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Designing Temperature Sensors for a Rocket Engine: Organisational change through technological innovation in a French SME

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DESIGNING TEMPERATURE SENSORS FOR A ROCKET ENGINE: ORGANISATIONAL CHANGE THROUGH TECHNOLOGICAL INNOVATION IN A FRENCH SME*

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ABSTRACT

There is an ongoing debate about SMEs and their innovative capacity, against the background of the emerging European system. SMEs are expected to face a new, more complex environment. Due to their heterogeneity, they will eventually develop a large variety of transition (or adaptation) patterns.

The paper presents a case study, using the data from a high-tech French SME. A well accepted idea is that, when firms face new problems, in general, before experimenting with new strategies, they rely on well-known solutions and methods of problem solving. Only when the methods prove to be insufficient, a radical change may take place. The case study shows, indeed, that when confronted with a challenge (i.e., designing temperature sensors for a new European rocket engine), the managers first tried the routine solutions, before finding out more inventive strategies.

The different stages of the innovation are analysed here as a process of transition and of organisational change. The technical challenge of the task helped this 'learning organisation' to deal with risk, uncertainty, and complexity. Once the experience proved to be successful, the staff gained confidence, and the managers became more aggressive. This is the 'cultural change' that helped them to take advantage of European programmes.

INTRODUCTION

SMEs operating in Europe may have an ambiguous perception of the European Union (EU). The EU provides an opportunity to share resources, information, competencies; however, it is also a source of uncertainty as new strategies and structures are to be created to face the new constraints[1]. On the one hand, SMEs are willing to learn to compete in larger markets, to deal with more diversified partners, to meet universities, research centres and big companies. Very often, SMEs are involved in such a context through European programmes. On the other hand, European funding and subsidies still concern basically the large firms. Thus, SMEs offer, both a picture of strength and weakness. They are more flexible, and they create 66 per cent of total employment in EU. However, they lack human and material resources to adapt to new markets, to maintain niche markets, or to innovate.

SMEs constitute only 32 per cent of all participants in European programmes. A total of 13,000 SMEs have been involved in the 4th Framework Programme. The French Minister of Education, Research and Technology recently stated that it is important to benefit from EU programmes. In response, the French government took action to enhance SME's contribution to R&D and innovation[2]. Still, SMEs are very heterogeneous, and therefore, only a few of them will be able to adapt to the emerging European system. Gathering more data on SMEs during this transition period is crucial. Surveys of samples have been used frequently to study SMEs. However, they only provide a snapshot (Blackburn and Jennings 1996, p. 5). Longitudinal studies would be useful, if not for their

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[1] Various aspects of these issues are discussed in: Dodgson and Bessant 1996, Etzkowitz 1998, Garcia and Sanz-Menéndez, eds. 1998, Laredo 1998, *Revue Française de Géoéconomie*'s Special Issue (Technological Battle in the XXIst Century) Winter 1998-99, Rothwell and Dodgson 1992, Pike *et al*. 1994, Sharp 1998.

[2] See the interviews with Edith Cresson and Claude Allègre in the special issue of *Revue Française de Géoéconomie*. Winter 1998-99.

expense in time and money. Case studies are probably the best choice for three reasons: (1) they have none of the disadvantages of the previous methods; (2) they are easier to be conducted by individual researchers; and, (3) they are more appropriate to the study of transition periods, when the questions the investigator will more frequently ask are ‘why’ and ‘how’ (Yin, 1989).

This paper presents a case study of a French SME who designed and processed temperature sensors for the Vulcain engine (developed for the European launcher Ariane V by SEP, Société Européenne de Propulsion). The company, that I will refer to as Allcapt, specialises in the design, development, manufacturing and marketing of measurement systems and sensors for aerospace, space, and defence industries, as well as for nuclear and marine applications, and for process industries, in general. Allcapt’s customers are well-known large firms such as Air Liquide, Airbus, Alcatel, Matra Marconi Space, Rolls Royce, SEP (now a division of SNECMA), and SNECMA. The company’s plant operates in (AB), a medium-sized town situated in a region in the central part of France which is a region designated as being in ‘industrial decline’ (referred to as ‘Objective 2 region’ by the EU). Allcapt is very actively involved either in European programmes, or in regional programmes targeted by the EU to stimulate local industrial recovery.

The aim of the present study is to answer the following questions: How Allcapt came to adopt new strategies focusing first on innovation and, second, on participation in European programmes? How Allcapt evaluated these strategies? More generally, Allcapt’s experience, combined with similar studies of other SMEs, may also contribute to an understanding of obstacles and factors of change. Comparative methods are indeed useful when similarities and differences in various patterns of adaptation are to be identified. They also may help the progressive development of new concepts and new theoretical approaches, where the paucity of empirical studies is a limitation.

