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Complex project, complex innovation processes: evidence from an Aircraft company

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COMPLEX PROJECT, COMPLEX INNOVATION PROCESSES: EVIDENCE FROM AN AIRCRAFT COMPANY

I. Introduction

The concept of complex product systems (CoPS) is relatively recent. CoPS can be defined as high cost, engineering and information technology intensive customized products, systems, networks and constructs (Hobday, 1998). The CoPS characteristics differ from mass products, and also the way of acting in its administration and the applicable concepts has been shown different. The traditional concept of simple products does not seem to be suitable for the study of CoPS.

The literature about complex product systems has been growing, in recent years. Scholars suggested that CoPS represents a distinct and important analytical category for the purposes of innovation research, company strategy, project management and government policy (Zhang & Igel, 2001). Hobday (1998) proposed six dimensions that distinguish CoPS from simple products. One of those is innovation process.

Innovation process might be understood as predefined sequence of activities, from idea to launch e.g. (Cooper, 1999). Based on contingency approach, Salerno et al. (Salerno, Gomes, da Silva, Bagno, & Freitas, 2015) identified eight different innovation processes. Although these recent works represent an important advance in understanding how firms manage innovation, they do not focus on complex project.

Aircraft is a typical example of complex products considering either the number of parts of the products or the number of functions designed in the product (Griffin, 1997). The traditional innovation process does not seem appropriate to describe the complexity of this product with its systems and subsystems, customers and suppliers. The following research question guides our research: which are the innovation processes employed for managing a complex project?

Through a qualitative case study, this paper seeks to investigate which innovations processes are applied to manage the development of an airplane. From eight types of processes suggested in the Salerno classification, it was possible to identify seven processes used in the production of the two different jets studied – Phenom 300 and Legacy 450. It was also possible to identify that they may be applied in parallel.

The paper begins with a brief review of the literature. Section 3 describes the methodology used in this research. Section 4 offers an introduction to each different innovation process suggested by (Salerno et al., 2015) and examples of how Phenom 300 and Legacy 450 can fit each one. Section 5 presents the conclusions.

II. Literature review

A. *CoPS*

The notion of complexity that defines CoPS is born from the significant number of customized components and the vast field of knowledge that is necessary to produce those components and the whole products (Hobday, 1998). It has its seminal article in 1995. The extent and depth of design and systems integration activity are much bigger in relation to each product in CoPS compared with high volume production. The user involvement is also much higher in CoPS than in standardized consumer goods. Functional capability as systems integration is required to design, engineer and integrate the diverse knowledge inputs and subsystems that build each CoPS. For example, airframe manufacturers (e.g. Boeing and BAe Systems) have the capabilities to design and integrate airframes, aero-engines, avionics and other subsystems into a finished system (Davies & Brady, 2000).

Although CoPS are typically purchased by a single user, the vast knowledgebase needed to manufacture these products often exceeds the engineering capacity of a single firm (Hobday, 1998; Davies & Brady, 2000). They are made up of many interacting components and subsystems, belonging to different technical fields (Prencipe, 1997; Gunawan, 2002). These industries are involving technology-intensive capital goods, systems integration, embedded and largely tacit knowledge and skills, project-based manufacturing, low-volume production and concentrated and politicized markets with few buyers and few suppliers (Majidpour, 2016).

The creation of a major CoPS often involves extreme production and innovation complexity, not only because they embody a wide variety of distinctive components, skills and knowledge inputs but also because a large number of companies or different organizational units of the same company often have to work together in their production (Hobday, Rush, & Tidd, 2000). The production of an aircraft needs a wide scope of knowledge in new materials, software technologies, fluid mechanics, and communication systems (Naghizadeh, Manteghi, Ranga, & Naghizadeh, in press).

B. *Innovation process*

Cooper (Cooper, 1990) has proposed the idea of well-defined stages and decision points for the realization of development projects (Stage-Gate®). This method of management has been validated and very well accepted for most of the developments. Later, the same author (Cooper, 2007) has stated that, for projects with technological innovation, the traditional way of managing, using phase-review, Stage-Gate® or PACE® is not always adequate. “For non-traditional projects do not use traditional methods.” Shenhar (2001) has shown how different types of projects are managed in different ways and that one size does not fit all projects.

