Sustainable Prevention and Work Environment

Studies and Research Projects

REPORT **R-926**

Prerequisite Conditions for Implementing Job Rotation in an Aircraft Assembler Population in the Aerospace Industry

The Impact of Quality Requirements on Development of Versatility and the Learning Process

Denys Denis
Marie St-Vincent
Maud Gonella

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SUMMARY

A large company in the aerospace industry wanted to develop versatility among its assemblers by introducing job rotation. Recognizing the complexity of the problem, it turned to the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) for assistance. The Institute was asked to identify the conditions required to implement job rotation with a view to preventing the musculoskeletal disorders (MSDs) that affect this worker population. The focus of the study was the department where the cockpits for one of the company's flagship aircraft are assembled; this department was chosen because of the physical demands associated with it, its strategic position in the lean production cycle, and the high level of expertise required to perform the related assembly tasks. It includes four assembly stations with more than 20 assemblers divided among them and working under the supervision of three team leaders. The work is characterized by, among other things, long cycles – since the complete assembly of a cockpit takes several days – and high quality requirements.

The approach adopted was to carry out, monitor, and follow up on job rotation trials. The assemblers and supervisory staff were strongly encouraged to participate during both data collection and the development of the conditions needed to implement and manage job rotation. A steering committee was given regular updates on the work progress. A first phase, involving interviews with key stakeholders (n=16) in the organization, provided a better understanding of how this vast company operates and shed light on the role of its various departments and their interactions. A survey of the assemblers' (n=22) health and perceptions of job rotation was conducted simultaneously by means of a questionnaire. Prior to the job rotation trials, data were collected on risk factors and learning issues. The data collection process required developing innovative methods combining observation, individual interviews, and group validation meetings. These data formed the basis for the job rotation scenarios developed by the stakeholders themselves and made it possible to specify the conditions needed to facilitate implementation of job rotation. Original follow-up methods were applied to study the situation prevailing after the two implementation trials were carried out at four-month intervals. With a wealth of information gained from the trials, a committee was formed in the company to take charge of the matter in the form of a structured, "project management" process, with the assistance of the research team.

This report documents the process followed, methods developed, and main results obtained. It discusses the conditions that appeared necessary to implement job rotation in this worker population. It highlights the great importance both of the learning issues specific to jobs held in this industry, where quality requirements are extremely high, and of organizational support for coach-trainers and team leaders. The latter face a twofold challenge: managing the job rotation dynamics and coping with the numerous unforeseen events that occur in an organization with a just-in-time production cycle. It must be stressed that given the assemblers' high level of expertise and the defining aspect of the quality requirements, the implementation of job rotation is not something that can be improvised in this industry. It must involve a real organizational project that provides leeway to facilitate the self-management of job rotation by workers and first-line supervisory staff.

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1. INTRODUCTION

This study responded to a joint request made by the management and union of a large company in the aerospace industry. The company wanted to promote versatility (or multifunctionality) among its assemblers, but both the employer and union agreed that the problem was a complex one. They asked the researchers to identify the prerequisite conditions for fostering versatility in this population through a form of work organization that would prioritize job rotation. An underlying objective of the requestors – apart from their concern for health and safety – appeared to be that of gaining greater leeway in deploying assemblers in order to offset absences, occasional lack of personnel, and production fluctuations.

1.1 Job rotation and versatility

First, the difference between the terms *versatility* and *job rotation* must be explained. Job rotation is a form of work organization in which the person changes workstations regularly in a specific order and at a pre-established frequency. Versatility is a personal characteristic: a person is considered versatile if he[1] has a variety of skills and can perform several different types of jobs. For job rotation to be effective, workers must be versatile (Vézina et *al.*, 2003).

Job rotation is a form of work organization that can be beneficial for companies in several ways. While existing knowledge of job rotation is still very piecemeal, it is generally believed that the practice of rotating workers among several workstations/jobs enables them to acquire greater versatility, thus facilitating management of absenteeism and staff turnover. Job rotation can also be seen as a means of enhancing communication among members of the same work team, reducing monotony, and shortening exposure to the risks associated with task performance in certain jobs. However, it also has disadvantages, such as the difficulty of adapting workstations/jobs to all team members or the imbalance in the demands of one workstation/job compared to another.

As stated by Rocha et *al.* (2012), some authors (Coutarel et *al.*, 2003; Falardeau and Vézina, 2004) find it difficult to say whether job rotation is an effective means of preventing musculoskeletal disorders (MSDs). The impact of applying job rotation, depending on the conditions of implementation, may be contrary to expectation. Once implemented, job rotation may increase workers' tolerance of the work demands and simply delay the onset of symptoms. Implementation that does not meet a certain number of conditions runs the risk of hastening the onset and increasing the incidence of MSDs. Decreasing physical demands is not the only reason for introducing job rotation, as psychosocial aspects are also very important (Aptel et *al.*, 2008; Ouellet et *al.*, 2003; Vézina, 2005). In addition to offering a variation in physical demands, the advantages of job rotation include reducing monotony through task enrichment and the development or expansion of skill sets. Yet the task of implementing job rotation in a company must not be taken lightly. According to Coutarel et *al.* (2003), it constitutes a real organizational project that must first be approached from a project management standpoint, i.e. as a structured process in which the stakeholders and roles are clearly defined.

[1] The masculine form is used in this text solely in the interests of readability. It refers equally to women and men, with no gender discrimination intended.

A literature review on job rotation (Vezina et *al.*, 2003) yielded the following findings. As most authors are interested in obtaining gains for the company, they believe in achieving improved product quality through job rotation. Yet there is little consensus on the impact of job rotation on MSD prevention among these studies. What does emerge, though, is the particular importance of the way job rotation is implemented. It appears to determine the success or failure of job rotation as a tool for preventing this type of injury. In a survey conducted in a car assembly plant, St-Vincent et *al.* (2003) asked the workers if they were for or against job rotation. Of the 189 respondents, 21% were for, 33% were against, while 46% said their position depended on the conditions under which it would be implemented. The workers wanted, for example, less demanding conditions at the workstations, time to learn their new tasks, the right to choose their teammates, and job rotation on a voluntary basis. It therefore appears that job rotation could result in benefits for workers if certain precautions were taken.

A second issue is the leeway given to workers involved in job rotation (Coutarel et *al.*, 2003; Vézina et *al.*, 2003; Vézina, 2005). In one unit where job rotation was practiced, this form of organization was accepted because the job rotation was managed by the workers. For example, the workers had decided to change workstations every hour. According to Dadoy (1990), a balance must be achieved: if changeovers are too frequent, the adaptation involved becomes too onerous; if they are too infrequent, the fatigue associated with the type of work performed at a given workstation sets in. In Gaudart’s study (1996), it was observed that the more demanding the workstation/job in terms of efforts and postures, the more frequent the job rotation. In the study conducted by Vézina et *al.* (2003), the workers all emphasized the importance of entrusting the management of the job rotation conditions to the group involved. Thus, workers with back pain can avoid the workstation/job that aggravates their pain for a certain length of time and reduce the number of workstations/jobs they rotate between. An external party could provide useful guidelines that enable workers to make informed decisions about managing job rotation.

Other conditions noted in the literature involve workstation characteristics, because there is always the risk of aggravating a worker’s pain or discomfort if he or she suddenly has to perform more demanding tasks. Improving conditions at workstations therefore appears to be the first area where resources and energy should be invested if there is to be any benefit from job rotation. The study by Vézina et *al.* (2003) showed that even small variations in workstations/jobs were enough to modify the postures and movements required.

The vast majority of studies on job rotation have been conducted in the context of short-cycle repetitive tasks. Some authors, working from more physiological and biomechanical standpoints, evaluated the impact of job rotation on very specific variables with no significant concern for analyzing the work (Hinnen et *al.*, 1992; Jonsson, 1988a, 1988b; Frazer et *al.*, 2003; Rodrigo et *al.*, 2012; Horton, 2012). Some cases involved simulated tasks (Horton, 2012). Other authors analyzed, from varying perspectives, teams where job rotation was already in place (Rocha et *al.*, 2012; Simoes et *al.*, 2012; Vézina et *al.*, 2003; Ouellet et *al.*, 2003; Coutarel et *al.*, 2003; Gerling et *al.*, 2003). Researchers on the Daniellou team showed discrepancies between the way in which the prescribed job rotation was organized and how it was actually practiced by the workers (Rocha et *al.*, 2012; Simoes et *al.*, 2012). They documented the collective strategies for preserving health developed by operators in a soft drinks factory. Everaere (2008) cited the notions of “nomadic” rotation – where the operator moves from one workstation/job to another – and “sedentary” rotation – where the operator stays at one workstation/job and expands and develops his skills. In the aerospace industry, the notion of workstation/job is vague; we talk more about stages in the work or main tasks generally performed in a specific work environment/situation. To our knowledge, there are no studies on job rotation involving complex, long-cycle tasks such as those found in the aerospace industry, nor have there been any studies that have tested a job rotation scenario under real production conditions as opposed to analyzing the existing situation.

