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Technological Capability of Brazilian Aircraft Maintenance

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Abstract

In Brazil, the expansion of air transport industry requires the support of aircraft maintenance sector. Thus, this paper's objective is to visualize the maintenance sector's technological capability, analyzing its expertise based on their current technical competence, and providing insights on its managerial capability and its ability to provide new services

Key Words

Aircraft Maintenance, Technological Capability, Brazil

1. Introdução

The aircraft maintenance service is very important to support the air transport and ensure continued airworthiness in countries like Brazil, which have a wide territory connected by a strong air traffic (MACEDO et al., 2007). This support is of fundamental importance in the scenario of rapid expansion of the air traffic demand in Brazil, which has grown at annual rates of more than10% over the last decade (ANAC, 2010, MCKINSEY & COMPANY, 2010).

The significant expansion of air transport services requires an aircraft maintenance industry able to support such an expansive process. This ability to provide quality services at low cost (KNOTTS, 1999) can be appreciated by many perspectives. The first one is the technical training that refers to the range of services that companies are allowed to provide, in accordance with certificates issued by the National Agency of Civil Aviation (ANAC). The second perspective is the management capability that supports companies in their process of developing competitiveness and high performance. Both capabilities are basic elements of technological capabilities (LALL, 1992; FIGUEIREDO, 2003), whose concept can be adapted to the aircraft maintenance industry as being that set of internal capabilities that enable the company to develop innovative services, which keep pace with needs and maintenance requirements imposed by the new aeronautical products.

This ability to develop innovative services requires a well developed management capability, which enables companies to induce changes in their technical competences. Alternatively, the existence of problems in management may reflect the lack of a sophisticated management model, and so the lack of technical skills dynamics. Based on these assumptions, this paper intends to carry out a preliminary analysis of the technological capability that prevails in the Brazilian aircraft maintenance industry, investigating the patterns of technical and management capabilities that prevail in the Brazilian aircraft maintenance industry. This goal is achieved by relying both on primary data, which provide a picture on the technical capability of the sector (MACHADO et al. Al., 2011), as well as in the analysis performed by Machado and Urbina (2009), utilizing sample information about managerial capability of companies that provide maintenance services for military aircraft. Thus, this article begins with a presentation of basic concepts related to technological capability, which are applied to aircraft maintenance activity. Next, it is briefly discussed the Brazilian regulatory framework, which ensures and circumscribes the aircraft maintenance activities that companies have the technical competence to perform. Based on ANAC´s primary data about types of technical capabilities possessed by Brazilian companies, it is performed an exploratory research looking for detecting the profile of technical capabilities in Brazil. Afterwards, it is made an analysis of management capabilities of companies that provide aircraft maintenance to the military segment, in light of the airspace maintenance management model. Finally, we present the conclusions and recommendations of this article.

2. Aircraft Maintenance Capabilities

The aircraft maintenance activities form an essential part of flight safety, aiming to provide full service condition for the aircraft at the time an operator requests, with the expected quality and with minimal cost (KNOTTS, 1999). This service is of vital importance to support the air transportation in countries like Brazil, which have a large territory, whose regions need to be linked by a strong air traffic (MC KINSEY & COMPANY, 2010). The volume of that traffic in the 2000s exceeded 50 million trips per year with an annual demand growth of 10% in the period 2000-2008 and almost 30% in the period 2009-2010 (ANAC, 2010). This growth trend is considered as part of a possible scenario, given the expectations of income growth and the impact of social programs in Brazil, which have significantly raised the demand for air transportation of the poorest regions and of the lower income classes (MC KINSEY & COMPANY, 2010).

In this scenario, the expansion of the air transport industry requires aircraft maintenance services able to support such an expansive process. Therefore, it is necessary to examine the concept of technological capability, which is useful as a background for the examination of technical skills in the Brazilian aircraft maintenance.