To deal with Allcapt’s case, I conducted semi-structured in-depth interviews in 1996-97 and again, in 1999, representing a total of 18-hours of tape-recorded data. As usual, anonymity of people, places and companies is protected in the paper. In 1996-97, the

Aerospace Equipment Division Vice-President (hereafter *AED manager*), the *Industrial manager* of (AB) plant, the Deputy-production manager, who now is the production manager (hereafter *Production manager*), and the *Materials manager* who is working for the R&D unit and who reports to the technical manager was interviewed twice. Both the *Production manager* and the *Materials manager* were interviewed a third time, in 1999. In May 1999, I also interviewed a *Project manager* working at (AB) plant since 1998, and the *Technical manager*, who is also in charge of European programmes. As part of my fieldwork, I organised one visit to the company's headquarters in the Paris area, and three visits to the (AB) plant (two visits to the old plant and one visit to the new one, as in 1998 Allcapt moved to this larger plant situated in the same town), to observe people working or interacting, and to have informal discussions with the staff.

In the following, I will first briefly present the history of Allcapt. The innovation challenges and accomplishments of Allcapt will be described in the second section. They are identified as a period of transition. The third section will analyse the company's new culture, and the factors that contributed to the radical transformation of Allcapt. To deal with both of these aspects, in my presentation of this case study, I prefer to draw upon Allcapt employees' perception of change, as this is part of the company's culture. In that way, the original data presented in this paper will be more useful to those who seek published secondary data. As a sociologist, my contribution has been to propose an interpretation of this experience, using well-known sociological concepts, in order to set the framework within which Allcapt employees' perceptions can be understood. This is necessary if one wishes to make sense of unstructured, dispersed information and data.

PRESENTATION OF ALLCAPT

Allcapt and the (AB) plant to process industrial sensors, were founded in 1960 by an engineer[3].In 1965, in order to benefit from lower labour costs in Spain, a subsidiary (hereafter referred to as Icapto) was created in Madrid. In 1967, Allcapt acquired a licence from a company in order to enter the nuclear power industry that was expected to expand as a result of the new French energy policy. Before retiring in 1972, the owner sold the company to an American holding. In 1975, Allcapt was organised in three divisions: Aerospace division, nuclear division, and systems and sensors division for marine applications:

> '*Diversification has always been one of our assets. We developed our aerospace division thanks to the benefits coming from the nuclear division, and with the booming of aerospace activities nowadays, we have more opportunity for R&D*' (*Production manager*).

In 1972, Allcapt was contracted by SNECMA to process temperature sensors (thermocouples) licensed by an American company. Allcapt created two joint-ventures in Russia, in 1988 and in 1995. In 1993, Allcapt acquired a company that specialised in

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[3] The origins of the company go back to the end of the 19^{th} century when an engineer created a family business that manufactured threshing and other steam machines. After WWII, the plant was moved to (AB) and was specialised in metal cutting and produced mainly screws for automotive industry. The engineer who created Allcapt is the grand son of the founder. Before being united, the old and the new plants co-existed for some time at (AB).

pressure transducers. More recently, in 1997, a US company that specialised in fluid regulators was acquired by Allcapt, together with the pressure product line of a French company[4].

When the economic recession hit the company, between 1986-93, Allcapt fired 70 employees. An important recruitment campaign took place in 1993, and, since then, the number of employees has grown continuously due to the strength of the Aerospace Equipment Division (AED) and to the recent acquisition of the above mentioned companies. Today, the company has 18 service networks in France as well as abroad, to compete in global markets.

In this paper, I will focus on the AED, the most important and rapidly expanding division of the company, with a turnover of US $ 50 Million (projection 1998-99), representing 63.5 per cent of the total turnover. AED currently has 340 employees which is more than the total number of employees of Allcapt in 1994 (317). Very recently, Allcapt recruited a human resources manager. The division employs 115 production workers, and 60 engineers and technicians at the (AB) plant. The role of R&D increased rapidly in areas such as high temperature and cryogenic ceramics and ultraviolet pyrometers.

The Search for Security and Excellence

During the initial stages of the company's development, Allcapt's management drew heavily on networking and personal knowledge to reduce uncertainty and risk. Indeed, '*SNECMA sub-contracted Allcapt mainly because its founder graduated from the same engineering school as several of their managers*' (*Production manager*). For years, the company operated in a very comfortable (almost routine) context with this friendly customer. This period is named by the managers '*the mono-customer period*'. Allcapt

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[4] Since very recently, due to these latest acquisition, the number of total staff reached 600 persons, that is slightly over the limit of an SME, but an important number of the employees operate in the US, a few in other countries such as Russia and Spain.

processed thermocouples for the Atar engines of Mirage IV aircrafts. The *Industrial manager* states that ‘SNECMA furnished the drawings and all the details on the conception’, before adding: ‘*We only had to follow them*’.

Nevertheless, the processing of sensors requires a certain degree of tacit skill and know-how. Thus; the company’s main concern has been to create an environment that allows employees to develop the necessary skills and a ‘*culture of individual and collective responsibility*’. Even the official propaganda was stressing the craft dimension of Allcapt’s production operations: ‘Processing temperature sensors is Allcapt’s main craft (*métier*)’.

