albeit through distinct administrative and funding mechanisms.

France's ability to channel a larger budget into space programs has resulted in a more centralized approach that accelerates decision-making and project execution. In contrast, DLR's decentralized structure supports a broader range of initiatives but may lack the focused impetus that has propelled CNES to the forefront of European space operations. This divergence in strategic orientation underlines why the headquarters of ESA are in Paris and why French-led programs, such as the Ariane launcher series, have achieved global recognition.

New Space Market Trends and the Emergence of a Hybrid Supply Chain

As the industry progresses, a notable shift is observable in the transition from traditional, highly qualified (HiRel) components to the adoption of Commercial Off-The-Shelf (COTS) parts—a shift that underpins the New Space paradigm. The term "New Space" signifies not only a change in market participants—with private companies such as SpaceX and Rocket Lab taking center stage—but also a transformation in how space systems are designed, built, and operated.

Historically, the space industry depended on custom-built, rigorously tested components designed to meet stringent reliability standards. These components, while exceptionally durable, came at high cost and were often produced in low volumes with long lead times. New Space companies, seeking to lower costs and shorten development cycles, are increasingly turning to COTS components sourced from commercial and even automotive supply chains. Automotive-grade components, originally developed to endure harsh conditions in terrestrial environments, offer a balance between cost efficiency and acceptable reliability for missions that typically operate in low Earth orbit and have shorter operational lifespans.

This pragmatic approach does not imply a complete abandonment of quality standards; rather, it signifies a redefinition of risk management. New Space ventures accept a degree of risk by leveraging high-volume manufacturing and statistical quality assurance methods. Manufacturers, distributors, and space agencies are adapting by establishing hybrid supply chains that integrate both HiRel and COTS elements. This blend allows for faster procurement cycles and continuous technological updates, as the supply chain is no longer constrained by the lengthy qualification processes of traditional components. The introduction of standards such as ESA's ECSS-Q-ST-60-13C underscores a formal recognition of this evolving paradigm, setting guidelines that permit the use of non-qualified parts provided that system-level redundancy and rigorous risk mitigation strategies are implemented.

Supply Chain Dynamics: Traditional Versus New Space Approaches

The divergence between traditional and New Space supply chains is most apparent when comparing their procurement strategies and quality assurance practices. The traditional HiRel supply chain is characterized by a painstaking selection process where every component is subject to exhaustive testing—temperature cycling, vibration, and radiation assessments are routine; each part is chosen for its proven heritage and traceability. This meticulous process, though ensuring near-zero failure probabilities, results in high costs and inflexible production timelines.

In contrast, the New Space supply chain operates on principles akin to modern industrial manufacturing. Components are sourced from well-established commercial distributors, and their selection is guided by performance specifications and cost considerations rather than exhaustive pre-qualification. This approach allows for rapid design iterations and the frequent adoption of the latest technologies, as seen in the automotive industry. Manufacturers now frequently offer dual versions of components: one that meets traditional space-grade standards and another that is optimized for rapid production and cost efficiency, albeit with supplemental screening measures. Distributors have also evolved to provide enhanced tracking and rapid delivery, thereby reducing the risk of obsolescence or supply disruptions. Such agility in the supply chain not only benefits private New Space enterprises but also influences established agencies like CNES, which are increasingly open to integrating COTS elements in certain mission profiles.

Future Perspectives: Industry Convergence and Sustainability Challenges

Looking ahead, the trajectory of the space industry appears to be one of convergence, where traditional state-led programs and private New Space ventures increasingly overlap in both technological and operational practices. One significant trend is the growing collaboration between the space and automotive industries. Automotive manufacturing has perfected the art of mass production with tight quality controls, and its practices are being applied to satellite production with notable success. For example, initiatives that leverage assembly-line production techniques have demonstrated that satellites can be built faster and at lower cost, without sacrificing the performance necessary for their intended missions.

At the same time, the space industry faces challenges that extend beyond technical considerations. Orbital sustainability has become a critical issue as the proliferation of satellites in low Earth orbit raises concerns about collision risks and space debris. Both traditional and New Space entities are now investing in technologies and operational protocols aimed at mitigating these risks—designing satellites with controlled deorbiting capabilities, improving space traffic management, and enhancing the robustness of constellations through redundancy. Supply chain vulnerabilities, highlighted by recent semiconductor shortages, further underscore the need for diversified sourcing strategies and enhanced collaboration between suppliers and space operators.

The role of emerging technologies, such as blockchain, is also beginning to influence supply chain management. By establishing an immutable, transparent ledger for tracking the origin and quality of components, blockchain can enhance traceability and accountability in a supply chain that increasingly relies on commercial parts. Smart contracts, embedded within blockchain systems, have the potential to automate procurement processes and ensure compliance with agreed-upon standards, thereby reducing administrative overhead and mitigating risks associated with counterfeit or substandard components.

Furthermore, as global competition intensifies—with nations like the United States, China, and emerging space players ramping up their investments—the need for international collaboration becomes ever more pronounced. European agencies, spearheaded by CNES and complemented by contributions from DLR, are likely to pursue joint projects that leverage the strengths of each national approach. Such collaborations not only enhance technological capabilities but also help spread the financial risks and rewards associated with ambitious space missions.