1.2 The learning process and skill development

Several studies document the conditions that need to be taken into account to ensure successful job rotation (Aptel et *al.*, 2008; Coutarel et *al.*, 2003; Ouellet et *al.*, 2003; Vézina et *al.*, 2003; Vézina, 2005). One noteworthy finding is the prime importance of the problems posed by learning and maintaining versatility (Chatigny, 2001; Coutarel et *al.*, 2003; Everaere, 1999; Gaudart, 2003; Sailly, 1998, Vézina et *al.*, 2003). According to Vézina (2005), there are three phases in learning how to perform tasks, even repetitive tasks. The first phase involves becoming familiar with the prescribed task, the company requirements regarding production quantity and quality, and the expectations of the various parties involved, including coworkers. It also includes becoming familiar with the means and conditions available for performing the task. This learning takes only a few days and sometimes only a few hours. The second learning phase is that of becoming skillful at and adapting to the job. During this time, workers try to find their own work methods, to discover the “tricks of the trade”, such as how to position themselves, what order to perform the operations in, and how to prepare their tools. In a sense, they develop their own specific way of regulating their work to reduce the demands, save time and increase their leeway. Striving for efficiency appears to be central here. It seems that this phase takes weeks or even months. In the last learning phase, workers develop the ability to handle variations in the work, as well as unforeseen incidents and events. In repetitive jobs, the importance of the skills that have to be acquired to achieve this level of competency is often underestimated. This means that when implementing job rotation, the costs related to training should not be underestimated. While it is essential to spend time on training, the quality of the training is equally important and is reflected in, among other things, the possibility a trainer has to pass on the tricks of the trade and prudent knowledge (Cloutier et *al.*, 2012). Fostering learning is therefore a vital issue and a prerequisite for successful job rotation. As Everaere points out (2008), the following conditions are required for this purpose:

> *Stability in a complex work situation and time are essential conditions to the slow and gradual acquisition of skill. They allow each individual to become a competent specialist in a given work situation through the various techniques he learns, one step at a time, in order to master the work situation at hand (...) The area of specialization is therefore very informative in terms of the very principle of skill and expertise, skill that is built gradually by having to cope daily with problems or variations that should all fall within a relatively homogenous cognitive field. [Free translation]*

1.3 Aim of the research project and structure of the report

The aim of this study was to identify the prerequisite conditions for implementing job rotation in an aircraft assembly plant in the aerospace industry in the hopes of preventing the MSDs that affect workers in this industry. The approach adopted was that of testing job rotation scenarios and monitoring and following up on the trials, from which lessons were drawn about the facilitators and barriers involved in implementing this form of work organization. A better understanding was also gained of the impacts of applying job rotation on the relationships between quality requirements and the process of learning to perform the tasks. We found no studies on job rotation involving complex, long-cycle tasks. Our study therefore represents a unique experiment in which the study of long cycles led to the development of innovative methods for examining both the learning issues and conducting the risk factor analysis, given that traditional methods (primarily designed for analysis of short-cycle tasks) were poorly adapted to our context.

In our job rotation implementation trials, we adhered to the main principles identified in the literature. First, the assemblers' perceptions were surveyed. The job rotation implementation phase was then defined, followed by a workstation/job improvement phase and the actual testing of job rotation scenarios with the assemblers' and supervisory staff's participation. A steering committee, which was informed of results and progress on a regular basis, played a key role in the running of the project. Risk factors and learning issues were a focal point of our analyses. Original follow-up methods were used to study the situation prevailing after the implementation of job rotation. The following sections describe the main aspects of the process followed and the methods developed, as well as the principal results obtained. The discussion section highlights the prime importance of learning issues in this industry, where the requirements are very high, as well as the importance of organizational support for coach-trainers and team leaders. In fact, non-quality events – particularly major errors – require adapting the entire work team to ensure a smooth production process: the team leader coordinates these adaptations, which have consequences on the implementation of job rotation and development of versatility among assemblers. We will begin by presenting background information about the company context, the work, and the assemblers' characteristics in order to facilitate understanding of the later sections.

2. CONTEXT OF THE STUDY

2.1 The company and the industry sector

The company studied is a Québec multinational operating in the transportation sector. It produces aircraft (commercial, amphibious and business) and transportation vehicles (e.g. commuter trains, high-speed trains, subways). The aerospace division employs over 35,000 workers worldwide, including 12,000 in the Greater Montréal area, where the head office is located. In a global production context, competition between the company's production sites (Mexico, Morocco, and China) is intense. However, the high-value processing activities – requiring high levels of technical skill – stay in the Montréal plants to ensure that jobs are kept in Québec. The Montréal plant employs approximately 2,000 assemblers assigned to parts manufacture and aircraft assembly and 2,000 white-collar workers divided among several departments (engineering, training, human resources, health and safety, etc.).

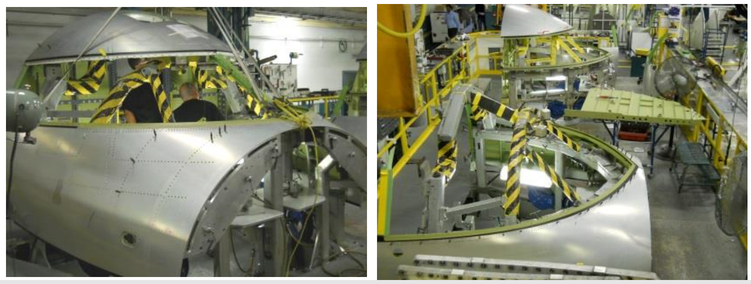
2.2 The workstations/jobs studied and the assembly work

At the company's request, the study was carried out in the department where cockpits for one of the company's flagship aircraft are assembled. This department faces two major challenges: production problems related to the complexity of the structures assembled (cockpits) and to the positioning of cockpit assembly in the production cycle; and major risks for the workers' health that are related to postural demands and typical assembly operations. The four stations that make up this department are described and illustrated briefly by identifying the main assembly objectives of each station, the types of parts installed, the physical work environment and the number of jigs that can be used simultaneously (one jig can accommodate one cockpit) (Table 2-1). In actual fact, this department is divided into two entities functioning relatively independently of each other: stations 1 and 2 make up the first entity, and stations 3 and 4, the second. As will become apparent later in this report, these two "sub-departments" were analyzed separately for practical reasons.

2.3 Organization of the work and the production process

In terms of organization, one assembler-team leader is in charge of the first two stations, while, while two other team leaders are assigned to the last two stations (there is also a team leader on the evening shift for the entire department). In fact, natural links exist between the first two stations, while the third and fourth stations are more independent. It is preferred that the assemblers in the department work at only one station, but they often circulate around the various other stations to meet production demands. The assembly work is carried out over two work shifts: day and evening. The department had from 22 to 25 assemblers, depending on the phase of the research project. The total number of assemblers fluctuated constantly during the study period according to production demands.

Table 2-1: Description of the four stations

Stations	Illustration
1. *Objective*: begin cockpit assembly, position upper part of cockpit *Parts*: essentially big *Environment*: fairly open space, but cramped (massive jigs) *Production sites*: two	
2. *Objective*: reinforce upper part of cockpit, solidify inside structure *Parts*: medium-sized and small *Environment*: open space *Production sites*: three	
3. *Objective*: assemble lower and upper parts of cockpit, assemble parts on sides (inside and outside) and in/on back (inside and outside) *Parts*: big on sides, small in/on back *Environment*: small space *Production sites*: two	
4. *Objective*: assemble upper part of cockpit, assemble parts on front and inside *Parts*: big on front, small inside *Environment*: small space *Production sites*: two	

Production is organized on a just-in-time basis, with cockpits produced and delivered according to customer orders. This department is the place where more than 700 parts of varied shapes and sizes (fig. 2-1) from nearby stations and from subcontractors converge and are assembled in a predetermined sequence. The work sequences are described in the assembly specifications, which spell out the operations to be carried out and procedures to be followed. On the whole, these specifications are not consulted much, as will be seen subsequently. The parts are assembled using more than 13,000 fasteners, which again vary greatly (fig. 2-2).

The first station is where assembly begins; the cockpit takes shape as it moves from one station to the other, assuming its final shape at station 4. This means that from one station to the next, the parts accumulate to form an increasingly complex “puzzle”, while also presenting increasingly cramped work spaces. It is a well-known fact within the company that stations 3 and 4 are the most demanding.

The department constitutes a “bottleneck” in the production cycle, with cockpit production impacting directly on when the assemblies leave the plant. Moreover, the stations in this department are seen as the exit door to other plants in the group. Any delay at the stations studied therefore has major consequences that result in financial penalties.

a. Small parts measuring only a few centimetres

b. Big parts measuring several tens of centimetres, sometimes even more than one metre. On the left, skin station 1; on the right, canopy station 1.

Figure 2-1: Examples of parts that have to be assembled to build the cockpit

Examples of fasteners:
a. Rivets of various sizes; b. Rivets in transparent box used to carry them between workstations; c. Hi-lites (screwed rivets)

Figure 2-2: Examples of fasteners used to attach and secure parts

Table 2-2 summarizes the characteristics of the worker population at the beginning of the study; the population changed during the second year of the project. The assembler population was somewhat older and had considerable seniority in the plant, and there was a degree of stability in the department as a whole at the beginning of the study.

Table 2-2: Characteristics of the assembler population (n=22)

	TOTAL	Station 1	Station 2	Station 3	Station 4
Men	21	3	3	9	6
Women	1	0	0	1	0
Average age					
30-35 years	9	2	1	3	3
36-40 years	8	0	1	6	1
41-50 years	5	1	1	1	2
Average age in the department	39 years	39 years and 6 months	40 years and 3 months	37 years and 5 months	39 years and 6 months
Seniority in the company					
10-15 years	15	0	2	8	5
16-20 years	5	2	1	1	1
21-25 years	2	1	0	1	0
Average seniority in the company	14 years and 5 months	19 years	13 years and 6 months	15 years	14 years
Seniority on the job					
0-6 month	7	2	1	3	1
7 months -1 year	2	0	0	0	2
1 year $< n \leq$ 2 years	3	0	1	2	0
2 years $< n \leq$ 5 years	7	0	0	4	3
5 years $< n$	3	1	1	1	0
Average seniority in the department	3 years and 1 month	4 years and 6 months	2 years and 9 months	3 years and 5 months	2 years and 3 months

3. METHODOLOGY

3.1 The Request

In the summer of 2010, the research team was approached by the plant ergonomist and union representatives, who were interested in developing the personnel's versatility by implementing job rotation. Both the employer and union were interested in this form of organization, but recognized that it was a complex problem and wanted the researchers' guidance. The research team's mandate was defined: the people at the company wanted to know, in their particular context, what conditions were required to implement job rotation and whether these conditions existed in the company. A research project on this question was therefore begun in the summer of 2011. The cockpit assembly department was the focus of the study.