The production workers and operators are called ‘*compagnons’*, which refers to highly skilled craft people producing unique products. This linguistic choice is important. Not only does it stress the role of experience[5], manual dexterity and practical and tacit knowledge[6], but also individual responsibility for every stage of the process:

> ‘*We want our people to understand the importance of following exactly the instructions indicated by the Engineering unit. They have to be conscious of the fact that we are producing ‘a five-legged sheep’. Everything is ‘in the hands’ of our compagnons. If the worker accepts that each of his/her actions, movements, or decisions will impact the final product, s/he will not, for example, twist a wire with more strength than is required, assuming one cannot detect it’* (*Industrial manager*).

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[5] As put by the Industrial manager :‘Experience is important, as we are learning by doing, rather than exclusively relying on R&D results. Only experience could teach people, for example, that if the thermal treatment of the material is done during a specific stage, this will cause a lengthening of its lifetime’.

[6] For this concept, see: Polanyi 1958, 1966.

Knowledge Creation and Management

As Allcapt's main challenge is to manufacture reliable sensors, workers' craft, skill and knowledge are considered the company's most important assets. Competence building has been one of Allcapt's initial challenges. When the plant opened, the company recruited people from other companies and trained them further. To handle the very tiny wires used for the sensors, patience and precision are so important that the company preferred to hire women who, previously, had been employed in the textile plants of the area, as the textile industry began to de-localise its operations to low-wage countries in the 1970s[7]:

> '*The company completed their training by providing them with some basic knowledge concerning the principles of electricity, the reading and interpretation of the measurements provided by the instrumentation, and of the drawings provided by the engineering unit*' (*Industrial manager*).

For more complex operations, people from technical schools were recruited and initiated to the job by senior workers, technicians and engineers. After a period of training and on-the-job experience, the production staff was evaluated and assigned to existing positions in production and technical operations according to their results. This method was, according to the *Industrial manager*, '*very costly and inefficient, because the workers would acquire new skills only after many years of employment*'.

[7] See Bagla-Gökalp 1990, 1993.

More recently, Allcapt's managers considered that the best solution would be to create their own school with a more adapted curriculum. The industrial manager made every effort to communicate the relevance of such a project. As soon as the Ministry of education accepted the project, Allcapt proposed a policy called 'qualification contracts' to those who applied for technical positions. While employing these young persons on a part-time basis, Allcapt provides them a two-year education programme, for a total of 900 hours, and eventually hire them according to their performance. In 1997, when the experience began, they represented 40 per cent of AED's operators.

Internal Communication: A Precondition for Quality

In the 1980s, the new Chief Executive Officer (CEO) emphasised the importance of internal communication and of shared values. As a symbol of the strong culture of responsiveness and communication, the CEO created open areas to allow people to meet easily to solve problems and to facilitate the circulation of information. He changed the internal organisation and architecture of the (AB) plant, to make managers easy to reach:

> '*Our compagnons working with the drawings and instructions of our engineers must be able to inform them if things don't work as expected. If they err, they should be able to inform their boss, even if the error is not detectable. To this end, an adapted structure to enhance relevant communication patterns and good human relations, is necessary*' (*Industrial manager*).

An efficient means of internal communication is perceived at Allcapt not only as a key factor for processing reliable and accurate sensors, but also for accelerating product development:

> ‘*Communication is also important in order to save time. If you have a problem while you are developing a product, you should be able to go and ask your neighbour who may already have the solution. Communication must be a part of our culture*’ (*Production manager*).

When communication is at stake, the project manager is a pivotal person. In charge of the development of several products, the project manager is the co-ordinator of all aspects of the project, including the units such as the prototype shop, the quality unit, and also the sales and marketing divisions (that are located at the headquarters). The *Project manager* argues that: ‘*The role of the project manager is to facilitate the relationship between different departments and let their constraints and needs be expressed*’.

ALLCAPT BOARDS ARIANE V WITH SEP

The decision to launch Ariane V was made in the 1980s. This was a big project for ESA (European Space Agency). The French group CNES (National Centre for Space Studies) opted for a new design for the Vulcain engines, using liquid oxygen and liquid hydrogen, together with a new design for the turbo-pumps. New instrumentation capable of functioning in extremely harsh conditions was needed to provide information on the engine’s internal conditions and deliver this data to the computers controlling the launcher. However, as the engine itself was yet to be developed by SEP, no precise data about the temperature of burned gases and cryogenic fluids, the pressure, the vibration level and the velocity was available, except those provided by numerical modelling and simulations based on extremely simplified hypotheses.

SEP wished to use both thermocouples, smaller and easier to integrate in less accessible locations in the engine, and resistance temperature detectors (RTDs), which are much more precise. Still, ‘*contrary to aircrafts, there was no knowledge about what kind of measurement will be accurate, and in which parts of the engine one should insert the sensors*’ (*AED manager*) .The thermocouples and

RTDs were designed to measure cryogenic temperatures of liquid oxygen and liquid hydrogen (about – 150°C) which are the propellants used in Vulcain engine. These propellants are pumped from reservoirs by turbo-pumps and atomised into the combustion chamber through several hundred co-axial atomisers.