III. METHODOLOGY

The purpose of this research is to identify if a same company might use different innovation processes when dealing with complex projects. And more, if the same project can use different innovation processes at different times and / or for different objectives or even simultaneously. It is also important to understand the rationale of each kind of process verifying if it fits with the 8 types suggested by Salerno et al. better than the traditional innovation processes (linear process: “from idea to launch”).

A field research has been conducted with two product innovation projects, the executive jets Phenom 300 and Legacy 450, in one company, Embraer. People from different areas, engineering, customer support, program administration, industrial designer, market intelligence and R&D, have been interviewed. In this way, different approaches for the same project have been covered. The saturation concept has been the criteria to stop.

All the interviews have happened face-to-face and performed by the author using an open semi-structured questionnaire. The paper “Innovation processes: which process for which project?” was made available prior to each interview. The intention was to allow the interviewee to be more familiarized with its terms and concepts. However, only two of the interviewees have accessed the paper before the interview.

A. *Each interview has been structured as follows*

- The first part of the interview has been about the formal innovation process of the company in general.
- The second part has been about how innovative projects rise before formalization. What are the possible project sources in general and what sources have been used for Phenom 300 and Legacy 450.

- The third part has been specifically about those two executive jets. What are the products characteristics, market characteristics, supply chain, clients and post enter into service developments.
- The fourth part has used the eight different innovation processes suggested by Salerno et al. Each of them has been explained and, from that, the interviewees have been asked to bring examples of their application related to the projects object of the present research. Sometimes the interviewees have used examples related to other projects; those examples were not considered on the findings and results of this research, but they improved the author understanding about their opinions and experiences.

It is important to say that Embraer is a large multinational company with many different formal innovation processes. As this research has focused on the projects Phenom 300 and Legacy 450, the processes related to organizational innovation and R&D has not been considered, as well as innovative process of how to do faster and how to do cheaper, even if related with Phenom or Legacy.

IV. MAIN FINDINGS AND DISCUSSION

CoPS tend to be produced in projects or small batches tailored for individual users (Hobday, Rush, & Tidd, 2000). Comparing commercial and executive jets, this difference is significant, because prived owners usually buy only one unit of the executive jet. Which is customized for them. Therefore, executive jets are often projected differently one from the other, one by one.

In the business jets, the OEM starts the innovation process to build a new aircraft driven by the market intelligence, and, as soon as the first concept has the technical approval, the loop producer-user interaction starts. Technical approval comes first because of the rigid regulatory standards to follow, since the airplane must not be only manufacturable, but projectable and certifiable. Aircraft industry has to comply with the regulations specified by certification authorities. So the dialog between the OEM and the regulator authorities can shape innovation paths by dictating matters such as safety issues.

Since the first concept is technically approved, many clients participate in the discussions until the concept is freezed. But it doesn't stop there. The continuous dialog between the project team and the user is often necessary. During the long development cycle, the user redefines product requirements many times, demanding higher performance, capacity, and reliability, adding, at the same time, further complexity (Hobday, 1998; Hobday, Rush, & Tidd, 2000; Dedehayir, Nokelainen, & Mäkinen, 2014).

Embraer designs, develops, manufactures and sells aircrafts and systems for commercial aviation, executive aviation, and defense and security segments. The company also provides after-sale support and services to customers worldwide. It's seven-aircraft portfolio includes from the entry-level Phenom 100 to the ultra-large Lineage 1000.

Phenom 300 is an entry-level jet for eight up to eleven occupants. It's a clean-sheet design project started formally in 2005 and first delivered in December 2009. Embraer's Phenom 300 light jet earned a reputation as a game changer in its first year of operation. "Since our launch announcement of the Phenom 100 and Phenom 300 jets just over a year ago, we have logged in excess of over 235 firm orders" said Luís Carlos Affonso Maurício Botelho. The editors of Flying Magazine granted to the Phenom 300 their Choice Award as one of the year's most remarkable accomplishments in terms of innovation, vision and determination. It was the most delivered business jet all over the world in 2013, 2014 and 2015. The innovative Phenom 300 also granted the prestigious award "Robb Report's Best of the Best Award" five times: 2011, 2012, 2013, 2014 and 2016 (Embraer Phenom 300, 2016).