3.2 Social construction and the steering committee

The study was an action research project on job rotation, a type of project in which social construction plays a crucial role in the successful implementation of changes. Preliminary observations, informal interviews and a questionnaire were used to gain the trust and collaboration of the assemblers targeted by the study. The study was conducted using participatory structures, interviews, and validation meetings in which the assemblers participated on a regular basis. Potential changes were identified and job rotation assignments determined by working groups assisted by the project ergonomists. The stakeholders in the department under study were mandated to implement job rotation under the guidance of the ergonomists, who also monitored and followed up on the implementation.

A project steering committee was formed in the plant to oversee the research, support the researchers, and ensure that the project ran smoothly. The committee received regular updates on project progress from the research team and was sometimes called upon to facilitate access to the field. In addition, presentations made to the steering committee then led to a collective decision as to the subsequent steps. The committee met eight times between September 2011 and April 2013 for 60 to 90 minutes at a time. It comprised members of the plant's senior management, union representatives, the manager of the assembly department and the manager of the engineering department, training representatives and representatives of the occupational health and safety department, the supervisor of the department under study, as well as members of the research team.

3.3 Overview of the process followed

The project was carried out over a period of just over 24 months (fig. 3-1). From June to November 2011, the researchers made preliminary observations of the actual work being performed and wrote chronological workshift-task descriptions. At the same time, interviews were conducted with key stakeholders in order to describe the company context. A questionnaire was administered to the assembler population during this same period in order to describe their health and obtain their perceptions of the implementation of job rotation. Lastly, the four stations were videotaped during this period. As will be seen later, each of these stations encompassed several jobs (called "rotation units") between which rotation was possible. Working with the company, we decided to document the issues involved in job rotation, to do an initial data collection for stations 1 and 2, and then to follow a similar process for stations 3 and 4. Despite the company's willingness to implement job rotation on all four stations, the complexity of the required analyses compelled us to divide our data collection process into two phases.

From March to September 2012, stations 1 and 2 were analyzed prior to implementing the job rotation scenario. This involved defining the job rotation units and describing the physical risk factors and learning difficulties associated with each unit. In spring 2012, a working group was formed to identify potential changes that would reduce risks at the source prior to implementing job rotation. Again using a participatory approach, a working group then planned a job rotation scenario for stations 1 and 2.

In December 2012, we proceeded with a first trial implementation of the job rotation scenario developed for stations 1 and 2. Some problems arose at that time and obliged us to stop the trial. A second trial implementation took place in March 2013. Following a similar process, stations 3 and 4 were analyzed prior to job rotation implementation. No trial implementation was carried out for these last two stations because the trials at the first two stations showed that certain conditions had to be assured for effective implementation of job rotation. To create these conditions, an action plan, which is detailed later in this report, was drawn up in collaboration with the company stakeholders.

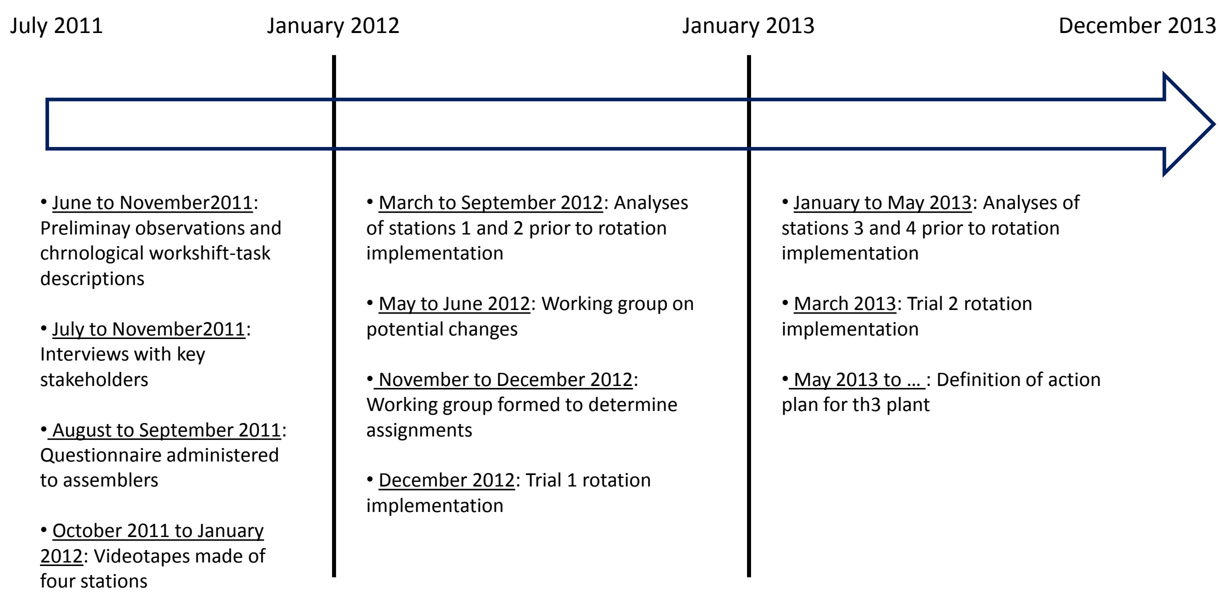


Figure 3-1: Overview of process followed

3.4 Description of the context and characteristics of the assembler population

At the beginning of the project, we deemed it important to understand how the company was organized and the roles of the main departments. We also wanted to describe the study population, particularly regarding the musculoskeletal and psychosocial demands they experienced, and to find out the assemblers' perceptions of job rotation. We therefore interviewed key stakeholders (sub-section 3.4.1) and had the assemblers under study complete questionnaires on their health and perceptions of job rotation (sub-section 3.4.2).

3.4.1 Interviews with key stakeholders

Sixteen key stakeholders in the plant were interviewed in order to obtain their viewpoints on the company's socio-organizational context and on occupational health and safety activities. The various departments and hierarchical levels of the company were represented: production, human resources, training, health and safety, engineering, and first-line supervision.

Eight main themes were broached during the interviews: the stakeholders' perception of their work, general prevention, MSD prevention, job rotation, the continuous improvement program, training and learning activities, communications within the company, and the work atmosphere. The interviews were all audiotaped and transcribed to produce a verbatim record. Summary tables were then produced for each main theme covered.

3.4.2 Survey of assemblers' health and perceptions of job rotation

The assemblers in the department targeted by the company for the study completed the questionnaire found in Appendix A. The questionnaire had three main sections: questions taken and adapted from the Nordic Musculoskeletal Questionnaire (Kuorinka et *al.*, 1987), questions taken and adapted from Karasek's Job Content Questionnaire (Karasek, 1985; 1998) and more general questions on perceptions of job rotation. The questionnaire was self-administered by all the assemblers (n=22) in the department. The data were compiled using Excel, which enabled us to produce summary tables (occurrences and percentages, Karasek indicators).

3.5 Job rotation implementation strategy

Given the problem's complexity and the production issues involved, it was decided that job rotation would be implemented on a participatory basis involving primarily the team leaders and assemblers. It was they who proposed the job rotation scenarios. The pertinence of the scenarios was then evaluated using the data collected by the research team. Prior to implementing the job rotation scenario, analyses were performed to gain a thorough understanding of the assembly operations and to describe these operations in terms of two major issues identified in the literature: MSD risk factors and difficulties in the learning process. The idea was to be able to alternate between steps regarded as easy or as more difficult from the standpoints of both risk and required learning. We will see later in this report that these two requirements are in fact two sides of the same coin.

3.6 Analyses prior to implementation of job rotation

3.6.1 Observations

As a preliminary step, the research team familiarized itself with the four target stations and the assembly work in general, made open observations and wrote chronological workshift-task descriptions of the four stations (day shift and evening shift). Information meetings and simultaneous verbalizations ("thinking aloud" sessions) held with the assemblers, team leaders, and department supervisor introduced us to the ins and outs of cockpit assembly. A complete work cycle was then filmed for each station: 50 hours each for stations 1 and 2, 180 hours for station 3, and 130 hours for station 4. The stations were filmed simultaneously from various angles, and from inside (inside views) and outside (overviews). When possible, cameras were also attached to the assemblers' safety glasses to film the work performed inside the cockpit structures.

3.6.2 Dividing cycles into "rotation units"

Initially it appeared difficult to identify the jobs that would lend themselves to job rotation. The form of work organization used in the department and which allows for traceability of the assemblers' work by the company – a requirement of quality standards in the aerospace industry – was far from easy to decode at first glance. Apart from this traceability requirement, the distribution of the work among the assemblers was the result of a complex amalgam that took into account the total number of hours assigned to each assembler to keep him busy during the entire cockpit assembly cycle; the logic of the assembly, in which some operations must precede others; and the physical distribution of the assemblers to ensure they do not get in each other's way (for example, one assembler inside and one outside the cockpit, or one above and one below). Preliminary work was therefore done to divide up the cycles (from 50 to 180 hours, depending on the station) into major stages or phases of assembly operations. These major stages in production, called "rotation units", represented, by analogy, the different jobs/workstations that could be occupied on an assembly line, for example. When proposing a job rotation assignment, the assignment was therefore described in terms of the job rotation units occupied. Data from several sources were aggregated in order to divide up the cycles. These sources were open observations of the assembly work, meetings and informal talks with the assemblers and team leaders, and our consultation of the assembly specifications and assembly charts. The pre-defined rotation units were presented, validated and completed with the assemblers during the various data collection stages. These units constituted homogeneous work stages, with clear-cut beginnings and endings for the assemblers. However, they varied greatly in length, ranging from a few hours to over 20 hours. A total of 37 rotation units were defined for the four stations (seven for stations 1, 2 and 4; 16 for station 3).