No existing sensor was able to operate in the expected conditions. Allcapt was contracted to develop the required sensors. Given the uncertainty of the conditions within the engine, it was difficult to specify *a priori* the characteristics the sensors would require. Conversely, the development of the Ariane engine required sensor information to ensure safety constraints were met. Thus, development of the engine and sensors necessarily proceeded together, step by step. Modifications of the engine often required changes in the specifications of the sensors.

As thermocouple technology was relatively well understood, while the RTDs raised more concern, I will focus on the development of the latter.

Winning the SEP Contract

As for more than 15 years Allcapt had a privileged relationship with SNECMA, the company was encouraged by SNECMA to consider SEP's bid. Specialised in processing thermocouples since the 1970s, Allcapt was, indeed, a credible candidate:

> '*The companies able to compete in this niche market were not more than three or four. German manufacturers were quickly eliminated, I guess because they were not really interested in this operation. And let's not forget that we were proposing one of the best quality/price ratio*' (*Production manager*).

Allcapt’s management took advantage of the existence of Icapto, the above-mentioned Spanish company affiliated to Allcapt. The *Materials manager* states that:

> ‘*ESA’s European funds had been distributed mainly to countries such as France and Germany. Spain, Portugal, among other European countries, were far from getting their ‘share’. When Allcapt’s managers applied for the SEP bid, they specified Icapto as the supplier of required sensors. In that way SEP had subcontracted a Spanish company. Allowing Spain to participate gave us the advantage*’.

There is a consensus about the importance of the involvement of Spain, *via* Icapto, in the Ariane V project, and according to the *Production manager*, ‘*Allcapt has been contracted for political, as well as for purely technical reasons*’. The same strategy was used for the RTDs, when, ‘after CNES decided to create a French supplier, a second campaign was launched by SEP’. Having already been contracted for thermocouples, and proposing, once again, a good quality/cost ratio, Allcapt was, once again a good candidate. The company also demonstrated the feasibility of its proposal: Allcapt would be assisted by one of the company’s American suppliers (hereafter referred to as Nimco), who designed RTDs for industrial applications. Once again SEP was informed that Icapto would be involved. The *Materials managers* states that:

> ‘*The strategy was again effective and Allcapt, through Icapto, was successful. RTDs processed at the (AB) plant are controlled by Icapto because they have a cryostat. This is a*

technology used to control the sensors at various temperature levels and to calibrate them at cryogenic temperatures'[8].

However, there was one additional concern: Allcapt was, since 1972, an affiliate of an American holding, while SEP was searching for a European company:

> '*SEP tried to learn more about the exact nature of our relationship with the American owner. We told them Allcapt is completely under French jurisdiction and that both Allcapt and Icapto are European companies. We had to persuade SEP that our link to the US company was purely financial. No company owned by this holding specialises in sensors and so, none of them is able to copy and exploit the technology we developed'* (*Production manager*).

Different Stages of 'Problem-Solving'

As Allcapt, backed by SNECMA, was used to manufacturing well-known products, the new contract forced Allcapt to deal with uncertainty and complexity. To adapt, Allcapt required a period of transition. Companies, as well as individuals, are known to have some routine or standard solutions when faced with new problems (March and Simon, 1958; Cyert and March, 1963; Levitt and Marc, 1988). Only when they fail companies seek new solutions and accept the uncertainty that results. Indeed, Allcapt initially employed problem solving methods well known to the company before new solutions progressively emerged.

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[8] 'First it was stated that RTDs would be processed and controlled by Icapto, once the prototypes would be developed at (AB) plant'. Later, Allcapt's managers eventually decided that as Icapto had no competency and know-how in manufacturing RTDs. Icapto is now sub-contracting the manufacturing of RTDs to Allcapt. 'What Icapto's staff do is just to control the RTDs and to calibrate the sensors at 20 Kelvin with their cryostat' (*Materials manager*)

Routine Solutions

To deal with uncertainty, Allcapt initially (in 1988-89) chose platinum resistance RTDs, developed by Nimco as the best candidate, '*because to wind platinum wire on ceramic mandrels, and to heat them to high temperatures requires that the platinum and the ceramics have the same coefficient of thermal expansion. Nimco developed the ceramic having this property. However, early formulations of this were not sufficiently resistant to required conditions*' (*Materials manager*). Allcapt then tried to adapt these RTDs using existing know-how through licensing.

Not only did Allcapt's management try to adapt an existing technology, but they also tried to adapt existing skills within the company. Amongst available *in situ* human resources and skills, Allcapt's management decided to train an electronics operator, used to handling very tiny components and wires. As the sensing element of the RTD consisted of platinum wire 17 microns in diameter, wound around cylindrical ceramic mandrels, she was an ideal candidate to be trained in the US at Nimco, to become a 'prototype technician'.