Concluding Reflections on the Future of the Space Industry

The evolution of France's space strategy, as embodied by CNES, is a testament to the power of consistent investment, strategic policy-making, and a strong industrial base. France's leadership in the European space sector is built on decades of targeted funding and an integrated approach that unites civilian and defense objectives. The distinct yet complementary strategy of Germany's DLR highlights an alternative model based on multidisciplinary research and broader industrial integration. Together, these models have not only advanced Europe's independent access to space but also set the stage for a more dynamic and competitive global market.

At the same time, the emergence of New Space is reshaping traditional practices. The adoption of Commercial Off-The-Shelf components and the reengineering of supply chains to mirror high-volume industrial practices represent a shift in mindset—from striving for near-absolute component reliability to managing risk at the system level. This change is accompanied by evolving standards and hybrid solutions that offer a balance between cost efficiency and acceptable risk. As manufacturers, distributors, and space agencies adjust their processes, the boundaries between traditional and New Space are increasingly blurred, fostering an environment where innovation and efficiency can coexist.

Looking forward, it is likely that the space industry will witness closer ties with the automotive sector, as both industries benefit from shared manufacturing techniques and quality control practices. While challenges such as orbital sustainability and supply chain resilience remain, the drive to innovate—supported by both public and private investments—ensures that space will continue to expand as an essential component of modern infrastructure. In this evolving landscape, European leadership—anchored by the strategic vision of CNES and complemented by collaborative efforts with partners like DLR—will play a central role in shaping the future dynamics of space exploration, commercial exploitation, and international cooperation.

The coming decades may well be defined by a hybrid ecosystem in which traditional state-led programs and agile New Space ventures converge, supported by technological advancements and strengthened by cross-industry partnerships. As space becomes an increasingly integral element of global economic and security frameworks, the lessons learned from decades of focused investment and strategic planning in France, as well as the innovative approaches emerging in the private sector, will serve as a roadmap for balancing ambition with responsibility. Ultimately, the future of the space industry will be determined by its ability to integrate diverse sources of expertise, adapt to rapid technological change, and maintain a sustainable balance between cost, risk, and performance.

In summary, the historical evolution of France's space strategy, the pivotal role of CNES in driving European initiatives, and the contrast with Germany's DLR provide valuable insights into how state support, industrial strength, and innovative risk management have shaped today's space landscape. As the industry navigates the challenges and opportunities presented by New Space, the integration of commercial practices, the embrace of flexible supply chains, and the deepening of international cooperation will define its trajectory in the years ahead.

2 Exercise 2: Supply Chain Tokenomics

2.1 Chapter I: Current landscape and evaluation of Web3-Digitalization potential

There are many reasons why using Commercial Off The Shelf components (COTS) components. The main ones appear to be that they are easily available, they have been experiencing an increase in both processing power and memory, that this type of product showcases new innovations every 3 years, and is characterized by a low cost. However the use of these components in the space sectors has several challenges.

2.1.a Challenge 1: Lack of Control Over Manufacturing Process and Documentation

The COTS parts are designed and specified by manufacturers and not explicitly for space applications. Up until the 2000 COTS were mainly used when no Mil/Aero alternative existed or in non-critical applications. Since 2010 there has been a significant increase in the use of COTS in space applications and is seen as a cost efficient alternative.

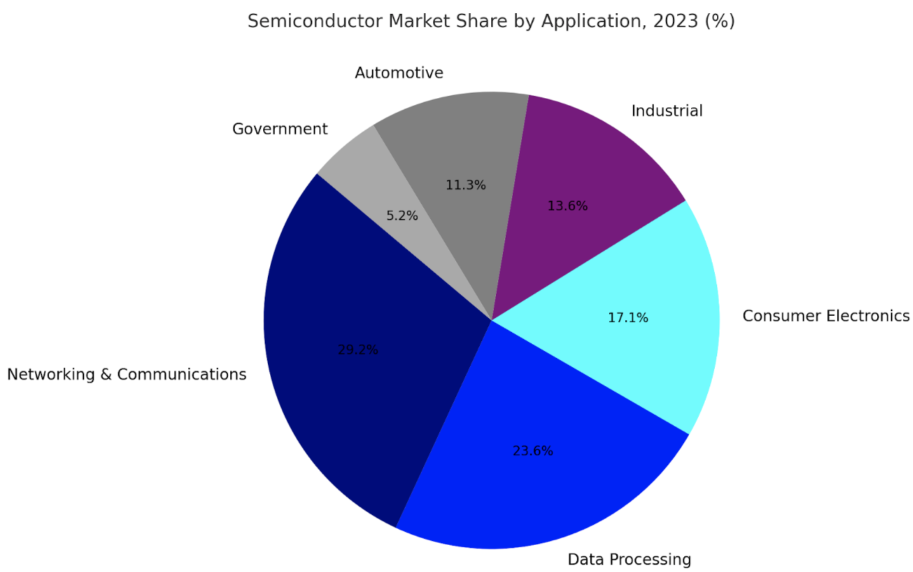

Figure 1: Semiconductor Market Share by Application

The networking and communications segment is the dominant share of the market and is forecasted to stay in this position. This is mainly due to an increasing use of smartphones and smart devices in general and an increasing access to the Internet across countries. The industrial segment is expected to grow even more with the adoption of automotive vehicles in developing countries and in countries with low availability of public transport. COTS components for the space industry only represent a very small fraction of the demand in the semiconductor market, more precisely about 1%. This shows a reliance on commercial components and with the increase of market share of other sectors and a rise in the use of AI, the smaller actor they will become, making it more and more difficult for them to obtain information or specific tests done on the product (Experts and Electronic 2024).