3.6.3 Analysis of difficulties in the learning process

Given the complexity of the assembly work and the importance of learning issues in the implementation of job rotation, it was decided to characterize the difficulties in the learning process associated with each rotation unit. We developed an innovative method combining observations of the work, informal talks, and validation meetings with the assemblers for this purpose.

3.6.3.1 Classification grid

A grid for classifying the learning difficulties was developed and used to identify the difficulties specific to each rotation unit (Appendix B). Three dimensions of the assembly activity were retained to estimate the level of learning difficulty for a given rotation unit: basic skills,[2] which describe the assembly work and tools involved; the task of fitting the parts together; and memorizing the sequences of the assembly operations to be performed. Three levels of difficulty (low, moderate, and high) were defined for each of the three dimensions and then presented to the workers for validation using a colour code (green, yellow and red).

Basic skills

These refer to the basic operations that have to be mastered to do the assembly, and essentially consist of drilling, countersinking, and riveting (fig. 3-2). One particular requirement of the assembler's job is that of having to position the tools properly in relation to the work surface. The worker has to "find the perpendicular (right angle)" between the tool and the work surface: the workers talk about finding "a flat surface" or "feeling your angle". To do so, the assemblers have to adopt many compromising postures. "Finding the perpendicular" is sometimes a complex process and depends on a combination of factors, including the shape of the parts (single, double, or triple curvature) and their position in the assembly jig (e.g. high up, low down, at a distance). Among other things, it is complicated by the proximity, within the work space, of certain "fragile" parts that must not be damaged.

The basic skills involved fall into the category of manual know-how[3]. Mastering these skills requires time for practicing them under the real conditions where they will have to be applied. Fine motor skills and eye/hand coordination are particularly important. Tactile control and the application of force are also aspects that must be considered.

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[2] We kept this term, as it was widely used in the company.

[3] This criterion evaluating one dimension of the difficulties in the learning process is in fact closely linked to the physical requirements of the cockpit assembly jobs. The skill of finding the perpendicular and of maintaining it despite cramped spaces and vibration of the tools, as well as the need to control one's movements so as not to damage fragile parts nearby (or behind), is a matter of motor control. While such movements can be learned, they also depend on postural constraints and efforts, which can be one of the factors at the origin of the MSDs reported by the assemblers.

a. and b. Drilling at stations 1 and 2; c. Countersinking at station 2 ; d. and e. A pair of workers and one person alone riveting at station 4.

Figure 3-2: Examples showing the main assembly operations and related postures

Fitting

This dimension covers aspects of the spatial presentation of assembly and of understanding the play within tolerances that allows the worker to anticipate the overall cockpit assembly. It also includes spatial awareness. It is important to understand that the cockpit is the place where hundreds of parts of different sizes, manufactured in other departments or elsewhere (externally), are assembled. Any given part, despite all efforts, always has (small) variations: no two are perfectly identical. The assembler must be able to assemble the parts while respecting the play within tolerances, which is sometimes measured in only hundredths of a millimetre. In addition, as a general rule, few parts are of the part-to-part type, which simply require aligning the holes of the various parts to complete the assembly (like the parts of a Meccano set). Despite the apparent similarity in operations from one assembly cycle to the other, no two cockpits are ever assembled in exactly the same way. In fact, within the company they sometimes say that the assemblers "make art" like the craftsmen of the past: they are "industrial craftsmen" (Buchmann, 2013).

Fitting requires both manual know-how (trimming and adjusting) and knowledge (required tolerances). Great care must be exercised and the consequences of a poor fitting are high (costs, production delays, etc.).

Sequencing

Sequencing refers to assembling the parts in the right order. Several aspects have to be taken into account: the number of parts to be installed, the complexity of the order of the assembly operations, the location of the parts on/in the cockpit, and their positioning. Sequencing is essentially a question of knowledge: you simply have to know the sequence.

3.6.3.2 Interviews on the learning process

The information gleaned from the interviews conducted with the assemblers (n=19, for the four stations, see Appendix C) on the learning process enabled us to apply the classification grid to the 37 stages (or rotation units) identified in the department. Each stage was then described in terms of the three dimensions: basic skills, fitting, and sequencing. Anywhere from one to three assemblers gave their views of a given stage. We then produced a summary of the data, which was validated at a collective meeting of all the previously interviewed assemblers. Generally speaking, we found that few stages were considered difficult for all three dimensions, which created interesting job rotation possibilities. However, the grid highlighted the great complexity of the assembly work and the need to provide the assemblers with thorough training on the specific nature and context of the company.

Further investigation of the issue of quality

During the project, the issue of quality and its impact on the assemblers' work appeared to be increasingly critical. It was therefore decided to do an *a posteriori* analysis of the interviews with the assemblers, which had initially been conducted to describe the difficulties in the learning process and categorize the various stages (n=19 interviews). Content analysis was performed using Atlas.Ti software. In addition to the theme of quality, which was extensively covered in these interviews, three other and complementary themes were also broached: learning issues, the work team, and occupational identity. The results of the analyses of these three other themes will not be presented here, however, due to the amount of space required to do justice to all that was learned. Regarding the issue of quality, four themes were defined for analysis: the risks of error, control, actual errors, and requirements and demands. These four themes were in turn broken down into 12 analysis variables. All the variables analyzed and their definitions are presented in Appendix D.

3.6.4 Analysis of physical risk factors

Two methods were used to analyze the risk factors. The first (see Appendix E), based primarily on methods designed for short cycles analyzed from video observations, was used for stations 1 and 2 (Chiasson, 2011). This first method generated interesting results, but was deemed poorly adapted to long cycles and much too costly in terms of analysis time. In fact, it represented a colossal data collection task: for example, the continuous analysis of postures of five body regions required viewing more than 100 hours of videotape five times. None of the results obtained using this method can be presented because an unfortunate accident destroyed the database and rendered it unusable.

For stations 3 and 4, we developed a new method of analysis that we considered better adapted to long cycles. It combined several sources of data (interviews, observations, and assembly specifications) and focused more on the assemblers' perceptions. It took into account a broader range of risk factors, but without doing as detailed an analysis as in the method used for stations 1 and 2. Specifically, it allowed links to be established more easily between reported risks and the characteristics of the work performed: the risks could be associated with one or more targeted operations in the whole stage (which could last several hours).

3.6.4.1 Alternative method for long cycles: applied to stations 3 and 4

First, a risk factor analysis grid was developed to cover five categories of factors: postures (general posture, back posture, posture of the upper extremities), efforts, vibrations, upper extremity posture combined with vibrations, and a variable we called "aggravating factors". The last item allowed us to document factors in the general context that increased/aggravated the risk, such as working in a small space and poor visibility. For each category of variable, three levels of severity were defined: low, moderate and high. The grid, including the definition of the severity criteria, is presented in Appendix F.

Second, a questionnaire (see Appendix G) was developed for the assemblers in order to document the risks, using this grid. Visual materials were also developed to make it easier for the assemblers to express themselves. Photographs showing the various operations and types of postures adopted were shown to the workers (see the examples in Appendix H). The risks associated with each of the job rotation units at stations 3 and 4 were documented by means of the questionnaire and compiled in the grid. All the assemblers who carried out a given stage were questioned.

The assembly specifications were also analyzed to complete these perception data and obtain more factual information (see examples in Appendix I). The latter information focused more on the workload. Various aspects were covered: number and size of the parts installed, number of fasteners (rivets) placed, and repetition of standard assembly operations (drilling, countersinking, and riveting). Regarding this last aspect, repetitiveness is an important risk factor to consider. However, rather than observing the repetitiveness of the operations, which quickly becomes tiring when long cycles are involved, we inferred it from the data in the assembly specifications.

3.6.5 Summary sheets combining data on the learning process and risks

In order to comment on the job rotation plan/scenario developed by the stakeholders (see sub-section 3.7.2), a user-friendly summary sheet showing the data on the learning process and risks was produced for each rotation unit. Two contrasting examples of these sheets are shown in Table 3-1 (difficult stage) and Table 3-2 (easy stage).

Table 3-1: Example of summary sheet showing data on the learning process and risks associated with a so-called difficult stage

Rotation unit 2, Station 3			
Compétences – apprentissage			**Explications, liens avec l'activité de travail**
Basic skills		3	Countersinking and riveting near the sill/critical part, several thicknesses, riveting onto a curved part: perpendicular hard to find, reverse spatial orientation when working on back
Fitting		2	Controlling depressions by inserting liquid shims (large number)
Sequencing	1, 2, 3 …n	2	Many rivets to install with variable tolerances, many details to remember
Postures			**Explanations, relationship to work activity**
General		------------ ---------------- ------------	-
Back		3	Constraining back postures, particularly back extensions (lying down), adopted when working inside the hole
Upper extremities		3	Working with arms stretched upward and away from the body to countersink and rivet along the two big triple-curvature skins
Aggravating factors			Work performed near critical parts
Efforts vibration			**Explanations, relationship to work activity**
Vibration		3	Using the countersink, riveter, and bucking bar throughout this stage
Combination		3	Constraining work for upper extremities and heavy use of tools
Use of tool		3	Nearly 850 holes drilled, countersunk, or riveted
Effort		2	Overall effort rated at 3, countersinking, and riveting efforts rated at 7
Aggravating factors			Work on multiple layers

Levels of learning difficulty or presence of risk factors: 3 = **high** level; 2 = **moderate** level; 1 = **low** level.