Competence Building

There are several models of learning. One of them rests upon tacit knowledge, where formal, written information is an inadequate source (Collins 1992, pp.56-58, see also Bagla-Gökalp 1996a, 1996b and note 6). Manufacturing reliable sensors draw mainly upon this model:

> '*Processing RTDs is the most specific job we have at the (AB) plant. It's impossible to totally formalise and codify the operations. We hired two people to process the sensing element and it took our prototype technician six months to train them*' (*Materials manager*).

As it was not easy to standardise the RTD manufacturing, one possible solution was to always assign this job to the same operators, and this was indeed included in the contract. The *Materials manager* confirms that '*the SEP project is the only one with assigned operators*'. The tacit knowledge of these operators was the guarantee for the reliability of the product, and SEP maintained some control over the processing of the sensors by controlling the identity of persons who manufacture them.

Searching for New Technology

In 1990, after a two-year development period, Allcapt's RTDs failed in tests specified by SEP:

> '*The ceramics and the glass used were not sufficiently strong. Unfortunately, Nimco was not interested in investing any more resources for this product. We had to find another partner*' (*Production manager*).

The production manager contacted an engineering school (hereafter referred to as NCIC) in a neighbouring region, which specialised in the development of industrial ceramics. Two scholars, S1 and S2 from NCIC were offered grants: S1 for the glass covering the mandrels, and S2 to improve the ceramic mandrels. As the problem of the glass was relatively easy to solve, I will focus on the ceramic mandrels. S2 was expected to formulate a new powder with the appropriate proportions. Allcapt was short on time and had to push S2 to accelerate the process.

Managing to Meet a Different Culture

Industry is often suspicious of academic researchers of using part of the money to do basic research, hence the importance of close monitoring:

> '*We organised monthly meetings to interview S2, to follow step by step the results of his research and evaluate them. Because if you let a laboratory go without proper reporting*

for six months, you will never know how things are evolving' (*Production manager*).

Nevertheless, S2 was not working full time on this project, letting students and trainees deal with it, because '*S2 would not recognise the importance of deadlines and the impact of a delay on the company. Academic researchers don't necessarily focus on one particular aspect. As soon as they observe something interesting, they are eager to pursue in this direction*' (*Materials manager*).

As the RTDs had to be validated by SEP in 1995, in order to have a full-time researcher on the SEP project, Allcapt contracted, in 1992, the present materials manager, who was recently graduated from NCIC and who had been a student of S2. He became a 'translator'[9], helping two different cultures to communicate:

> 'S2 was supervising the technical aspects of my job, but I was employed by Allcapt. Thanks to this double-identity it was easier to me to communicate Allcapt's constraints to S2' (*Materials manager*).

The difficulty to adapt the product to the needs of industry was the next major problem:

> '*At NCIC, you mix a powder with another, and process them for 5 to 10 hours, in the hope that at some point, you get what you were looking for. There is little fundamental understanding. You always tinker. It was not necessary to reproduce standard products. Once the product is developed*

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[9] For the concept of 'translator' see : Aitken 1976, 1985 and Gökalp 1992, 1994. A sociological approach developed at the Centre for Sociology of Innovation by French sociologists such as M. Callon and B. Latour at l'Ecole des Mines in Paris use also the concepts of 'translation' and 'translator', the latter referring to a social actor who is at the core of an innovation process that can be stabilised thanks to his/her translation when the various, human as well non-human actors, are aligned around the same definition of a project (see, Callon 1986, Latour 1987).

> *and designed, NCIC researchers and scholars considered that their job was over. They were not interested in industrial or standard processing of the product. I know what I am talking about because I worked 10 months with S2 on the ceramic mandrels, for the SEP project. S1 had the same attitude. He is our supplier for the glass covering the ceramic mandrels, but he will not become enthusiastic over processing it for us*' (*Materials manager*).

From Laboratory to Industry

When the ceramics were finally adapted to Allcapt's needs, '*the transfer of technology from the laboratory to industry was the second step*' (*Materials manager*). In June 1993, the machines, ovens, and other technology were bought to process the ceramic mandrels at (AB) plant, after adapting them to Allcapt's specific needs. Still, to process standard products was not that easy, and '*the mastering of the various stages of the production and of the details of the operations in order to produce a consistent powder and ceramics took some time*' (*Materials manager*). The materials manager then left Allcapt, as his contract ended.

During the development period, Allcapt managers were aware that the testing of their sensors would be crucial, '*as simulating the conditions inside the engine was impossible, separate tests for vibration and temperature were performed, even though all of these parameters would impact simultaneously the sensor under real operating conditions*' (*AED manager*).