2.1. Aircraft Maintenance

The maintenance function contributes to achieving world class performance, enhance quality and productivity, and reduce costs (MISHRA, 2006). An effective maintenance service is essential for many operations. It can help to extend the product life cycle, improve the availability of equipment and keep it in good condition. On the other hand, maintenance neglect can lead to more frequent failures, equipment underutilization and the consequent delay in production schedules. In most companies, the maintenance activity is an activity to support the organization's core competency, which is the reason for its survival and it is central to his strategy of differentiation from competitors and customers (FLEURY AND FLEURY, 2003, FLEURY AND FLEURY, 2004; PRAHALAD and HAMEL, 1990). As a support activity, the maintenance is designed to keep the equipment on operating status. On the other hand, according to Martin (1997), there are other companies for which higher-level corporate skills are centered on the provision of maintenance services. In the aircraft industry it is possible to clearly distinguish between companies that have maintenance as a support organizational function and companies that have maintenance as a core activity. Airline cargo or passengers companies, normally have in its organizational structure a department responsible for maintaining their equipment (aircraft), while other companies just provide aircraft maintenance on equipment from different aircraft systems. The aircraft maintenance can be divided into two activities, which though are completely linked, do have characteristics that distinguish them. The first activity refers to the maintenance of aircraft as a single device, and the second activity refers to the maintenance of components that serve as inputs to the first. The first activity can be classified on:

- preventive maintenance – According to Tu *et al*. (2001), preventive maintenance is the practice of replacing components or subsystems before they fail, usually with predetermined frequency (hard time) or due to inspection and test (on-condition). The goal is to maintain continuous operation of the system, in this case the aircraft;
- corrective maintenance – In accordance with Moayed (2009) this is one that occurs after the identification and diagnosis of a problem. During this diagnostic maintenance technicians have to identify the failed parties to implement their correct actions and repair;

- predictive maintenance - it takes into account the continuous monitoring of the operational limits of a given component or subsystem. If any tendency for the occurrence of a component or subsystem functional failure appears, it should be removed for maintenance. Some mechanisms for the implementation of predictive maintenance are the PDM (Product Data Management) and PHM (Product History Management).

2.2. Technological Capability and Aircraft Maintenance

In today's economy, the development of technological capabilities is critical not only to strengthen the capacity to generate innovations (LALL, 1992), but also to perform services involving activities related to products with innovative and technological content, which grows over time (GALLOUJ, 1998; VARGAS, 2009). In particular, it is important that aircraft maintenance activities can be able to keep up with technological developments of the aircraft for which it intends to provide services of better quality and minimum cost, while providing guarantee of flight safety.

To face innovation, aeronautical maintenance companies must develop technological capabilities that, paraphrasing Figueiredo (2003), are the company's internal capabilities that enable it to develop innovative services, which keep pace with maintenance needs and requirements imposed by the new aeronautical products . Thus, these capabilities are the set of resources, embodied in people and organizational systems that enable companies to obtain and manage maintenance improvements in their processes and their technical skills (ability to perform the various standards with their respective classes of certified activities ANAC).

It should be noted that the technological capabilities of companies and industry evolve and mature as long as there is acquisition of knowledge to create and accumulate such capabilities

(Figueiredo, 2003). Therefore, one can argue that technological capability in Brazil depends in the current technical competence, which reveals trends, and the management capability of companies. The latter includes not only the pursuit of excellence in management for a particular set of skills, but also the formulation of strategies to innovate in technical skills, developing innovative services that because of its greater knowledge content generate more value and profitability.

3. Aircraft Maintenance Technical Capabilities in Brasil

3.1. Regulatory Framework of Brazilian Aircraft Maintenance

In this section is presented the Brazilian regulatory framework that circumscribes and certifies the activities that companies have the technical competence to perform. Even though requirements imposed on aircraft maintenance regulate its operations, there are differences between the military and civil aircraft maintenance programs (CHOCKIE; BJORKELO, 1992). The first type of program have requirements imposed by the Strategic Air Command, while the civilian maintenance programs are driven by, both, business objectives and ANAC's requirements.

In Brazil, ANACT has as mission to promote safety and excellence in the civil aviation system, in order to contribute to the country's development and welfare of Brazilian society. Therefore, it is its responsibility to establish and monitor the implementation of regulations that govern the activities of maintenance companies. In regard to the activities of aircraft repair station, the ANAC classifies companies according to the type of services that they are able to perform. Thus, they may be aircraft, cells, engines, propellers, rotors, equipment and parts of those sets repair stations.