Judged one of the top 15 most influential business aircraft of all times by industry press, the light Phenom 300 is the roomiest in its class. The aircraft has the best climb and field performance for any light jet. It is designed for 15% lower operating costs and offers the largest range and speed in its class. It can fly at an altitude of up to 45,000 feet (13,716 meters) and has a range of 1,971 nautical miles (3,650 km), including NBAA IFR fuel reserves, which means the aircraft is capable of flying nonstop from New York to Dallas or Houston to Los Angeles for example (Embraer Phenom 300, 2016).

The mid-light Legacy 450 is a new breakthrough aircraft that promises a new paradigm in business aviation by offering features normally available in larger and more expensive aircrafts. It is a remarkable union of technology and design offering digital flight controls with full fly-by-wire.

The Legacy 450 replaces conventional controls with full fly-by-wire technology. This technology enables a smoother, more natural feeling flight by translating the manual input from the pilot electronically rather than mechanically. Electronic fly-by-wire systems increase the number of control surfaces that can be actuated simultaneously. This allows for maximum performance and control, while at the same time, reducing the pilot workload and creating a smoother flight for passengers. Additional flight envelope protection also increases flight safety. The Legacy 450 and Legacy 500 fly-by-wire system has received a prestigious Flightglobal Achievement Award in the Innovator of the Year category 2010. Embraer Executive Jets started Legacy 450 deliveries on December 22nd, 2015 (Embraer Legacy 450, 2016).

Constructing complex products and systems, as an aircraft, requires a wide range of capabilities. Aircrafts are made up of many interacting components and subsystems, belonging to different technical fields, rarely under control or ownership of one single enterprise (Gann & Salter, 2000). Just inside de OEM, around two thousand people are involved to conceptualize, design and produce an executive jet, an even more than this is on the suppliers/partners side. The role of the supply chain is tremendous: the suppliers can be responsible for delays in the schedule for the first flight and for delivery to customers or can bring an important innovation, for example. In the work of identifying the innovation processes applied to the Phenom 300 and the Legacy 450, both suppliers and customers were mentioned as key players in the process.

As explained before, the eight types of innovation processes suggested by Salerno et al. have been used to classify the innovation processes applied to Phenom 300 and Legacy 450.

A. *Process 1. Traditional process: from idea to launch*

Fig. 1. Traditional linear process: from idea to launch

Since executive jets are complex products that can be splitted into several systems, each system has, in general, several functions and features. Considering this, three main cases where the process one is applicable were found:

- During the main aircraft development cycle, some systems are made internally, and other in the suppliers. On the Phenom 300 and the Legacy 450, some systems (like the AMS system and the eletrical system), that were developed internally in the OEM, followed the process above.
- When the aircraft enter into service, not all the features are developed, they are called follow-ons; the innovation process used for those is the traditional one. For example, the Phenom 300 has the standard configuration with 8 occupants or optional items such as the 7th seat, the belted toilet and the 2-place divan (Embraer Phenom 300, 2016). Not all of these options were ready on the first delivery. The Legacy 450 has even more options such as forward 2-place divan, belted toilet, forward side facing seat, wet or dry galley (Embraer Legacy 450, 2016). As happened with Phenom 300, not all the options were available at type certificate.
- After some time, the aircraft is in service, it is recommended to work on a refresh. In this case, the process from idea to launch is normally used.

B. Process 2. Anticipating sales: the tailor-made approach (open order)

The innovation idea is jointly constructed with the client; only after this joint construction the project is formalized (e.g., order and contract). There is then a period of maturation that includes the definition of product specifications prior to the order (or sale). The client pays for the development before the delivery of the product, anticipating income for the company compared to the traditional process (process 1). Thus, the client finances the development of product and process. The delivery of the product ends the process 2 (Salerno et al., 2015).

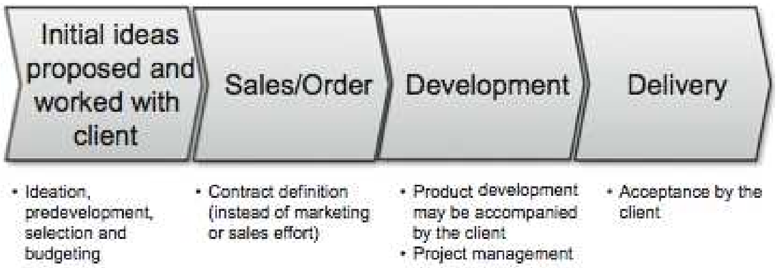

Fig. 2. Anticipating sales: the tailor-made approach (open order)

Executive jets allow customization. Usually, as bigger the airplane is, bigger the customization is. The customization is not related only to trim and finishing, but to configuration and special requests too.