In 1993, after testing, the first 'critical review for product specificities' (*définition du produit*) of the RTD was not accepted by SEP. The platinum was still not resistant enough and the sensor presented an insulation problem. In 1994, Allcapt decided to recruit the present materials manager as project manager, to deal with the development of the RTD. With the assistance of the product quality person, he conducted product validation studies:

> '*It was a great learning experience. Her method was interesting: to cut the product in a multitude of components*

> *and parts, to see where the problem is coming from. Before that, I concentrated on the mandrels. I then realised that this was just a very small part of the RTD. I got a broader view of the product. The number of operations to process the RTDs was amazing. Controlling the process required expert understanding of each process step*'(*Materials manager*).

It appeared to Allcapt's management that there would be no perfect sensor, because '*this is not an exact science: there are several parameters to control such as resistance, conductance, and strength; one cannot have them all within a single material. One has to find a compromise among these parameters. It's a genuine trial and error process*' (*Industrial manager*). According to the *Materials manager*:

> '*If you want to improve the glass, and eliminate the bubbles, you have to leave it in the oven for a longer period. However, this will damage the platinum wire*'.

Even today, only slightly over one-third of the total RTD output is delivered to the customer as 'usable':

> '*During the initial periods, when SEP was waiting for 60 or even 80 RTDs, we would give them only 30, because of processing failures. We were doing exactly the same operations, and it was difficult to understand why sometimes we would have good products, and sometimes we would fail. Things are getting better but we know that we have to accept losing 30 per cent of our products*' (*Materials manager*).

Negotiating Design and Accuracy

Allcapt's managers rapidly learned that innovation is always a compromise:

> '*For a new sensor to be designed, those who develop the launcher will ask for the best and the most rapidly feasible sensor, those who work directly on the engine will ask for the most accurate and reliable sensor that is easy to use. The corporate finance division will ask for the least expensive sensor. These are people with different (and sometimes, conflicting) concerns. Ultimately they must negotiate. The final decision is always a compromise*' (*Production manager*)

Negotiating with suppliers, and particularly with customers, is also very important as '*the final design is a compromise that blends scientific, economic, commercial, human relational and managerial aspects*' (*Production manager*). Not only RTDs necessitated a compromise among the parameters as expressed by the industrial manager, but they also forced people dealing with various aspects of the innovation to negotiate, in accordance with the expectations of those who analyse the technology as a 'social construction' (Bijker, Hughes and Pinch eds, 1987; Mackenzie 1990, Mackenzie and Wajcman eds, 1985).

When the specification ('*définition*') of the product has been refused by SEP, according to the *Materials manager*, Allcapt's managers were under great pressure:

> '*I think SEP was ready to abandon us. We had to prove our trustworthiness. You easily feel when your customer no longer trusts you. The problem reached the highest levels of hierarchy*' (*Materials manager*).

The major problem was the pressure level set to test the sensors. To Allcapt's management it was clear that SEP should accept to lower it. There was no option, indeed, to delay Ariane V launch:

> '*Given technological and time constraints, processing new RTDs that match SEP's expectations was not feasible.*

Industrial culture means that to be able to innovate you have to accept some flexibility' (*AED manager*).

At this point, the question was not technological but political, and it was the AED manager who solved the problem:

'*By experience I know that you always have to negotiate at the management level. The engineer who calculated the pressure levels the sensors would face was a young theoretician, not very well acquainted with practical problems. It is very hard to negotiate with engineers when they imagine that if they lower the standards, they will lose their credibility, and this may damage their career. If his boss tells him to do this, he will be freed of the responsibility if something goes wrong*' (*AED manager*).

Allcapt had to negotiate with SEP in order to lower the pressure constraints by modifying the '*measurement points*' (i.e. the various locations in the engine where the temperature sensors were to be placed) and the *AED manager* knew that '*the instrumentation division manager was the right person to negotiate with*'. Moreover, the *AED manager* '*have known him for many years' and 'was able to anticipate his reactions*'. Together they sought the acceptable solution: The initial pressure level in the measurement points indicated by SEP engineer was 400 bar. After negotiations, the maximal pressure was lowered to 240 bar, a level the RTD could resist. The success of the compromise was evident when the product was accepted in December1994, and Allcapt began the processing of sensors in 1995.

BEING READY TO FACE EUROPE

The SEP project helped Allcapt's managers to recognise that a purely technical project does not exist. When they have been contracted by SEP, Allcapt's managers understanding of the importance of Europe was limited to the political understanding that to be more attractive for the contract, they should involve Icapto:

> ‘*Allcapt processed sensors for Ariane V, a project funded by ESA, co-ordinated and supervised by the CNES, and functioning with engines developed by SEP, our direct customer. Ariane V is more than a technical project. It is also a political project. It has been decided that Ariane V should be a truly, completely European launcher*’ (*Production manager*).

Since then, Allcapt’s understanding of Europe quickly evolved, as the *Technical manager* states:

> ‘*Europe brings you contracts, networks, the possibility to co-operate with research centres and universities. This helps SMEs to hire people with greater expertise and also PhDs specialised on a given subject that is of interest to the company. Everybody wins from these opportunities. You learn who’s who, and who can help you to solve your problem*’.