Table 3-2: Example of summary sheet showing data on the learning process and risks associated with a so-called easy stage

Rotation unit 5, Station 3		
Compétences – apprentissage		**Explications, liens avec l'activité de travail**
Basic skills	2	Working on the ground, crouching down, perpendicular hard to find
Fitting	3	Fittings, measurements, and positioning of the box to be totally defined
Sequencing (1, 2, 3 …n)	1	Only the box has to be positioned
Postures		**Explications, liens avec l'activité de travail**
General	3	Working bent over inside the cockpit
Back	1	-
Upper extremities	1	-
Aggravating factors		-
Efforts vibration		**Explications, liens avec l'activité de travail**
Vibration	1	-
Combination	1	-
Use of tool	1	-
Effort	1	-

Levels of learning difficulty or presence of risk factors: 3 = **high** level; 2 = **moderate** level; 1 = **low** level.

Insofar as possible, the data were related to and explained through specific references to the assemblers' work activity (last column of the table). These relationships made it much easier for the assemblers and team leaders to grasp the data, because they were able to see how it related to the nature of their work.

3.7 Activities related to implementation of the job rotation scenarios

3.7.1 Prerequisite conditions for the first job rotation trial at stations 1 and 2

3.7.1.1 Changes requested

A set of data concerning potential improvements to the workstations was derived from the various analyses performed. It was decided to begin the job rotation experiment at stations 1 and 2 because they seemed less complex and more conducive to successful implementation. A working group was formed to reflect on possible changes. The group included various stakeholders in the project: two assemblers/team leaders, the department supervisor, a union representative, the plant ergonomist, and, on an *ad hoc* basis, a representative of the engineering, training or tooling department (department responsible for the jigs on which the aircraft structures and parts are assembled), as well as the research team. This working group met four times over a two-month period. The participatory mode of functioning enabled the group members to identify three unavoidable priority changes. We considered it important that these changes be implemented prior to the job rotation trials.

3.7.1.2 Other requests made

In addition to these changes, a request was made for resource persons to be present at the workstations, i.e. individuals who could act as coach-trainers to support the assemblers while they learned the new assembly steps. Three coaches were identified: one team leader and two experienced assemblers.

3.7.2 Working group: determination of job rotation assignments

A sub-group comprising the team leaders, supervisor, in-house ergonomist, and research team then met twice to draw up a job rotation plan. This involved "envisaging" the job rotation, or establishing the order of job rotation among the various work stages ("rotation units"), assigning the assemblers to each stage, and identifying potential coaches. A job rotation plan for trial 1 was proposed for the first 20 cockpits.

3.8 Job rotation trials and monitoring

The research project was conducted over a period of more than two and a half years (June 2011 to December 2013). During that time, two rotation trials were implemented at stations 1 and 2 and were observed and supported by the research team. The two trials – the first in December 2012 and the second in March 2013 – were monitored and evaluated in virtually identical ways.

3.8.1 Trial 1

To monitor this trial, it was planned to observe the assembly of certain cockpits, specifically numbers 1 and 2, 9 and 10, 11 and 12, 19 and 20, at the two stations. In actual fact, only cockpits 1 and 2 were assembled at the two stations over the four work days covered by this trial. When the trial was stopped, the assembly of these two cockpits had not been finished. Various data were collected to monitor the job rotation; a summary of the tools used is presented in Table 3-3. The reader will recall that coaches had been identified when the working group met to determine the job rotation assignments (sub-section 3.7.1.2).

Table 3-3: Data collected to monitor the first two trial implementations of job rotation

Data collected and methods used	Analyses performed
Videotapes providing overview of the two stations	Extraction of data from videotapes and illustrative photographs
Open observations: notes (daily log), photographs, survey of difficulties/problems, differences relative to planned assignments, incidents, etc.	Synthesis, reports
Observations of interactions (learning, critical quality-related situations, other) between coaches and assemblers: observation form (Appendix J) and photo-taking	Interactions entered into a database, analysis/synthesis
Audio recordings of coaches (microphones)	Integration of coach-assembler exchanges (transcript) into the interaction database
Interviews/end-of-day meetings with coaches and team leader: how the day went, problems/difficulties encountered, differences relative to planned assignments	Transcript of interviews Synthesis

Based on this trial, new conditions conducive to implementation were identified. Added to the list of conditions – which involved changes to the stations and the presence of coaches – was that of re-examining the team leader's workload and ensuring greater stability in the assembler team. In fact, based on trial 1, we first noted the central role played by the team leaders in this department in several respects: passing on knowledge and skills to the younger workers, managing assignments according to the progression of the work (e.g. delays), managing errors, and so on. At the same time, and to prevent production targets from not being met, the team leader was frequently obliged to change the planned assignments as there was little leeway for doing otherwise. This had a major impact on the job rotation because the team leader's strategy was, contrarily, to have the assemblers specialize to ensure that production deadlines were met. This was the main reason for stopping trial 1. The team leader faced the added constraint of having to cope with frequent changes in his team of assemblers, as some of the more experienced workers were needed in other departments and their absence was compensated for by adding very inexperienced assemblers.

3.8.2 Trial 2

For the second job rotation trial, which took place in March 2013 over a five-day period, the assembly of two cockpits was again monitored. New assignments were proposed this time for the first ten cockpits only, with job rotation to start with the sixth cockpit. During this time, the number of assemblers at the two stations rose from seven to nine, including the team leader. The coaching responsibilities were less clearly established than for trial 1, but remained an ongoing concern. For the assignments in this trial, given the increased numbers of workers assigned to the evening shift, decisions were also made to prepare the evening-shift assemblers to work autonomously (the most experienced assemblers worked days due to their seniority).

The same tools were used to monitor this trial as those described in Table 3-3 in the preceding section. However, the team leader's role and activities were tracked more exhaustively. This was done essentially by observing his activity at the stations involved in the trial, but also elsewhere in the department under study, by monitoring his interactions with other stakeholders in the plant (quality assurance managers, engineers, sub-contractors, etc.) and describing his tasks and responsibilities.

3.9 Project management approach to implementing job rotation

Further to the two job rotation trials and the lessons learned, the company formed a committee responsible for putting in place the conditions conducive to implementing job rotation. A person from the training department was put in charge of this committee, which consisted of the in-house ergonomist and the research team in a support role (e.g. providing additional information needed, presenting interim results in terms of learning achievements and tools developed). Depending on the subjects raised at the meetings, the committee was sometimes joined by supervisors and/or a technician from the training department responsible for designing material on the stages in assembly, in collaboration with the assemblers who had experience at the workstations. A detailed action plan was drawn up and presented to the plant's senior executives for validation. A total of 12 meetings (between one and two hours long) were held between May and September 2013, five of them via conference calls.

4. RESULTS

4.1 Key stakeholders' perceptions

The previously held interviews shed light on the key stakeholders' perceptions of prevention and OHS, the presence of MSDs, job rotation, training, communications, and the work atmosphere.

4.1.1 Prevention and occupational health and safety

All the stakeholders interviewed agreed that occupational health and safety was a key issue in the company. Some even said it was more important than production. The seriousness with which the company takes OHS is reflected in the way it welcomes and orients employees and in the structures it has put in place. It has a health and safety department headed by a manager, staffed by six counsellors with varying areas of expertise, and including one ergonomist, who was our key contact person throughout the study.

The company introduces its employees to OHS by offering a generic training program. Most of the stakeholders have taken this training. Some stakeholders, mainly team leaders, have received OHS training focused on ergonomic concepts. According to the stakeholders interviewed, when the OHS committees began in 1992, there was not much of a prevention culture. Since that time, the perception of OHS has changed in the plant. A genuine prevention culture has been established since the introduction of the Achieving Excellence System (AES) seven years ago. The frequency of work accidents has diminished. However, it was often reported that the OHS culture remains more reactive – when emergencies occur – than preventive in the medium and long terms. There are increasing numbers of communications about prevention and the employees are more involved. This finding was reflected in the various prevention activities:

- frequent meetings: these meetings foster interactions between assemblers and hierarchical superiors;
- creation of a health and safety committee (HSC): the HSC is made up of about 20 people, including five members of the union who are released full-time to take care of OHS. A number of tasks are associated with the committee's mandates: preventing accidents, observing work postures, overseeing tools and equipment and the use of hazardous products. When problems arise, email messages are thus sent to the supervisors and counsellors instructing them what action to take;
- creation of a local health and safety committee (LHSC): the company offers groups of employees (around 150) the possibility of creating LHSCs that can meet to discuss concerns that affect them directly. A member of the LHSC also assists new recruits during their training to explain the risks characteristic of their sectors;
- interventions carried out on the shop floor with all employees participating: studies are also done of the workstations following declarations or accidents involving musculoskeletal disorders (MSDs);
- the "*We need to talk about it*" system set up in the department: this system fosters dialogue between assemblers and supervisors about OHS questions;
- group work (preventionists, engineers, tool and equipment managers, workers, supervisors, etc.): group work brings people from different departments together and

provides a forum for dialogue about possible solutions for prevention problems and for finding the best compromise;
- assemblers are made aware of the importance of reporting pain as soon as possible;
- the Achieving Excellence System (AES), with the implementation of safe habits through daily interventions, indicator-based management of priorities and preventive audits.

However, certain stakeholders expressed difficulties with prevention due to time constraints. It sometimes takes time to convince certain managers or assemblers of the relevance of OHS actions. One stakeholder also cited the frequent turnover in supervisors as a problem that hinders implementation of a sustainable prevention culture.

4.1.2 Perceptions of MSDs

The MSD problem in the company is recognized by all the stakeholders. MSDs are associated with repetitive movements, awkward postures, vibrations, and effort. The stakeholders also reported various organizational, technical, and environmental determinants. The most frequently cited organizational factors were lack of versatility and absence of job rotation, as well as production-related pressures. Regarding technical aspects, the perceived constraints were the significant presence of vibrations and limited access and mobility in the cockpits and jigs, which are big and cumbersome and too costly to be replaced.