Each time that the customer desires a feature that hasn’t been offered before, the innovation process described above happens. This is very common. Private owners are usually seeking to meet specific needs. Companies in the fractional marketplace customize looking for promptness and economy, and, with the customization, the fractional owners have the feeling that they are flying on their own plane.

For instance, in October 2010, NetJets, the pioneer and world leader company in private aviation, signed with Embraer an US$1 billion order that included 50 firm orders and 75 options, creating a partnership that would develop into the NetJets’ Signature Series™ Phenom 300 (Embraer Phenom 300, 2016).

NetJets has specified an aircraft that features advanced technologies to ensure maximum safety, reliability and operating efficiency as well as superior cabin comfort, advanced inflight entertainment systems and custom cabin designs. The aircraft seats up to seven passengers and features a full refreshment center, custom cabin amenities including a customized galley, advanced inflight entertainment systems, WiFi and a fully enclosed aft lavatory. It also included the Prodigy Touch Flight Deck, based on the Garmin 3000 platform enhancing pilot interface and situational awareness. This marks the first-in-service application of this advanced avionics system (Embraer Phenom 300, 2016).

Part of the NetJets' Signature Series™ Phenom 300 followed this second innovation process of Salerno et al., and another part of it followed the next process depending on the degree of specification of the request.

C. Process 3. Anticipating sales from a given client specification (closed order)

As opposed to the previous process, the client in process 3 has a predefined specification (e.g., functional requisites or form) that the order must fit. For the vendor, this process contains neither idea predevelopment nor a maturation period for the specifications. For the firm, the selection phase involves a decision about whether to develop the product.

In this process, sales precede development. Even if specifications come defined from the client, the company may suggest new functionalities or specifications. Salerno et al. found cases in which companies took advantage of orders to build platforms that could be utilized in future projects with other clients (Salerno et al., 2015).

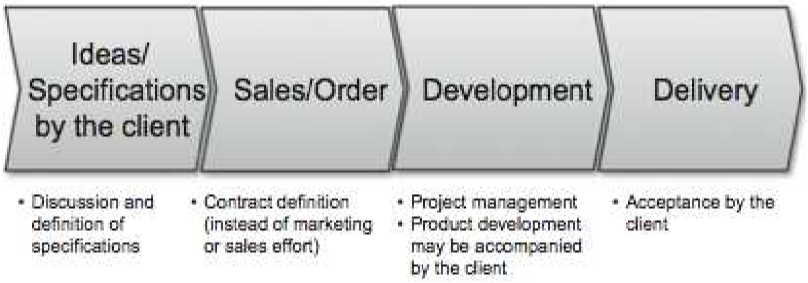

Fig. 3. Anticipating sales from a given client specification (closed order)

The process with the specification given by the client is pretty common in two ways.

- When the customer brings the finishing material that he wants to be applied in his aircraft. In this case, it's necessary to pay an extra amount because the OEM will need to test and certify its use with the authorities. Therefore, it's necessary to do the development step.
- In the relation so called build to print among OEM and the supplier. Embraer chose this path for some parts of the Phenom 300 and the Legacy 450. In those cases, Embraer provided drawings and the supplier was responsible for producing the part according to the specification using the correct materials. The design specifications included performance and quality requirements.

D. Process 4. Started by a public or private call

Private contract bids, e.g., when a systems integrator launches a request for bids, such as in the automotive, aircraft, or home appliances industries. The call usually defines the functional requirements of the product to be developed. The flow begins with predevelopment, which consists of preparing an initial analysis of the feasibility of the project for the company (Salerno et al., 2015).

Fig. 4. Process started by a call

Embraer Executive Jets participates in customer's bids and creates bids for the suppliers.

- Either Phenom 300 as Legacy 450 has already participated in private calls. Usually, companies that buy airplanes call for bid; many of them need to do this in order to meet their regulations. When the order includes a larger number of airplanes, this is even more common due to the bargaining power. Buyers increase competition within an industry by forcing down prices, bargaining for improved quality or more services, and playing competitors against each other.