In regard to the activities of aircraft repair station, the ANAC classifies companies according to the type of services that they are able to perform. Thus, they may be aircraft, cells, engines, propellers, rotors, equipment and parts of those sets repair stations. To make this division possible, the ANAC has also established standards, classes and limitations on the maintenance activity. Thus, any company that wants to be classified as an aircraft repair station, should submit a request to the ANAC for a certification, specifying which aircraft, engine, propeller, rotor, equipment or component, they will perform the maintenance service. Based on Brazilian Civil Aviation Regulation (RBHA) 145 it is evaluated the technical and organization qualifications of the company and if confirmed these qualifications, a Brazilian Repair Station Certificate (CHE) is issued to that company.

3.2. Domains of Certification Technical

The Brazilian Repair Station Certificates, issued by ANAC are given to aircraft maintenance companies and they are based on the patterns (standards) and classes shown in Table 1.

The national maintenance shops can be certified in one of the classes of Table 1, according to their technical field of certification. That certification domain may be narrow or wide. Thus, there may be companies that just have one class of certificate, while others may obtain certification in more than one class belonging to the same pattern or belonging to another one. For example, according to ANAC's information, Montevideo VRG (VRG) is certified to perform services in Standard C, Class 4 (Certification - C4), which indicates that this shop can perform maintenance, and alterations in cells belonging to aircraft of metal structure with approved maximum takeoff weight greater than 5670 kg (air) or 2730 kg (helicopters) for model aircraft. Another company, Rolls-Royce Sao Bernardo do Campo (Brazil Rolls-Royce Ltd.), can perform maintenance services in the following categories D3 and F3, which respectively include the following services: maintenance, modifications and repairs on aircraft turbine engines, and also it can perform maintenance and repairs on mechanical, electrical and electronic aircraft accessories. The scope of technical capability will depend on the strategy of each company which determines the type of services it intends to offer in the market. Table 1 details the technical competence in each of the standards (patterns) and certification class. There, it can be noted that, considering classes belonging to one particular pattern, each one requires different technical skills, due to the level of complexity of the resources and technologies that are necessary to perform the required tasks, as well as to the level of skills of the human capital employed in maintenance activities. Classes with higher numbers are associated with greater complexity. Thus, for example, the set of resources and technical skills required to maintain a helicopter rotor is greater than those required to maintain all other propellers.

4. Analysis of Aircraft Maintenance Technical Capabilities in Brasil

This part of the paper develops an exploratory and descriptive research, utilizing primary data published by the ANAC, in order to build a comprehensive view on the sector, highlighting its characteristics of technical nature. The research used data from 596 shops certified by ANAC to conduct aeronautical services. Most of these shops (487) is located in national territory, while only a small number of them (109) has its headquarters outside the country.

Pattern	Class
Pattern C – Maintenance, modifications and cells repair.	Class 1 - Composite structure aircraft, with maximum approved takeoff weight up to 5670 kg (aircraft) or 2730 kg (Helicopters) per aircraft model. Class 2 - Metal structure aircraft, with maximum approved takeoff weight up to 5670kg (aircraft) or 2730 kg (Helicopters) per aircraft model. Class 3 - Composite structure aircraft, with maximum approved takeoff weight over 5670 kg (aircraft) or 2730 kg (Helicopters) per aircraft model. Class 4 - Metal structure aircraft, with maximum approved takeoff weight over 5670kg (aircraft) or 2730 kg (Helicopters) per aircraft model.
Pattern D – Maintenance, modifications and	Class 1 – Conventional engines with up to 400 H.P., per model. Class 2 - Conventional engines with over 400 H.P., per model. Class 3 – Turbine engines, per model.

aircraft engines repair.	
Pattern E – Maintenance, modifications, and aircraft propellers and rotors repair.	Class 1 - Wood propellers, metal or composite, fixed pitch per model. Class 2 – All other propellers, per model. Class 3 – Helicopters rotors, per model.
Pattern F – Maintenance and aircraft equipment repair.	Class 1 - Communications and navigation aircraft equipment, per model Class 2 - Aircraft instruments, per instrument type. Class 3 - Mechanical accessories, aircraft electrical and electronics, per accessory model.
Pattern H – Specialized services.	Single Class - Specific activities for the maintenance implementation that aeronautical authority upheld, per type service (e.g., nondestructive testing, floats, emergency equipment, rotor shovels, screen coating).