Some stakeholders saw the assemblers as increasingly aware of the MSD problem, while others thought the opposite: that the assemblers were insufficiently or only minimally aware. It is often only when they experience persistent pain that they come forward. All the stakeholders recognized that some assemblers experienced stress problems associated with production rates and assembly delays.

4.1.3 Perceptions of job rotation

From the outset, all the stakeholders were in favour of job rotation, but cited the possibility that some assemblers might resist its implementation. Certain conditions had to be taken into consideration in order to institute sustainable job rotation. These conditions concerned personnel and workstation management, the learning process, and employee participation. The stakeholders indicated that job rotation would be beneficial for the assemblers' health and for the company. They in fact referred to it as a means of reducing the risk of MSDs and stress. Likewise, this form of work organization would be advantageous in terms of preventing monotony, fostering versatility, and valuing the assemblers. For the company, it would reduce absenteeism and the costs of the contributions paid to the Commission des normes, de l'équité, de la santé et de la sécurité du travail (CNESST). Over the long term, it would foster the discovery of new work methods to increase both quality and production. However, the stakeholders also mentioned some disadvantages, mostly short term. The implementation of job rotation could lower quality and production while incurring additional costs. The assemblers believed it could also undermine their solidarity and exacerbate their difficulties in the learning process. Most of the stakeholders believed it would be possible to implement job rotation with the assemblers' participation and on condition that production requirements were met.

4.1.4 Assembler training

To work as an assembler in the plant requires having a Diploma of Vocational Studies (DVS) in aeronautics. At the time of the study, recruitment was carried out using the plant's recall list of assemblers who had been laid off. There was a training school with a laboratory that simulated certain assembly operations and was referred to as the "incubator". For assemblers working on the existing models, training involved a seven-day program on basic operations. The stakeholders' perceptions of the time required to learn how to perform assembly work varied greatly. For some, it required four to six weeks, while for others, the learning time needed – particularly in the department under study – was a matter of years.

4.1.5 Communications and work atmosphere

Communications were deemed good in the company, and a survey is conducted annually to assess employee satisfaction at work. Communication between the different levels in the hierarchy is facilitated by the bottom-up cascade system. Meetings are held every morning. They start with a meeting between team leaders and assemblers to resolve any problems encountered. The problem may be resolved immediately or noted on a list. After this meeting, the team leaders meet with the supervisors, who in turn meet with the department heads. The meetings continue up the ladder to the level of the vice president. In addition, the entire plant staff meets once a week about more major problems. Big meetings can also be held whenever necessary.

On the whole, work relations were deemed good between the various stakeholders in the company and the assemblers, although some tensions existed between the assemblers and the engineers. The perception of work relations between the supervisors and assemblers varied, depending on the stakeholder: some saw the relations as good, while others mentioned that there were some tensions.

4.1.6 Main departments related to the cockpit assembly sector

The earlier interviews made it possible to identify the departments in closer contact with the cockpit assembly sector and proved to be important resources during the study. First, there was the methods department, which produces the assembly specifications. These define the sequence of the steps in assembly by means of numerous diagrams, but without actually specifying "how" assembly is performed. The quality assurance department was identified as a key resource. As will be seen throughout this report, assembly in the aerospace industry involves high-quality requirements, a fact that has a major impact on the actual work and on employees' willingness to participate in job rotation and the stress they experience. Another indispensable department is the training school (incubator). It orients new recruits and is responsible for training the assemblers. Given the central role of learning issues during the implementation of job rotation, contact was maintained with those in charge of the training school and the latter were involved in the working groups responsible for implementing job rotation. Lastly, the tooling department was a key player in the study. This department is responsible for jigs, among other things. Throughout the study, close cooperation was also consistently maintained with union representatives, the company ergonomist, the health and safety office, and the managers in the department under study.

4.2 Perception of job rotation and assemblers' health

4.2.1 Musculoskeletal health

To analyze the results of the Nordic Musculoskeletal Questionnaire, we applied the notion of MSD as defined by authors Vézina et *al.* (2011) of the Enquête québécoise sur des conditions de travail, d'emploi et de santé et sécurité du travail (EQCOTESST, or Québec survey on working and employment conditions and occupational health and safety), namely, having experienced pain often or all the time in the past 12 months and which pain is partially or entirely work-related. The occurrence of MSDs in different body regions in the assembler population is shown in Table 4-1, and the results are compared to those obtained in the Enquête Santé Québec (ESS98, the MSDs occurring in the different body regions are not analyzed in the EQCOTESST survey).

Table 4-1: MSDs in different body regions

Body region	**Staff (N=22)**	**Assemblers (%)**	**ESS98 (%)**
Neck	2	9.1%	14%
Shoulders	3	13.6%	12.7%
Upper arms	9	**40.9%**	**6.9%**
Elbows	6	**27.3%**	**4.3%**
Forearms, wrists, hands	11	**50%**	**7.8%**
Upper back	-	-	14%
Lower back	4	18.2%	25%
Hips, thighs	1	4.5%	-
Knees	2	9.1%	9%
Legs, calves	1	4.5%	6.7%
Ankles, feet	4	**18.2%**	**9.4%**

Very high prevalences are noted for the upper arms, forearms, wrists and hands, with figures far exceeding the results obtained for the Québec workforce as a whole. The EQCOTESST survey revealed MSD prevalence in the order of 20.5% for all workers, with the proportion reaching 33.2% in workers facing four or more demands. By contrast, MSD prevalence in our study population vastly exceeded these proportions: it was in the order of 77.3%. Table 4-2 shows that the proportion of MSDs was high at the four stations.

Table 4-2: MSD involving at least one body region

	Total		Station 1	Station 2	Station 3	Station 4
	N=22	**100%**	**n (%)**	**n (%)**	**n (%)**	**n (%)**
In the department under study	17	77.3 %	2	3	8	4

Since the assemblers reported pain in several body regions, we investigated the situation involving the most troublesome pain. Usually this involved the forearm, wrists, or hands (eight occurrences). The vast majority of the assemblers considered their most troublesome pain to be work-related, while 15 regarded it as entirely work-related, and five saw it as partially work-related. They had usually been experiencing this pain for a long time, with 11 assemblers reporting that it had begun two or more years earlier. The pain did not result in sick leave.

We asked the assemblers if they perceived various physical demands. The results are presented in Table 4-3. Constraining postures was the main demand that emerged, and to a lesser degree, the fact of making forceful exertions or having to sustain a fast work pace. The perceived demands appeared to be particularly high at station 3.

Table 4-3: Specific demands reported by the assemblers

Demand	Total	Station 1	Station 2	Station 3	Station 4
Forceful exertions	**8**	-	1	5	2
Fast pace	**10**	2	-	7	1
Stress/monotony	**7**	1	-	4	2
Constraining postures	**18**	2	2	10	4
Other	**4**	-	1	1	2

4.2.2 Psychosocial demands

As described in the Methodology section, Karasek’s Job Content Questionnaire (1985; 1998) was used to assess psychosocial demands. The main results are presented in Table 4-4 and compared to those assessed in the EQCOTESST survey. A higher proportion of our study population was subject to high psychological demands (PD) and low decision latitude (LAT) than in the Québec workforce as a whole. Nearly one assembler in three was exposed to high psychological work demands and low decision latitude – a combination known to be risky. The comparable proportion was only 17% in the Québec workforce.

The opposite was true when we looked at social support: 77.3% of our assembler population reported strong social support compared to only 52.3% of the Québec workforce. This result must be taken into consideration, because strong social support is recognized as a protective factor for health and may be indicative of a solid work team, which is conducive to the implementation of job rotation.

Table 4-4: Psychological health indices

	PD+		LAT-		PD+ / LAT-	
	N	%	N	%	N	%
Assembler population	11/22	50%	13/22	59.1%	6/22	27.3%
EQCOTESST	-	37.8%	-	48.6%	-	17.3%

4.2.3 Assemblers' perceptions of job rotation

Table 4-5 summarizes the assemblers' perceptions of job rotation. The vast majority of them said they were ready to rotate and thought that this form of organization was realistic for the company. A majority also thought that job rotation was good for health, reduced monotony, and made the work more interesting. However, they did express some reservations: most of them thought that job rotation could reduce quality, and a large proportion of the assemblers at stations 3 and 4 believed that job rotation would be a source of stress.

Table 4-5: Opinions of job rotation among assemblers (n=22) who answered YES to the question

	TOTAL	Station 1	Station 2	Station 3	Station 4
Ready to do job rotation	18	2	3	9	4
Job rotation feasible in the plant	22	3	3	10	6
Job rotation good for health	18	3	3	8	4
Job rotation bad for health	4	0	0	2	2
Job rotation reduces monotony	18	3	3	8	4
Job rotation results in problems with quality	17	3	2	7	5
Job rotation is a source of stress	12	0	0	7	5
Job rotation makes the work more interesting	17	3	3	7	4

4.3 Analyses prior to job rotation

4.3.1 Rotation units

To begin the analysis, the work cycles at stations 1 and 2 were divided into the main stages of production. Seven stages were identified for each station, but they varied in length from 3 hours to 12 hours for station 1 and from 2 hours to 11 hours for station 2 (see Table 4-6). We also identified rotation units for stations 3 and 4 (tables 4-7 and 4-8), specifically, 16 rotation units for station 3 and 7 units for station 4. We analyzed the learning difficulties and risk factors for each of these 37 stages in the work.