- Wide portion of systems suppliers were selected by bids. The OEM launches a call seeking for who accomplish with the HLR (high level requirement). Those who want to participate in the call do a pre-development and present their projects. Embraer receives the proposals and selects it taking into account several aspects, not just the financial ones, before signing the contract giving the go-ahead for development - the seats supplier, e.g.

E. Process 5. Process with a stoppage: waiting for the market

The first segment in the fig 5 concerns idea generation, idea selection, development, and initial diffusion/sales; the product is developed to pilot or experimental plant scale. Diffusion (sales) is performed for a specific market niche, e.g., the lead users. There is a stoppage in the process because the perceived market is not large enough to justify further development, whether in production processes, product specification, or production facilities. This stoppage represents active behavior: the development activity is interrupted, but the project is not abandoned because the company directs its efforts to "create" a market (Salerno et al., 2015).

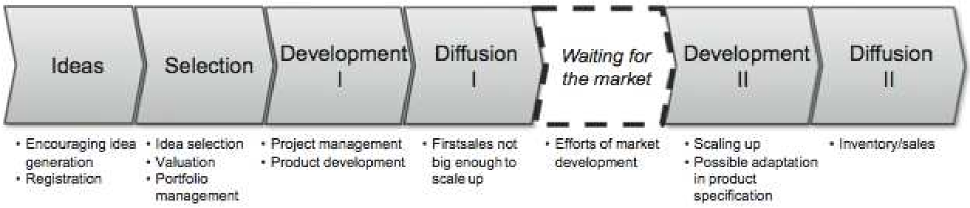

Fig. 5. Process with a stoppage: waiting for the market

The process with a stoppage waiting for the market is quite rare. Only one example was found concerning the two aircrafts used as objet of this research.

Aircell, that later on had its name changed to Gogo, was trying to create market for their products in the beginning of the years two thousand. Some clients liked it and installed the product in their airplanes via STC after receiving the aircraft. A supplemental type certificate (STC) is a national aviation authority-approved for a major modification or repair to an existing type certified aircraft.

Nowadays Legacy 450 customers can already receive the factory-installed UC5000. UCS 5000 is business aviation's smart cabin system from Gogo. More than a router, and beyond an

IFE service, UCS is a singular unit that orchestrates, manages and delivers data, voice, entertainment, information, and cabin management services.

F. Process 6. Process with a stoppage: waiting for the advance of technology

This process is similar to the previous one, but the stoppage in this process is caused by a technological bottleneck within the product or process development (Salerno et al., 2015).

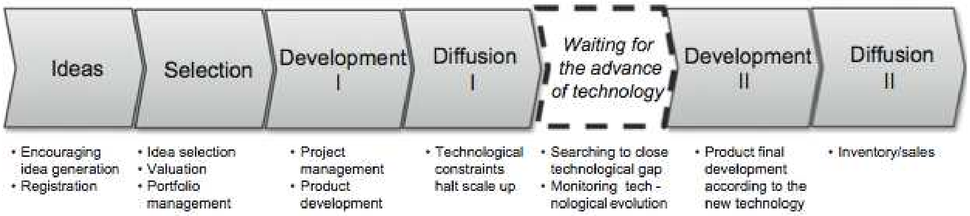

Fig. 6. Process with a stoppage: waiting for the advance of technology

This is not a frequent process, but it’s not unusual either.

A Phenom 300's example is the mirror in the interior of the plane, that was made with polycarbonate, but the advance of the technology allowed the use of glass mirror (gorilaglass).

On the other side, a Legacy 450’s example is the use of a polymeric product that imitates stone. It was used in the finishing of surfaces subject to water. With the technological evolution, it has started to be made with a thin layer of real stone (marble and granite).

The use of internet through band KA is another example. The size of the antenna prevented the use of this feature in smaller planes, so the internet was provided trough other options. With the technological advance, lighter and more compact design has allowed the antenna to be installed in most of the airplanes.

G. Process 7. Process with stoppage: waiting for the market and for the advance of technology

Process seven is the junction of the two previous processes with stoppages. There is a first stoppage because of technological issues and a subsequent stoppage to (actively) wait for market viability.

No case has been found.