Two main problems are that there is no screening process to access the lot integrity and the lack of specific documentation on the parts. Since there cannot be quality control, for now, what the space industry is doing to understand their limitations is running specific tests on a number of components to identify which ones are suitable for specific types of missions. The most important factor that is taken into account in selecting a commercial part is the type of mission for which it will be used.

In 2014, NASA introduced the ideas to develop and implement systems engineering-oriented mission assurance programs to address EEE parts derating, qualification, traceability and counterfeit control. And also provide data on the effectiveness to ensure failure rates are adequately bounded. They also introduced the idea of data sharing between the actors of the aerospace industry to reduce blind spots. For now NASA has a four step process to gather information on the components : the first step is procurement that takes into account lot traceability, return policy, return/failure experience, product specification and other criteria that are given by the manufacturer. The second step is characterization which assesses if the radiation, mechanical, thermal, contamination and electrical/software are acceptable. If so, it is deemed acceptable for use. If not, you try to find solutions that are validated and then tested to see if they are acceptable, and if these are still not acceptable, they either use other components or find other solutions. So the lack of control over manufacturing is dealt with by either more test or high qualification components and the lack of documentation is either dealt with by generating their own documentation or only using the one available (rugged.com 2017) (Jeanette Plante n.d.) (NASA 2014).

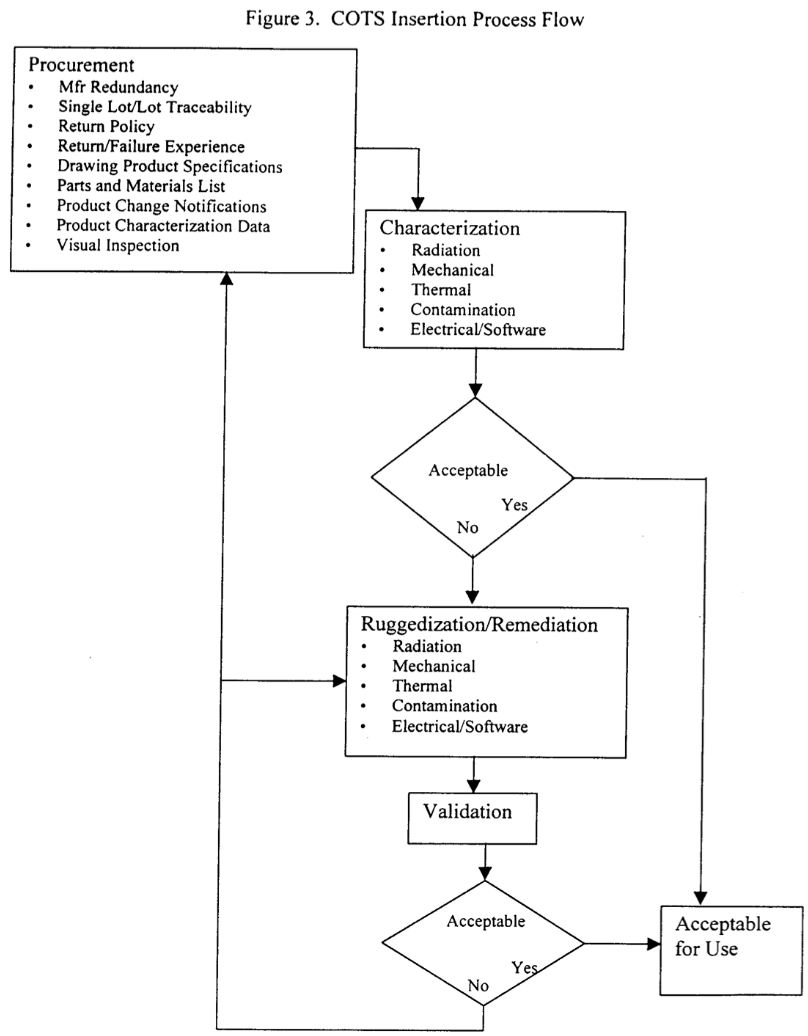

Figure 2: COTS Insertion Process Flow

Here are two potential web3 solutions to this issue. Firstly, it could be possible to use a decentralized supply chain ledger which would provide documentation for each component that would have been produced. Secondly, we could use a zero-knowledge proof to verify the authenticity of a component.

2.1.b Challenge 2: High Testing Costs

To the first challenge we can add the fact that conducting tests on the COTS components is highly costly as there is a non-recurring charge for the set up of the test and a per unit recurring charge.