Discovering all the Aspects of Complexity Simultaneously

According to Allcapt employees, working for SEP for RTD innovation has been an invigorating experience. They are eager to credit this project with helping Allcapt to discover new perspectives and horizons. Not only because after this success they were more confident, but also because they created a new environment, and learnt how to raise funds to enhance the once ‘*embryonic R&D*’ unit:

> ‘*In our company’s life, one can easily distinguish two periods: before SEP, and after. We learnt a lot about the complexity of networks: ESA, CNES, the Spanish governmental agency who redirected the European funds to Icapto, etc. SEP sub-contracted Allcapt who was licensed by Nimco and this means that in some way SEP was sub-*

contracting to Nimco. This kind of 'tri-partner relationship' was an apprenticeship to complexity. Things got even more complex when the first RTDs failed and when we contracted NCIC. For the first time we worked with academic researchers and learnt to co-operate with them. When we were working for SNECMA, we wouldn't know what it means to have a relationship with other companies. It was a relationship between two equivalent units or rather, between two individuals with similar functions in each company. With the SEP project we began to discover the complexity of our relationship with our customers, and our customers' customers' (*Production manager*).

Coming from MATRA, the technical manager states that he always knew that one cannot ignore Europe. Still, he recognised that to Allcapt staff who were used to working in a protected environment, the SEP project could appear like a transition to integrating the new European dimension:

'*The top management and I were moving in this direction. The previous situation was dangerous, as SNECMA represented more than 70 per cent of our sales. But one can say that the success of the first experience with the SEP project facilitated things a lot*' (*Technical manager*).

The production manager insists upon this aspect:

'*The arrival of new people in the ranks of top management has been an important factor for the development of new strategies. And when they understood that we had now achieved a new level of maturity, they were more eager to design new strategies*'

The *Materials manager* has a very similar perspective:

'*Thanks to the SEP project, the reputation of Allcapt grew, allowing the company to be entered into the European* *programme's milieu. During the critical definition and qualification reviews, the company's management established many connections and came to be known as a reliable and serious company. It was easier to contract them for new projects because of this positive image. They now know who we are, that our products are reliable. I think this greatly facilitated our technical manager's job*'.

If change concerns technical, human, and political aspects, the cultural aspect is perceived as being the most important:

'*The SEP project has been pivotal: it changed our mentality. We realised that we were able to deal with complex assignments and that there was no reason to have any inferiority complex. And we learnt to accept risk and uncertainty. We learnt to analyse situations, to make choices, and to accept the entire responsibility of our choices. This was a huge cultural change*' (*Production manager*).

Acquiring New Competencies

The SEP contract has been an opportunity to acquire new technology and knowledge. One of the consequences of this project was the ISO 9001 approval in 1992 making sure that Allcapt meets the new European standards. Allcapt's management also learnt to take more initiatives in exploiting new resources:

'*Our top-management is eager to benefit from European institutions. They are really active in writing proposals*' (*Materials manager*).

Finally the SEP project generated, directly or indirectly, several jobs, including five at the (AB) plant, according to a new development strategy:

'*When we develop a product, if we need some expertise, know-how or technology, we first try to sub-contract. When*

> *we have the means to buy the technology and hire the people who have mastered it, then we integrate them*' (*Production manager*).

Technical Aspect: Developing New Know-how

Once the staff learnt by doing, various improvements to the sensors were made by substituting more resistant alloys for the metals, and by more carefully insulating the wires:

> '*We did more than copying drawings and instructions from licenses. We acquired a competency in processing both the sensing elements of the temperature sensor and the materials. The SEP project has been a spring-board for us. We now manufacture our own sensitive parts and continue to work on the composition of the ceramics. Moreover, we developed variations of the original sensors that allows us to adapt them to the specific needs of customers such as Rolls Royce*' (*Materials manager*).

The funds collected from the successful SEP project were reinvested in new technology as well as in new expertise. One such example was the acquisition of specialised software for modelling. For the RTDs designed for Vulcain 1, the company sub-contracted a Belgian company. In 1997, Allcapt invested in this technology and the engineer in charge with modelling has been trained to master and use the computer programmes:

> '*The dynamic finite elements programme Pro Mechanica, combining a set of measurements and calculations related to the RTDs, is now used with the CAD. Pro Engineer allows to obtain 3D pictures of all the parts and components. We do*

> *much better than the Belgian company: We're closer to reality*'[10] (*Project manager*).

The expertise the company sought from their R&D people also changed, as one can see from the changes in recruitment policies. While '*initially they possessed a very general knowledge structure and would tinker with drawings to reach a result according to a product structure, today they all are specialised with specific domains of expertise, e.g. materials, optics, etc., and work according to an expertise structure*' (*Technical manager*). The adoption of ISO 9001 would not have been possible without this expertise. The path followed by the project managers has been the reverse, as they have been transformed into multi-skilled people.