Table 4-6: Brief description of stages at stations 1 and 2

Stage	Prescribed duration[1]	Tasks performed during this stage
Station 1		
1. Prepare work zone and installation of sills	3 h	Preparing jig to receive various parts of cockpit. Assembling three sections of sill together (to make one part), from front to back
2. Install right and left skins	12 h	Fitting, trimming, and assembling skins to prepare them for placement along sill, back-and-forthing to obtain proper fit
3. Prepare and install WEB 280 panels and put canopy in place	4 h	Preparing canopy, installing it on jig and on WEB 280 panels. Pre-drilling, marking, and assembling rear panels, and riveting by a pair of workers
4. Drill holes in windshield	5 h	Handling and installing drilling templates (4 pieces). Drilling and countersinking holes in nut plates
5. Install nut plates	11 h	Positioning and riveting (squeezing) nut plates (window supports)
6. Install splices on WEB 280 panels	5 h	Assembling splices inside and outside WEB 280 panels, preassembling certain parts on bench
7. Prepare and install three studs	7 h	Assembling three window studs, measuring/fitting and inserting sheets of metal
Station 2		
1. Install cockpit and countersink sill	6 h	Moving and installing cockpit on jig, countersinking sill
2. Rivet sill and frames	5 h 30	Putting fasteners in place (rivets, sealant) and riveting by a pair of workers
3. Position liquid shims	2 h	Inserting liquid shims, drying
4. Rivet machined parts	6 h	Assembling machined parts (lateral bracing for cockpit).
5. Install brackets on sill, in lower section inside	7 h	Assembling various parts in lower section of cockpit and on sill
6. Prepare and install (close) spaces of upper section inside *(close out)*	10 h	Inspecting and cleaning confined spaces, approval by inspector, covering and closing out zones by assembling various parts
7. Install small parts *(brackets)* in upper and rear sections, inside and outside	11 h	Assembling parts on WEB 280 panels and upper inside sections of cockpit

[1]: approximation obtained from the assembly specifications and representing an average for the two aircraft models assembled at these stations.

Table 4-7: Brief description of stages at station 3

Stage	Prescribed duration[1]	Tasks performed during this stage
1. Receive and install jig	7 h 30	Moving two parts of cockpit that have come from preceding stations and attaching them onto jig with fasteners
2. Install lifting eyebolts	2 X 45 min	Installing two lifting eyebolts on each side of cockpit. Drilling holes, fitting lifting eyebolts so they are at the right height
3. Saw rear section (trimming)	2 h 30	Sawing rear section of cockpit using a saw secured to jig. Activating saw and visually controlling the process
4. Install splices on stringers	2 X 13 h 45	Temporarily installing splices on stringers to fit splices on cockpit frames. Drilling holes of successive sizes, fitting and riveting small parts
5. Fit and drill skins	2 X 8 h 30	Preparing skins: trimming, drilling straps (long parts) and skins, installing several brackets before assembling skins
6. Countersink and rivet skins	2 X 18 h 45	Countersinking and riveting upper part of cockpit (inside). Assembling lower skins, countersinking, and riveting
7. Install ice detectors and pitot tubes	8 h 30	Installing detectors and pitot tubes above and below Positioning the templates so they are level and fitting them appropriately, drilling holes, and recording pertinent measures
8. Install brackets inside access hole	2 X 10 h 15	Assembling around ten brackets and clips on each side inside access hole
9. Install brackets inside	Not specified	Assembling parts above, in front and back, installing a total of around ten splices on and inside cockpit, drilling and riveting
10. Prefit guitar parts	4 h 15	Fitting and drilling so-called guitar parts
11. Prefit castings	Not specified	Drilling six holes. Installing helicoils in order to insert screws into part
12. Install door studs	23 h 45	Installing studs, drilling and positioning stud
13. Rivet guitars	Not specified	Riveting guitars
14. Rivet castings	7 h 15	Riveting studs using Hi-Lites
15. Jeppesen box	7 h 15	Assembling a plate (Jeppesen box) that reinforces internal structure of cockpit with brackets inside
16. Install rear brackets and WSIs	Not specified	Installing three WSIs and four small brackets in back of cockpit

[1]: approximation obtained from the assembly specifications and representing an average for the two aircraft models assembled at these stations.

Table 4-8: Brief description of stages at station 4

Stage	Prescribed duration[1]	Tasks performed during this stage
1. Receive, drill skins and install brackets	2 X 17 h	Receiving cockpit, attaching skins and butterfly parts. Marking layouts, positioning brackets, trimming and drilling parts. Assembling skins on both sides simultaneously; the same work is performed on both sides to join skins in middle
2. Countersink and rivet skins	2 X 12 h	Countersinking holes. Positioning of rivets, then riveting by a pair of workers. Verifying dimples after riveting, removing rivets and injecting liquid shims as needed. Both skins must be assembled simultaneously
3. Install doublers and big parts	2 X 3 h	Installing jig, positioning drilling plates, drilling, installing doublers. Fitting the opening, drilling to right diameter, countersinking, then riveting
4. Install drilling templates on right and left sides of inside of cockpit	2 X 5 h	Fitting and installing drilling templates, starting at centre, then locating and positioning templates on right and left sides. To finish, drilling and installing brackets, nut plates, and rivets
5. Install "potato box"	Not specified	Assembling both sides of box. Drilling rear panel, fitting and installing box (riveting)
6. Install bullheads inside cockpit	7 h 15	Assembling central and lateral studs to secure cockpit to canopy; this requires installing drilling templates and assembling
7. Install brackets inside cockpit	11 h	Installing and riveting brackets inside cockpit and on rear panels

[1] *approximation obtained from the assembly specifications and representing an average for the two aircraft models assembled at these stations.*

4.3.2 Difficulties in the learning process

Table 4-9 shows the difficulties in the learning process for the 37 rotation units in terms of the three dimensions retained: basic skills, fitting, and sequencing. We observed a considerable amount of variation and that not all tasks were difficult. Interesting potential for job rotation therefore existed, with the possibility of alternating between more and less complex operations.

Table 4-9: Overview of complexity classification for 37 stages in department's operations

Dimensions of learning		Station 1 (n=7)	Station 2 (n=7)	Station3 (n=16)	Station 4 (n=7)	Total (n=37)
Basic skills	Level 1 - Easy	-	-	5	-	5
	Level 2 - Intermediate	3	5	6	3	17
	Level 3 - Difficult	4	2	5	4	15
Fitting	Level 1 - Easy	1	3	9	1	14
	Level 2 - Intermediate	2	2	6	4	14
	Level 3 - Difficult	4	2	1	2	9
Sequencing	Level 1 - Easy	5	2	6	3	16
	Level 2 - Intermediate	1	2	5	3	11
	Level 3 - Difficult	1	3	5	1	10

4.3.2.1 Impact of the high quality requirements on the learning process and versatility

In the aerospace industry, and particularly at the cockpit assembly stations where the project was carried out, quality emerged as a major concern. The requirements in this regard – regulatory requirements to ensure passenger safety and meet customer requirements – demand constant quality control at all levels of aircraft production.

Having to anticipate the potential consequences of quality problems places added stress on the assemblers. They perform numerous additional operations to ensure that parts are protected (e.g. physically protected with adhesive tapes or plates) and they are continually exercising caution, handling each assembly meticulously. In fact, it is difficult to develop automatic responses because the fitting processes always vary and the assemblers must remain vigilant at all times.

We observed these quality requirements as having several impacts, both on the assemblers' health and on the actual organization of production:

- On the organization of the work: quality problems can suddenly rally many stakeholders, require disassembling the work, and necessitate overtime. This reduces the company's ability to plan because it essentially functions reactively at such times. Moreover, to try to reduce or at least control the risk of error, the assemblers are assigned to the same tasks and thus become specialized: this in turn means they are not very versatile or mobile when it comes to having to replace others;
- On the assemblers' health: we observed impacts on both their physical and psychological health. The hyperspecialization sought as a means of minimizing the risk of errors, but also the fear of performing the work badly, has an impact on the onset of musculoskeletal disorders, as it is a factor in overexposure (repetitive movements, efforts, vibrations). In addition, the fear of making errors, the potential costs associated with these errors, the memory of past bad experiences, and team pressure are all psychosocial risk factors for the assemblers.

The identification of a quality problem leads to a series of both administrative and operational procedures in order to correct it. Each quality problem has to be recorded and reported to the quality assurance department in the form of a non-conformance report (NCR). This involves:

- *describing the problem*: which assembler was responsible, the nature and scope of the problem, when it occurred and why;
- *identifying the means of resolving it*: by the quality assurance officer or the engineering department;
- *recording and describing the solution retained*: what was the solution, who did the repairs (assemblers, coaches, subcontractors, etc.);
- *closing the file*: when the defect has been corrected.

As all the NCRs for a given aircraft must be passed on to the customer, it must be possible to track and trace any problems that have arisen and the means used to make the appropriate repairs. These traceability procedures ensure product conformance and are designed to increase aircraft reliability and safety. Paradoxically, they also exert a form of pressure on the assemblers. At all times, it is possible to identify the person "responsible" for such-and-such a problem because assemblers always bear responsibility and have to be accountable.

Analysis of the interviews on the learning process revealed that quality is of great concern to the assemblers, with 19 of them referring to it in one way or another. Table 4-10 provides an overview of the points of greatest concern to them. A total of 248 excerpts related to the quality issue were identified in the interviews (any one excerpt might touch on several themes).