The main solutions employed currently by the space industry is to use components that have qualified for automotive use per AEC-Q100 which have very stringent qualification criteria and test or devices in ceramic for military usage, but have to take into account the potential resistance to radiation effects. In LEO and MEO this is a good enough solution as the temperatures and radiation levels are not as extreme as in GEO. For radiation, 90% of the part count is not harnessed for radiation. In the past few years however we have seen more and more companies offer services around specific concerns about the use of COTS in space, they offer to validate EEE components and take into account product assessment selection, procurement and testing. The testing is mainly done on reliability more than defectivity. There are two reliability tests that are performed: a step stress (hot/cold/radiation) to emulate a mission and a constant temperature long term test. However the tests at the product level are not able to cover all failure modes. In addition to that, this does not solve the fact that testing is expensive, is difficult and not necessarily efficient. Another solution that has been proposed is the use of Statistical Process Control which is done preventively during the manufacturing process which observes the performance of the production process to prevent the production of components that would be substandard. However, this solution would imply that manufacturers have to put it in place and bear the cost of it which makes it unlikely to be put in place in the near future. NASA acknowledges that parts that were produced on fully automated production lines using the SPC and had in-process testing were more reliable (Friedlander 2017) (LaBel 2017).

A possible Web3 solution to this challenge would be to use tokens in order to incentivize testing. It could be possible to set up predefined conditions in smart contracts to automatically enforce test standards. For instance, to be a part of the system, and be rewarded for that, the components that you implement would need to have been a part of a testing procedure.

2.1.c Challenge 3: Lack of Detailed Tracking in Automotive

If indeed the solution used instead of testing is to use components qualified for automotive use with qualification AEC-Q there is another challenge that comes with using components for automotive. Automotive suppliers use centralized ERP systems for tracking, which can be prone to data tampering, and also tracking codes are not standardized or with the same granularity which makes it difficult to have a precise tracking of the components and has an impact on tests. In the case of COTS reliability is established by volume, so low volume components have an uncertain reliability. COTS are most of the time deemed as unreliable because of the high percentage of worst elements in the broad category, due to high failure rates, standard requirements that are low and resources used in the components (plastic) (Leitner 2024).

One way to check reliability without extensive testing is to use components that have been used for at least one year so that there is data to verify their reliability, produced in high volumes and that were 100% electrically tested. As well as that with an increased demand for these parts so has the reliability increased to.

We could think of Web3 solutions. For instance, we could have the component history linked to an NFT to have the life cycle data, or oracle networks to have a real-time tracking and have reliable information.

2.1.d Challenge 4: Different Life Cycles and Processes

COTS have a lifespan that is much smaller than specific components which creates a lot of waste. This can be explained by the fact that COTS are designed to have high performances at low cost. A majority of manufacturers are not able to provide life cycle statistics. Very few contractors have put in place a commitment to life cycle that is analyzed. Space components have vastly different lifespans, making a single tracking approach difficult. However, for short span missions (5 years) it is not necessarily a problem since components are more likely to be used only once but are wasteful (Hennessy 2001).

A potential Web3 solution, similar to the previous one, would be to use NFTs that adapt to changing life cycle data. Another possibility would be to use different token types to represent various life cycle stages. Captors could be put into the components to actualize these information on the blockchain.

2.2 Chapter 2: Designing an incentivized token economy

The growth of the space industry, and more particularly the New Space industry, has been accompanied by increased reliance on commercial off-the-shelf (COTS) components in spacecraft manufacture. While these components are cheap and ubiquitous, they pose considerable quality control, traceability, and regulatory compliance challenges. In order to address these issues, we are proposing a blockchain tokenized economy using Non-Fungible Tokens (NFTs) as digital proxies for parts and an ERC20 utility token for transaction, reward, and incentives. The system will provide supply chain transparency, enable compliance, and minimize the risk of low-quality or counterfeit components.

2.2.a Initial Setup and Players in the Supply Chain

The pilot scheme will be launched through the sponsorship of national space agencies such as CNES and DLR, who will offer control of the system and regulatory conformity. These agencies will provide seed funding, establish quality control systems, and ensure compliance by all parties in the supply chain to international aerospace standards. Their involvement is required to encourage industry-wide take-up and secure public and private sector take-up.

Value chain for this model involves various interdependent players: satellite companies, space agencies, test houses, fabrication labs, and manufacturers, all of which have a crucial function in ensuring the quality and reliability of space products. The incentive, constraints, and interaction among them constitute the basis for an incentive-based economy to flourish. The manufacturers have the responsibility to create parts to be used in satellites and space vehicles. They need to put each of the parts they manufacture on the blockchain as an NFT, such that there is a distinct digital twin for each part. The NFTs have considerable metadata, including information about the component's history of origin, material, testing, batch number, and ownership. This not only improves traceability but also allows automatic verification every time parts are passed along in the supply chain. Companies are incentivized to join through token rewards every time a part is verified and documented properly.

These raw materials are taken by the fabrication labs, which integrate them into spacecraft systems. The fabrication labs offer mechanical, electrical, and software compatibility of components, as well as ensuring parts are within the space missions' design specifications. Fabrication labs, through blockchain, will have component histories available in real-time, reducing the chances of incorporating non-compliant or faulty components. Their rewards are linked to the accuracy and quality of their assembly activities, and they are able to receive staking rewards according to reliability ratings and mission success outcomes.