Table 1 – Aircraft Maintenance Companies Patterns and Classes.

Source: BRASIL (2005).

4.1. Patterns distribution of Brazilian Technical Capabilities

A Tabela 2 mostra a distribuição das empresas certificadas e dos certificados emitidos, de acordo com os padrões de homologação da ANAC. É possível observar que 70% das oficinas foram certificadas no padrão C, 58% no padrão F e 57% no padrão D. Deve-se notar ainda que os padrões C e F recebem 30% das certificações emitidas, enquanto que o padrão D é contemplado com 20% dos certificados.

Table 2 shows the distribution of certified companies and certificates issued in accordance with the standards of the FAA approval. It can be noted that 70% of the shops were certified in standard C, 58% in the standard F, and 57% in the standard D. It can also be observed that the standards C and F receive 30% of certificates issued, while the standard D is awarded with 20% of the certificates.

Thus, it is possible to infer that the vast majority of shops is certified in standard C (70%), and qualified to perform maintenance, and alterations in cells. However, it is observed that this pattern is not prevalent when considering the total number of certifications (30%). This leads to the inference that the companies who holds certifications in standard C, in any of its classes, not necessarily they would have other certifications within that same family.

By observing the data in Table 2, it is noted that about 60% of companies have certifications in patterns D and F, being qualified to perform, respectively, maintenance, modifications and repairs on aircraft engines, and also maintenance and repairs on aircraft equipment. In that Table, it can be seen that certification of standards D and F represent respectively 20% and 30% of the issued certificates, which also induces to think that there is a specialization of companies on the technical capabilities required by standards D and F. Furthermore, it is possible to believe that a lot of companies holding certificates of patterns D and F also has certificates in standard C.

Certifications Pattern	Certified Aircraft Repair Stations	Certified *versus* Total of Aircraft Repair Stations %	Certifications	Certifications *versus* Total of certifications %
Pattern C	418	70	583	30
Pattern D	342	57	388	20
Pattern E	71	12	105	6
Pattern F	356	58	564	30
Pattern H	260	44	260	14

Table 2: Patterns regarding aircraft repair stations and certifications quantity.

4.2. Technical Capability Clusters

The number of combined certifications (companies that possesses two certifications simultaneously) is shown in Table 3. Diagonally it is possible to note the absolute total of certifications for each class and pattern and also the number of companies certified in more than one class and pattern of certificate are shown combining lines and columns (MACHADO et al., 2011).

	C1	C2	C3	C4	D1	D2	D3	E1	E2	E3	F1	F2	F3	H
C1	86	83	1	5	55	7	6	12	13	1	6	3	31	19
C2	83	279	6	75	115	9	127	19	42	15	44	37	123	77
C3	1	6	9	1	1	0	7	0	1	2	3	3	7	6
C4	5	75	1	209	13	0	139	6	22	10	59	53	153	129
D1	55	115	1	13	134	8	38	20	28	6	8	7	75	37
D2	7	9	0	0	8	10	1	1	2	0	1	0	1	0
D3	6	127	7	139	38	1	244	9	38	15	71	66	179	135
E1	12	19	0	6	20	1	9	30	29	1	3	2	25	17
E2	13	42	1	22	28	2	38	29	60	5	18	16	49	34
E3	1	15	2	10	6	0	15	1	5	15	8	8	12	9
F1	6	44	3	59	8	1	71	3	18	8	112	98	104	70
F2	3	37	3	53	7	0	66	2	16	8	98	106	100	62
F3	31	123	7	153	75	1	179	25	49	12	104	100	346	202
H	19	77	6	129	37	0	135	17	34	9	70	62	202	260

Table 3: Combined certifications matrix

Therefore, data in Table 3 demonstrate that, from the total of 279 certificates issued to the C2 type, 115 were issued for aircraft repair stations that also have certifications D1 type. In the same way, from the total of 106 certifications issued for the F2 type, 100 were issued for aircraft repair stations that also have certifications F3 type.