Relational aspects: Communication with the Environment

During the product development process, project managers are increasingly expected to co-operate with scientists, as well as with the customer who consequently deals with the same person for every aspect of his problem. To allow Allcapt to be involved in European programmes, now project managers must also be fluent in English:

> '*All of these aspects changed our recruitment policy. If you look at the background and career of our first project managers, you can see the evolution: 15 or even 10 years ago, they would be promoted from the ranks of good technicians, who had a very good insight of the product. Today, the technical dimension is less important and we stress that they have to be very good communicators, inside as well as outside*' (*Production manager*).

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[10] This is consistent with Thomke *et al's*. approach to the role of computer simulation during the experimental cycle: Thomke *et al*. 1998, p. 320.

Finally, 'interactivity' and 'permanent adaptation' became key words. To this end, Allcapt's managers and engineers keep themselves informed about ongoing research on topics and subjects that are of interest to the company:

'*We have to work with university and scientific research laboratories, who are more prompt to communicate their results in meetings and scientific literature, contrary to the industrial milieu where the culture and attitudes are based upon secrecy*' (*AED manager*).

Becoming Aggressive

Allcapt's management is keenly aware of the fact that being a SME is, to some extent, a handicap:

> '*To collect European funding you have to be married with big companies who get the largest fraction of the money. There are incredible obstacles imposed by these large firms. Also, European structures and institutions are not eager to deal with SMEs because they try to reduce the number of partners. They prefer to distribute the money to a big company who in turn will give some crumbs to the SMEs*' (*Production manager*).

The *Technical manager* proposes some solutions:

> '*The SMEs must develop new structures to be able to compete with big companies. One can mention, for example, the Le Richelieu Committee, which includes French SMEs in the defence industry. Le Richelieu joined an association of similar high-tech industries based in various European countries, to become a large association of smaller companies. It's a new experience. These kind of solutions are being developed. It's important to help each other, to share expertise, information, and other resources, with laboratories, and other partners. Of course, it's not always that easy. When you have to develop a common project, you*

> *are often concerned that some of the partners will really work hard on the project and make progress, while others will take the project as an opportunity to benefit from European funding, without being really involved. So you have to fight continuously*'.

Allcapt struggles also in order to be innovative and competitive:

> '*We sometimes get stuck having to satisfy specific customers. We have to listen to them and try immediately to develop exactly what they need, but they are loyal up to the day they find a cheaper product elsewhere. Each year we have to negotiate the contracts, adapt ourselves and integrate the importance of quality and cost*' (*Production manager*).

An aggressive strategy has been adopted, to win new customers in the European market. To this end, the *Technical manager* presented their sensors to Rolls-Royce:

> '*As we worked for SNECMA, we thought that we had to go to other European engine builders. We decided to target Rolls-Royce, because Rolls-Royce, aside from being European, was the second most important aircraft engine manufacturer. I can tell you that we failed: They were not interested at all in our product. We analysed the situation and assumed that maybe the commercial arguments we presented were not the right way to convince them. So, we decided to try more technical arguments. We presented the high-tech aspect of the product, the teams who process it, the maintenance services, etc. We even manufactured prototypes for them to try. We created a 'service' relationship. This lasted for three years. After that, they were ready to recognise our expertise, but they still wouldn't go into business with us. But at least, they understood exactly what we were able to do. So when they were co-ordinating a European programme, they involved us in this programme and simultaneously, they*

proposed that we become a partner for a second European programme, where we were given an even more important role. Of course we won't stop there. We have other projects. Despite their handicaps, SMEs also have some advantages such as the rapidity of decisions, flexibility, and the ability to motivate people'.

This was Allcapt's first participation in a true European programme. Today, Allcapt is co-ordinating and leading a European programme, with 13 participants, all of them European companies, universities and research centres. After being acquainted with European programmes, Allcapt now participates also in a project aiming to develop in the (AB) city a strong R&D and manufacturing activity concerning a large variety of sensors.

CONCLUSION

Allcapt may be considered as a 'learning organisation'. Problems are solved step by step. Factors such as intuition, negotiation and networking talents (Bagla-Gökalp 1998, Hastings 1993), and trust[11], constitute an important aspect of the company's problem solving methods. These factors largely contributed to their success with technological innovation[12]. Thanks to this innovation, the company learned a great deal about handling complex problems and the associated uncertainties. They were able to develop a more aggressive outlook as well. Thus, innovation modified more than the technology the company can access. It initiated a cultural change. This irreversible change helped Allcapt to achieve unprecedented

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[11] Trust has become a major theme in managerial studies. See for example Blomquist 1998, Krieger 1988.

[12] For analyses of innovation (theoretical approaches and case studies) see: Aydalot and Keeble, eds. 1988, Biemans, Branscomb and Keller, eds. 1998; Bucciarelli 1996, Dodgson and Bessant 1996, Fountain 1998, Gregersen 1992, Lundwall, ed. 1992, Miettinen 1996, Murray 1997, Senker and Sharp 1998, Von Hippel 1977, 1998

levels of flexibility and responsiveness. All of these factors contributed to the success the company is now enjoying with European programmes.

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