Test houses play a critical quality control role, exposing each component to harsh environmental, mechanical, and radiation testing. Because of space's hostile environment, these tests determine the tolerance of materials and electronics to conditions such as severe temperature extremes, vacuum, and radiation. Each verified test result is appended to the component's NFT metadata, making it tamper-proof and verifiable along the supply chain. Test houses are incentivized with $SPACETRACK tokens for each component they successfully validate, and their reputation within the ecosystem is built through the honesty and accuracy of the test results they provide. In order to prevent fake testing, a multi-signature verification is implemented so that at least two independent test houses need to confirm the reliability of a component before a component NFT is labeled as fully verified.

Space agencies such as CNES, DLR, and ESA are governance bodies that regulate compliance

and governance. They ensure that the ecosystem only consists of authorized manufacturers and test houses. Agencies are also governance token issuers, which allows them to propose and vote on proposals for quality standards, token economics, and security protocols. Agencies are also responsible for investing in big-ticket infrastructure projects, such as the establishment of on-orbit servicing and in-space manufacturing, which will be significant consumers of this blockchain-based supply chain.
Satellite companies, as end-users, are the final link in the supply chain. They need high-quality, pre-qualified components to ensure mission success. These companies can directly source components using $SPACETRACK tokens, with a discount if they choose verified and well-documented components. This reduces the risk involved in sourcing faulty parts, makes procurement more efficient, and ensures that only reliable and space-ready hardware is utilized in missions that are mission-critical.
By uniting these various players within a tokenized ecosystem, we can ensure everyone is striving towards transparency, consistency, and efficiency in space manufacturing.

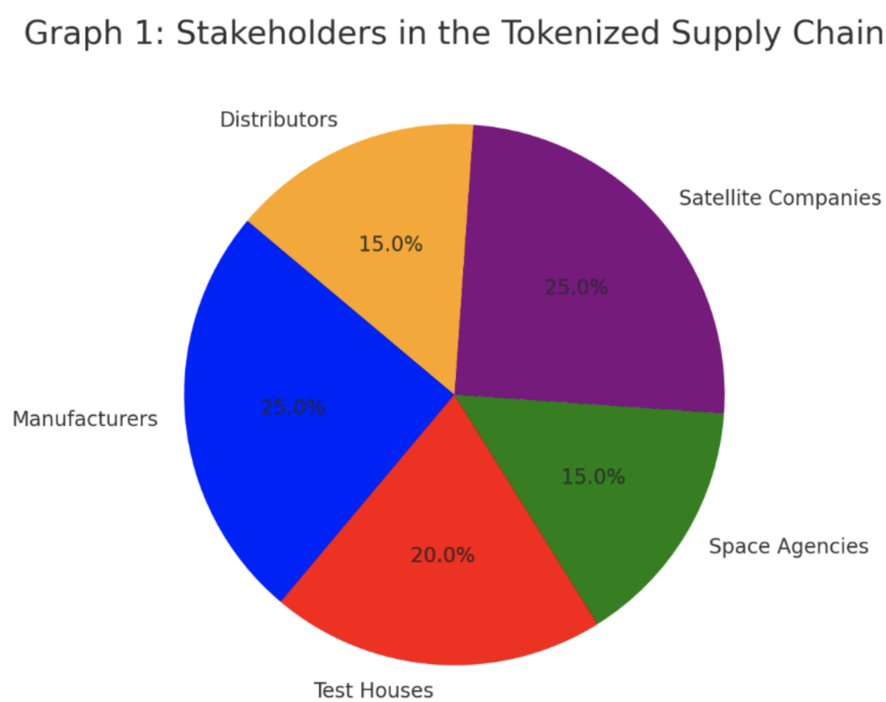

Figure 3: Stakeholders Tokenized Supply Chain

2.2.b Token System Design

The token mechanism as conceived has two key assets: ERC721 component digital twin NFTs and ERC20 payment and reward utility tokens ($SPACETRACK). The NFT design ensures traceability and immutability, self-refreshing with components transitioning through the supply chain. Each NFT is assigned a unique identifier that links to a physical part, recording manufacturing date, material blend, testing history, ownership history, and compliance declarations. The fact that these records are immutable eliminates fraudulent changes and increases interoperability across stakeholders.

Meanwhile, $SPACETRACK tokens are employed as the primary transactional and governance mechanism in this decentralized system. $SPACETRACK tokens incentivize stakeholders to fulfill compliance obligations and help maintain system integrity. Manufacturers are paid $SPACETRACK tokens for on-chain registration of authenticated components, test houses are rewarded with tokens for validating quality control, and satellite companies receive discounts for purchasing certified components. The token also supports staking mechanisms, where stakeholders lock tokens to participate in governance decisions on protocol upgrades, resolution of disputes, and compliance rule changes.