The standardized combined certification matrix (FÁVARO, 2009) can be used to analyze Brazilian technical capability clusters. Clusters were generated utilizing nonoverlapping methods which consider that an entity belongs to one and one only cluster (WEDEL and KAMAKURA, 2000). The chosen method is hierarchical, because it is useful to summarize (WEBB, 2002) Information obtained from the standardized matrix, which was built using ANAC´s data base. To perform the hierarchical analysis of clusters generation, it was chosen Euclidean distance with subsequent application of the Ward method, due to the quantitative analysis.

The Figure 1 presents the aeronautical maintenance homologation certificates cluster dendrogram by pattern.

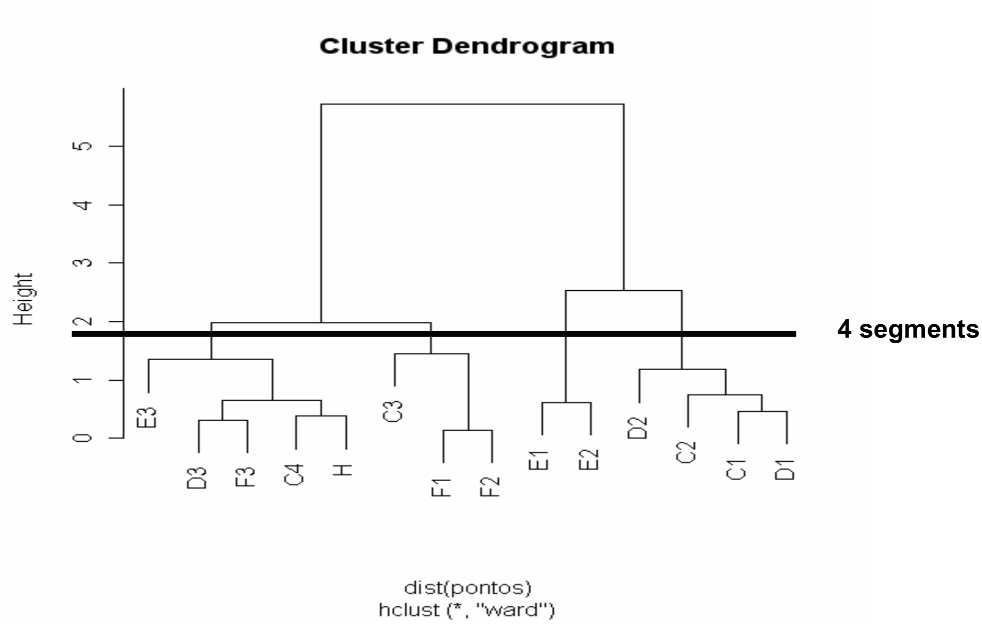

Figure 1 – Certifications cluster dendrogram.
Source: Machado et al. (2011)

When the clusters are observed, it can be verified that in the first cluster, from left to right, the E3 pattern (Helicopter Rotors) is in an isolated branch, situation justified by its specificity.

Still in the first cluster, the “D3” patterns (turbine engines) and “F3” (aircraft mechanical, electrical and electronic accessories) are in the same branch, which is also justified as the turbine engines have a large quantity of accessories that also need specific maintenance. The “D3-F3” pattern branches are associated to the “C4-H” pattern branches (“C4” related to metallic structure aircrafts, with maximum takeoff approved weight above 5670 kg (airplane) or 2730 kg (helicopters) and “H” being related to specific maintenance in activities execution). This makes sense as larger aircrafts are the ones that commonly have turbine engines.

In the second cluster, it can be observed that the “C3” pattern (combined structure aircraft, with maximum takeoff approved weight above 5670 kg (airplane) or 2730 kg (helicopters)) are in a specific branch, clustered, however, with “F1 and F2” patterns (aircraft communication/navigation equipments and aircraft instruments, respectively). Taking into account that combined structure aircraft are, normally, more modern and also that more modern aircraft are the ones which have more communication/navigation equipments and instruments, that agglomeration in the second cluster is coherent.

In the third cluster, it is possible to identify a certification cluster for propellers maintenance certifications (“E1 and E2”), which is justifiable by itself.

In the fourth cluster, are concentrated companies certifications that perform maintenance in conventional engines, “D1 and D2” pattern, along with “C1 and C2” patterns, associated to modifications and repairs of smaller aircrafts cells, which consequently use, generally, conventional engines.