H. Process 8. Process with parallel activities

The diffusion/sales phase starts before the end of product development (Fig. 7). The development continues until a first version or a sample of the product is obtained. This first version does not necessarily have all of the variations (e.g., models, colors, accessories, etc.), functionalities, or quality problems solved. However, there is a version of the product available that enables the company to begin diffusion, which is performed in parallel with the remaining development efforts.

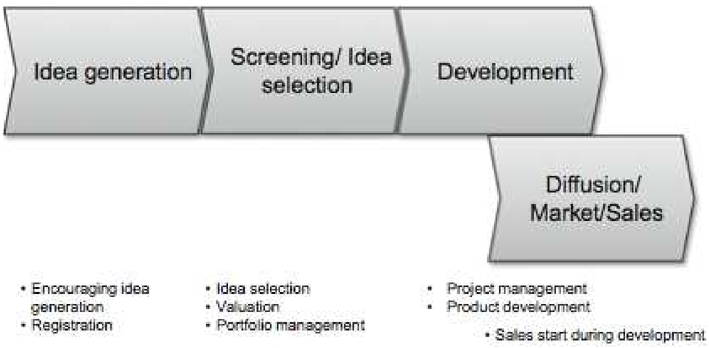

Fig. 7. Process with parallel activities

This is the Embraer executive jets innovation process for a new aircraft model. The generation ideas usually come from the market intelligence, and the selected ones are technically analyzed and discussed with some clients until the initial concept is defined. Once approved, the sales starts together with the development and both continue after the first deliveries. The development efforts keep going because follow-ons development, improvements, new configurations and corrections happen after the aircraft enter into service.

One example is the Legacy 450 extended range. Embraer Executive Jets started Legacy 450 deliveries on December 22nd, 2015. On July 12th, 2016, the Company announced that the Legacy 450 has received certification for an extended range of 2,900 nm (5,370 km). The improvement has been approved by the regulation authorities: ANAC (Agência Nacional de Aviação Civil, the Brazilian agency for civil aviation), FAA (United States of America Federal Aviation Administration) and EASA (European Aviation Safety Agency). The new range, with four passengers onboard plus reserves, is 329 nm (609 km) larger than the first certified range (Embraer Legacy 450, 2016).

"With this range that surpassed our original targets, the Legacy 450 is definitely the best-in-class business jet." The Legacy 450's increased range was certified after minor modifications to the wing to accommodate more fuel, along with updates to the Fuel Control Unit (FCU) and avionics. The extra fuel tank capacity is retrofitable at no cost for the first aircraft serial numbers (Embraer Legacy 450, 2016).

V. CONCLUSION

This paper aimed to contribute with the literature about innovation process in CoPS (complex product systems). It does not seem possible to define a single process of innovation for CoPS like executive jets. Different processes of innovation take place on it, depending on the stage it is in - before or after entering into service -, depending on the aspect focused - whether at the level of the product as a whole, its systems, subsystems or parts of a system (such as a component of a system) - and depending on the group of people involved. The development of Embraer's Phenom 300 and Legacy 450 exemplifies it with details.

In addition, different processes happen in parallel, simultaneously. The so-called Process 1 by Salerno et al. (traditional process: from idea to launch) usually takes place in a simultaneous way with the Process 4 (started by a public or private call) and the Process 8 (process with parallel activities): Process 1 related to systems developed internally, Process 4 related to systems developed in the suppliers and Process 8 related to the entire product. Different processes take place in parallel in different companies working on the same project and also in the same company, the OEM.

From all those findings, it seems to be clear that the "one fits all" approach is not enough for CoPS. The same project may require different processes. The Salerno et al. classification is more complete and appropriate. Interesting implications for practice and theory outcome from this research. For theory, it is necessary to understand that a complex project is managed in a network of innovation processes in which some are simultaneous or parallel. Such innovation processes can have different logics, demanding different competencies being articulated for the success of the project. This was not predicted by Salerno et al. For practical purposes, the implications are the need to develop an innovation system that recognizes that a complex project requires different processes, with its own management logic.

In this research, the processes of innovation within the vast supplier chain directly involved in the projects hasn't been specifically investigated. However, it is known that suppliers have crucial role in projects of the magnitude of an airplane. It is important to mention that CoPS contain a large group of products, and this article contributes to the understanding of a small portion of those, so more research is still necessary to establish the ideal classification.

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