Compared to traditional fiat-based transactions, which rely on centralized middlemen and suffer from inefficiencies of delayed processing time and nontransparent money flows, the system employs blockchain's decentralization and transparency to make all the transactions auditable and automated. The smart contracts governing the transactions automatically provide rewards and penalties based on conditions predetermined ahead of time, reducing human intervention and preventing corruption and prejudice. Additionally, the ERC20 token shall be backed with a guaranteed guarantee of an accepted European Space Agency (ESA) budget for stability. Off-chain collateralization operates in reverse of volatility by providing a stable financial backing to the ecosystem. ESA or institutional sponsors will deposit reserves (maybe in fiat or stablecoins) into a custodial account or treasury run by smart contracts such that the token does hold actual value and facilitates building institutional trust in the system. This is a move similar to classical central bank-backed stablecoins, with stable supply of tokens and promoting adoption by industry participants that are worried about blockchain volatility.

Apart from governance and transaction, $SPACETRACK tokens can be utilized for insurance-type mechanisms within the supply chain. For instance, satellite firms can utilize tokens as insurance against component malfunction, hence avoiding financial loss resulting from defective components. In the event of a component being faulty upon purchase, the smart contract can pay compensation to the buyer automatically utilizing some staked tokens.

This NFT traceability-based token model, ERC20 incentives, collateralization, and governance participation forms a self-regulating economy that aligns incentives of all stakeholders across the supply chain. Scalability, security, and long-term viability are guaranteed through the hybrid blockchain architecture with decentralized and permissioned nature beneath it.

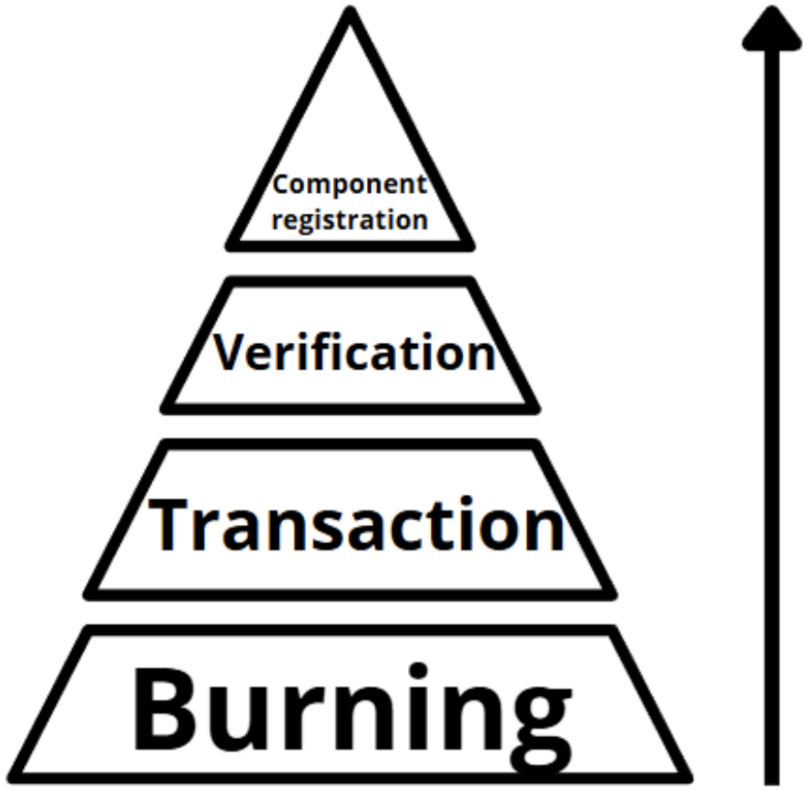

Figure 4: Token Flow Mechanism

2.2.c Incentives and Tokenomics

In order for there to be an equilibrium token economy, various incentive structures have been implemented. The test sites and manufacturers are rewarded in the form of $SPACETRACK tokens whenever they manage to update and validate the data so that the certification process is responsible and transparent. Satellite and fabrication businesses earn more by utilizing $SPACETRACK tokens, driving adoption and fostering a circular economy within the ecosystem.

For token stability, there is a mint-and-burn mechanism: tokens are minted once they have been tested and proven to be correct and then burned when problematic parts are discovered. This keeps supply in balance and prevents over-token inflation, otherwise diluting the incentives. The token system also features an adaptive model of distribution, where the rate of token release is automatically adjusted based on current demand and adoption levels. The greater the demand for authentic parts, the more tokens are released as incentive for activity; otherwise, during times of low demand, release is throttled so that there is not over-saturation.

The governing structure is that it prevents monopolization within a decentralized voting platform. The holders of the governance token are able to vote and suggest system changes, conflicts, and policy updates to ensure no business entity gets the authority to dominate the ecosystem. A multi-level governing structure can be leveraged to even further decentralize with token holders voting on matters of strategy and an impartial committee of industry stakeholders managing compliance enforcement.