This analysis, from the dendrogram, enabled to find out that the aeronautical maintenance companies are trying to certify themselves into groups and maintenance classes and patterns that will possibly increase their services scope for certain types of aircraft.

5. Management Capability in Brazilian Aircraft Maintenance Companies

This item is made a brief analysis of the management capability prevailing on aircraft maintenance companies, based on work by Machado and Urbina (2009) and Machado et al. (2009).

According to these studies, the aircraft maintenance management model proposed by Eurespace (2009) has as its central pillar its maintenance process, which is composed of interdependent functions considered as essentials: the planning of activities and maintenance installations, the execution fo aircraft interventions, the control of the intervention' results, and finally, the traceability of actions performed during interventions.

Machado and Urbina (2009) built Table 4 which shows that the major non-compliances identified in Brazilian companies, in light of the basic functions proposed by Eurespace (2009) for the maintenance process. Information about non-compliance of aircraft maintenance systems in Brazil were obtained from information presented in the 2003 Flight Safety Seminar on Maintenance performed by the Fifth Regional Service of Civil Aviation (SERAC 5, 2003).

Careful observation of Table 4 shows that there is room to improve the management of the maintenance process functions in Brazilian companies. In fact, the existence of non-compliances indicates that they still lack managerial capability to perform the core processes of the aircraft maintenance process.

	Maintenance Process of Eurespace Management Model				
Non-Conformities identified in national companies	**Planning**	**Preparation**	**Operation**	**Control**	**Traceability**
Lack of control of maintenance manuals			X	X	
Use of unauthorized copies of textbooks			X		X
Lack of Airworthiness Directives	X	X			
Lack of calibration of instruments and precision tools			X		X
Parts stocked without traceability conditions	X	X		X	X
Lack of control of the temperature and humidity prevailing at the stock or shop.			X		
Lack of care with storage conditions of electronic equipment	X	X	X		

Table 4: Cross-reference between the proposed model and the non-conformities identified in national companies.

It should also be noted that the adequate mastery of the various processes of the maintenance process does not mean that there is technological competence, as this would imply to have managerial conditions which enable companies to offer innovative services.

In this sense, the Eurespace model considers that the even though the aircraft maintenance process is central, it is affected by numerous external factors that modify the dynamics of activities over time. Those factors are: the evolution of the economic context that, in general, requires cost reductions; technological developments affecting systems and requiring the development of new expertise and technical capabilities; the evolution of aviation regulatory frameworks, which affect internal organization of maintenance companies, as well as the conditions for carrying out maintenance work.

Thus, to develop a consistent analysis of the Brazilian technological capability would require looking into the influence over management decisions of each of the external factors included in the Eurospace Model. However, that goal is postponed to future work, because currently there is no enough information.

6. Conclusions

This study sought to bring this aircraft maintenance subject into scientific discussion, and from primary data collected, to evaluate aircraft maintenance companies in terms of technological capability, analyzing its expertise based on their current technical competence, and providing insights on its managerial capability and its ability to provide new services.

This work shows a snapshot of the current maintenance and reveals an area with potential for significant growth driven by expected growth in the Brazilian air transportation.

The data here presented, represent a case study of Brazilian aircraft maintenance industry, consequently it is a descriptive approach with no pretension of generalization for the aircraft maintenance situation as a whole. However, there are some points that can be discussed from the analysis in this work.

The first one is related to the aeronautical maintenance technological capability. It is important to identify the "status quo" of the Brazilian aeronautical maintenance firms, because all the development and innovation related to this will be based on that status.

The second point concerns to the aeronautical maintenance current technical competence and the certifications types. As it was possible to state, the number of companies certified under the "C" pattern (70%) was significantly larger in comparison to those certified under the "D" pattern (57%) and "F" pattern (58%). Considering that specialization and technology training required to perform "D" and "F" services are significantly higher than those required to perform "C" services, Is it right to assure that other industries have technologically lagged behind Brazilian aircraft maintenance industry? Does the volume service for "C" pattern surpass those demanded by the "D" and "F" services?

The third point to be explored, regards to the managerial capability. What is the boundary in which managerial capability could affect the development of technical competences required for the aeronautical maintenance activity?

Thus, it is necessary a better verification on developed practices in this sector and the observation about how the actors in this scenario are enabling themselves organizationally and technically, considering the great importance of the subject.

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