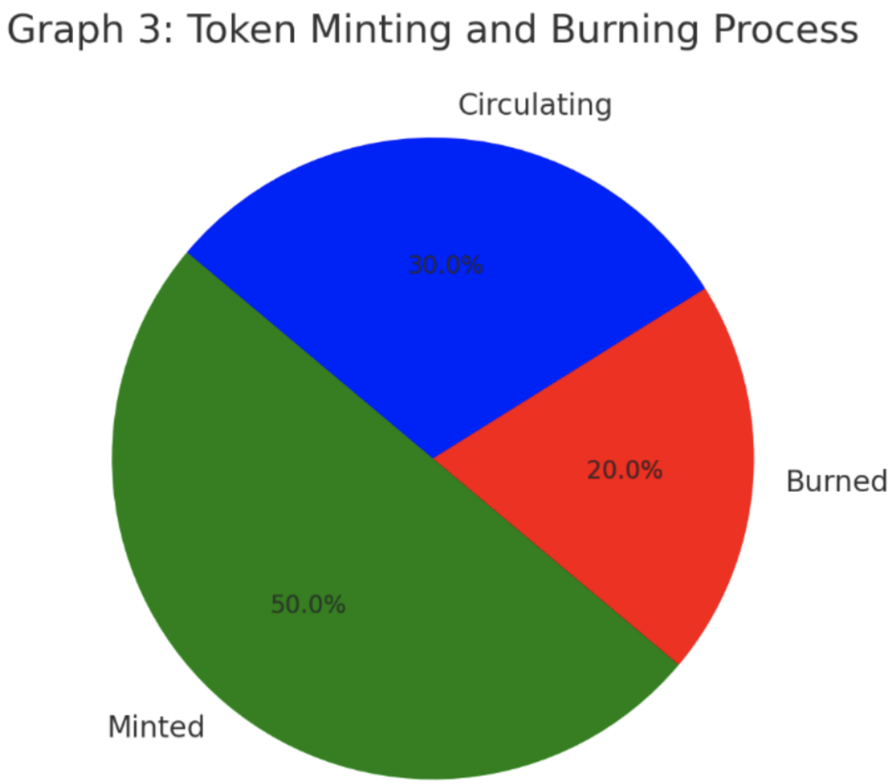

Figure 5: Token Minting and Burning Process

2.2.d Addressing Risks and Unintended Incentives

Even while the token economy is of significant value, there are risks involved like false reporting of tests, data tampering, and bias in regulation. Balancing risks of this kind, there will be multi-step verification that will be implemented where several test houses will need to verify a component in order to update NFT metadata. It removes risks of fake certification and maintains testing an unbiased process.

Additionally, there will be penalty systems and random checks to deter fraud. Test houses or manufacturers attempting to forge data will be penalized with token slashing, loss of staking rights, and short-term suspension from the network. These penalties will be automatically implemented by smart contracts so that they are impartial and free from human prejudice.

One of the unforeseen motivators would be placing reward in the shape of money before quality control and ending up in rushing or falsified testing. For this purpose, a staking system based on reputation will be used. Highly reputed test houses will be preferred, and fakes will be penalized and lose their contribution power. This trust framework will be integrated into smart contracts, which will provide penalties and rewards automatically and provide an auditable measure of trust between industry players.

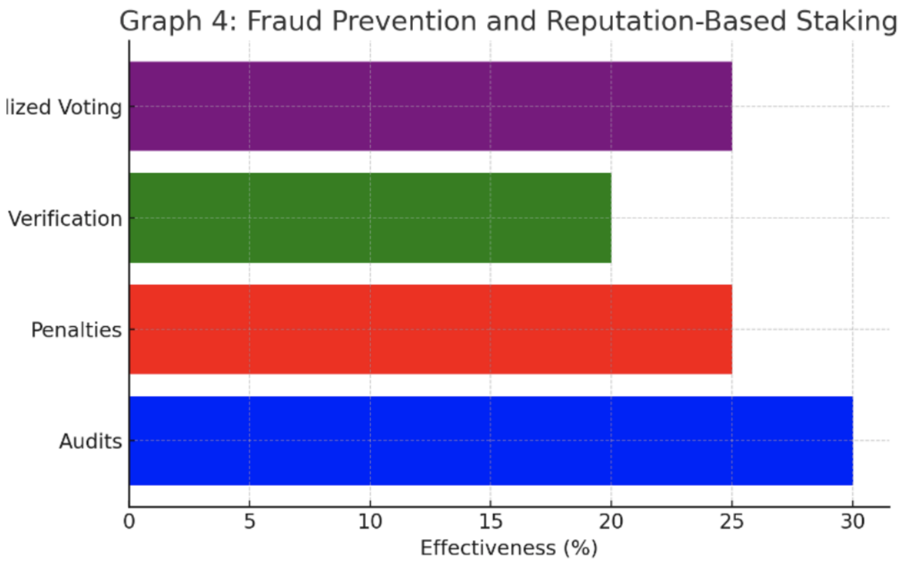

Figure 6: Fraud Prevention and Reputation-Based Staking

2.2.e Economic Model and Sustainability

This system is sustainable on a good economic model. The ERC20 token has a dynamic supply adjustment model wherein token supply will be tied to real demand in the ecosystem. Through an automatic supply regulation mechanism, fluctuations in token value are avoided, yielding long-term economic stability and speculatory volatility avoided.

Besides, on- and off-ramping of fiat mechanisms will also provide for ease of transition between blockchain transactions and traditional financial institutions. This will ease adoption for industry participants who may be hesitant towards a full shift to a tokenized environment. Strategic partnerships with regulated financial institutions will also be sought after in order to build bridges between digital and fiat currency, rendering the $SPACETRACK tokens more liquid and usable for use in real procurement processes.

By having its token-based economy, auto-regulating governance model, and robust fraud-protection protocol, this scheme is assured of long-term sustainability, global adoption, and high level of trust throughout the aerospace supply chain.

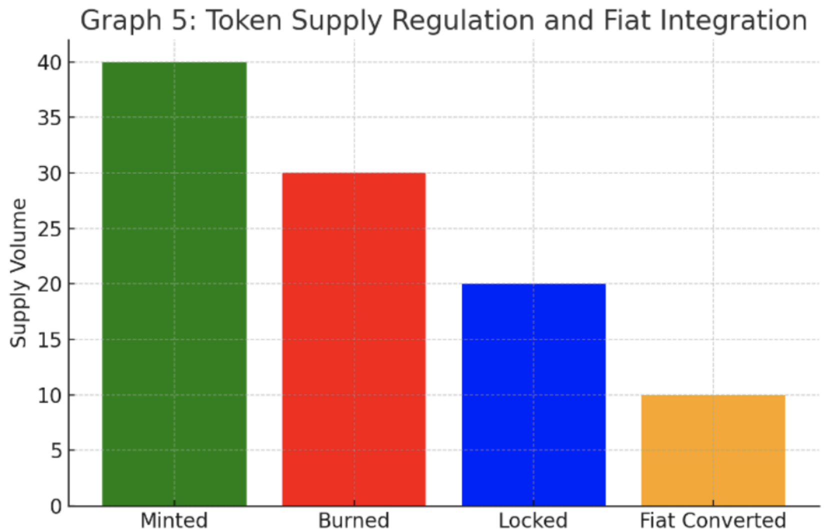

Figure 7: Token Supply Regulation and Fiat Integration

2.2.f Conclusion

Creating a blockchain token economy in the aerospace industry is an innovative leap toward an open, incentivized, and self-managed supply chain. With NFTs as digital twins and ERC20 tokens as rewards, the model enables quality assurance, reduces the risk of counterfeiting, and streamlines procurement processes. Adding governance functionalities, fraud prevention, and automated regulation of supplies makes it more credible. While there are hurdles to be overcome, namely stakeholder approval and regulation, this system is a good foundation on which to build New Space supply chain management in the future.

The next stage will involve pilot testing with industry stakeholders, measurement of system efficiency, and economic parameter optimization. Long-term success will depend on collaboration between space agencies, private industry operators, and blockchain developers to ensure the benefits of this technology-driven model are optimized.

2.3 Chapter 3: Technical Specification of Tokens

2.4 $SPACETRACK (ERC-20) Token Specification

2.4.a Summary

$SPACETRACK is a fungible token serving as the primary utility and governance mechanism in a space and aerospace supply chain network. It enables payments, rewards contributions, and facilitates on-chain voting.

2.4.b Abstract

The token adheres to ERC-20 standards by implementing essential functions for transferring tokens, querying balances, and managing allowances. It incorporates metadata support and role-based controls for minting and burning, along with governance hooks for decentralized decision-making, ensuring full Ethereum compatibility and a decentralized supply chain.

2.4.c Motivation

A distributed aerospace ecosystem demands a reliable and common currency to streamline transactions and align stakeholder incentives. $SPACETRACK addresses these needs through its robust ERC-20 framework, offering proven reliability and security, and enabling seamless integration into blockchain-based systems.

2.4.d Specification

Key token parameters include:

- **Name:** SpaceTrack Token
- **Symbol:** SPACETRACK
- **Decimals:** 18

The token implements standard functions:

- `totalSupply`, `balanceOf`, `transfer`, `approve`, `transferFrom`, `allowance`

and events:

- `Transfer` and `Approval`.

Extensions include controlled minting, burning, and an emergency pause feature, all governed by authorized roles.

2.5 CDTNFT (ERC-721) Token Specification

2.5.a Summary

CDTNFT represents unique digital twins for aerospace components. It records component details and ownership on a decentralized ledger, facilitating transparent tracking and verification throughout the supply chain.

2.5.b Abstract

Conforming to the ERC-721 standard, CDTNFT ensures each token is unique and provides functions for ownership tracking and metadata retrieval. It supports controlled minting and metadata updates, which are critical for effective inventory management in a complex supply chain environment.

2.5.c Motivation

Physical aerospace components require a unique digital representation that captures their provenance, testing data, and lifecycle information. CDTNFT offers a secure and transparent method for managing component history and verifying authenticity, thereby enhancing overall supply chain integrity.

2.5.d Specification

Token details include:

- **Collection Name:** Component Digital Twin NFT
- **Symbol:** CDTNFT

The token implements the ERC-721 standard functions:

- `balanceOf`, `ownerOf`, `transferFrom`, `safeTransferFrom`, `approve`, `setApprovalForAll`, `getApproved`, `isApprovedForAll`

and includes a `tokenURI` function to access JSON metadata. Additional functions allow for controlled minting, burning, and metadata updates, ensuring robust tracking of each component throughout its lifecycle.

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