The risk of error was the most frequently mentioned theme, accounting for 63% of the excerpts identified (n=155 excerpts). These risks were also mentioned by all the assemblers interviewed. Four sub-themes were raised under the risk-of-error theme:

- the potentially negative consequences of assembly operations: "You have to be careful when you're drilling not to damage the skin"; "It's a perfect place to make beautiful errors."
- the constant vigilance and foresight required of the assemblers to avoid, control, or reduce risks: "(…), you have to be conscientious (one rivet at a time)"; "You have to be vigilant; you have to really pay attention";
- the physical protections that the assemblers put in place to safeguard their work environment: "We apply a lot of protective tape"; "(…) you have to really protect the skin properly to avoid damaging it";
- fears often related to the assemblers' past experiences: "(…), everybody is afraid of that place"; "I'm not comfortable. I'm afraid of making marks, of slipping up."

Table 4-10: Distribution of excerpts by quality-related sub-themes

Quality-related sub-themes (N=248 excerpts)	Number of excerpts	Number of assemblers reporting the sub-theme	Maximum number of excerpts/assembler
Risks of error (potential)	155 (63%)	19	19
Potential consequences	98 (63%)	19	15
Caution, foresight	78 (50%)	17	12
Physical protection of assemblies	19 (12%)	11	3
Fears	13 (8%)	5	4
Requirements and demands	103 (42%)	16	20
Precision	69 (67%)	14	15
Fitting	28 (27%)	10	8
Required tolerances	25 (24%)	10	4
Actual errors	77 (31%)	17	13
Past events involving damage	49 (64%)	17	8
Techniques for identifying errors	27 (35%)	13	7
Non-conformance reports	11 (14%)	8	3
Control	63 (25%)	14	13
Verification/inspection	42 (67%)	12	9
Administrative procedure	28 (44%)	10	7

Another common theme important to the assemblers was the requirements and demands imposed on them. They described the normative requirements – or prescriptions – and the working methods they had to adopt to meet the quality requirements. This issue of normative requirements came up in 42% of the excerpts identified (n=103 excerpts) and was raised by 16 of the 19 assemblers interviewed. They talked about three points in particular:

- the precision required to be meticulous and exact: “Each hole is really calculated precisely"; "You really have to use the right tool to get the bracket right or to do a good job (…)";
- the fitting techniques required to build the assemblies: they reported the techniques used and the absence of locator markings for these fitting operations: “the difficulty is to fit it in the right place”; “We have to do a lot of layouts by hand”;
- the tolerances required, which concern the margins or intervals allowed by the methods department for doing the assemblies: “(…), the tolerances were calculated too tight”; “we have a drawing, specifications, depending on the size of the hole (…).”

Lastly, two other main quality-related themes were raised in the interviews. The assemblers talked about their errors or their real quality problems, those that had actually happened, which had had an impact on them and remained engraved in their memory. This theme concerned nearly all the assemblers (17 out of 19) and came up in nearly one-third of the quality-related excerpts (n=77). In this case, they indicated which clues allowed them to identify errors, visual, tactile or other (“You really have to pay close attention to avoid making scratches and toolmarks”); they cited past instances of damage, those that had had an impact on them (“I’ve also scrapped things in my work, but not that many"), or again the NCR (“(…), a part was damaged or there was a non-conformance report (NCR)”). Lastly, the aspect of control associated with quality came up in one-quarter of the excerpts identified (n=63 excerpts). In this case, the assemblers mentioned their personal initiatives or the control procedures carried out by the quality assurance officers ("We do our inspection”; “It’s because the aircraft was inspected and the inspector found some irregularities”) and the administrative procedures and other actions taken by the quality assurance department (“I have to go find the quality assurance officer, (…)”).

Our analysis of the interviews on the learning process proved highly instructive regarding quality and its impact on the assembly work. It can be broken down into numerous elements and affected nearly all spheres of the assemblers’ work activity. It provided information on the know-how used (precision, caution, foresight), on the work team and relations with the other departments (control), and on the emotional aspects of the work (fears). The different findings of these analyses provided a picture of the quality dimension, which forms an integral part of the assemblers’ overall work activity: not only does it guide them, but more importantly it obliges them to make compromises.

4.3.3 Risk factors

As explained earlier, we are unable to present the risk factors associated with the 14 rotation units at stations 1 and 2 because the data were lost. However, the data on the team leaders’ perceptions showed certain stages in the assembly sequence to be more or less difficult: there was therefore the possibility of alternating the risky stages with the less risky.

The results obtained from the analysis of risk factors at stations 3 and 4 are summarized in tables 4-11 to 4-13. Immediately apparent to us was the high level of exposure at these two stations, with the postural constraints and exposure to vibrations standing out in particular. More specifically, 20 stages at these stations required adopting postures generally rated as difficult: they might involve work that requires crawling on a platform or a small stepladder, standing unstably on one leg, or crouching or kneeling down. In terms of posture, over half of the stages (13/23) were deemed difficult for the upper extremities; this translated into work performed with arms raised or extended away from the body. These postural constraints could be aggravated by the presence of small spaces for nearly half of the stages (12/23). In terms of efforts and vibrations, the impact of vibrations appeared to be the most significant; 17 stages were rated as difficult (exposure to vibrations during more than two-thirds of the stage). However, the efforts were also rated as difficult for one stage (efforts > 5), while nine other stages were rated at between three and five. Work on multilayer structures was performed in more than half of the stages (13/23). For 10 stages, parts were located behind the work zone, which meant having to carefully control the efforts made and grips on the tools. As reported to us by our contact persons, the level of physical risks was very high at stations 3 and 4. There appeared to be less potential for alternating between risky and less risky stages than at the preceding stations, but the possibility did still exist.

Table 4-11: Risk factor results for station 3

Stage	Postures				Effort/vibrations				
	General	Back	Upper extremities	Aggravating factors	Vibrations	Combination Upper extremities and vibrations	Use of tools	Efforts	Aggravating factors
Stage 1- station 3	3	1	-		1	1	1	1	-
Stage 2 - station 3	2	1	3	-	2	2	1	2	ML
Stage 3 - station 3	3	1	-	-	1	1	1	1	-
Stage 4 - station 3	3	1	3		3	3	3	1	HPR, ML
Stage 5 - station 3	3	1	1	-	3	1	3	1	HPR, ML
Stage 6 - station 3	3	-	3	-	3	3	3	3	HPR, ML
Stage 7 - station 3	3	3	3	-	2	2	2	1	ML
Stage 8 - station 3	3	3	3	CS, PV	3	3	2	2	ML
Stage 9 - station 3	3	3	3	CS	2	2	3	1	ML
Stage 10 - station 3	3	1	1	-	3	1	3	2	HPR
Stage 11 - station 3	3	-	2	CS, PV	3	2	1	1	HPR, ML
Stage 12 - station 3	3	-	3	CS	3	3	3	2	HPR
Stage 13 - station 3	3	3	3	CS	3	3	1	2	-
Stage 14 - station 3	3	-	3	CS, PV	3	3	1	1	HPR
Stage 15 - station 3	3	3	3	-	3	3	2	1	-
Stage 16 - station 3	3	-	-	CS	3	-	-	-	ML

CS: confined spaces; PV: Poor visibility; HRP: hidden rear part; ML: multilayer.
Levels of presence of risk factors: 3 = **high**; 2 = **intermediate**; 1 = **low.**

Table 4-12: Risk factor results for station 4

Étape	**Postures**				**Effort/vibrations**				
	General	General	General	General	Vibrations	Combination Upper extremities and vibrations	Use of tools	Efforts	Aggravating factors
Stage 1- station 4	3	-	1	CS	3	1	3	2	HPR, ML
Stage 2 - station 4	-	3	3		3	3	3	-	ML
Stage 3 - station 4	1	1	-	-	3	3	1	2	HPR, ML
Stage 4 - station 4	3	3	3	CS	3	3	2	2	-
Stage 5 - station 4	3	1	1	CS	1	1	1	1	-
Stage 6 - station 4	3	3	3	CS, PV	3	3	1	1	-
Stage 7 - station 43	3	-	1	CS, PV	3	1	2	2	HPR, ML

CS: confined spaces; PV: Poor visibility; HRP: hidden rear part; ML: multilayer.
Levels of presence of risk factors: 3 = **high**; 2 = **intermediate**; 1 = **low.**

Table 4-13: Combined results of risk factor analysis for stations 3 and 4

Variables		Level of difficulty	Station 3 (n=16)	Station 4 (n=7)	Total number of stages at stations 3 and 4 (n=23)
Posture	General	Level 1 – Easy / - 30% of the time	-	1	1
		Level 2 – Moderate / < 30% to 50% > of the time	1	-	1
		Level 3 – Difficult + 50% of the time	15	5	20
	Back	Level 1 – Easy / - 30% of the time	6	2	8
		Level 2 – Moderate / < 30% to 50% > of the time	-	-	-
		Level 3 – Difficult + 50% of the time	5	3	8
	Upper extremities	Level 1 – Easy / - 30% of the time	2	3	5
		Level 2 – Moderate / < 30% to 50% > of the time	1	-	1
		Level 3 – Difficult + 50% of the time	10	3	13
Efforts - vibrations	Vibrations	Level 1 – Easy / – 33% of the time	2	1	3
		Level 2 – Moderate / < 33% to 66% > of the time	3	-	3
		Level 3 – Difficult / + 66% of the time	11	6	17
	Efforts	Level 1 – Easy / rated from 0 to 2	9	2	11
		Level 2 – Moderate / rated from 3 to 5	5	4	9
		Level 3 – Difficult / rated > 5	1	-	1
	Combination effort/vibrations	Level 1 - Easy	4	3	7
		Level 2 - Moderate	4	-	4
		Level 3 - Difficult	7	4	11
	Use of tools	Level 1 – Easy / - 200 operations[1]	6	3	9
		Level 2 – Moderate / ≥ 200-500 < operations	3	2	5
		Level 3 – Difficult / > 500 operations	6	2	8

4.3.3.1 Heavy physical demands

The cockpit assembly department stands out from the plant's other departments because of its heavy physical demands. The very nature of the structures assembled increases the demands involved in the assembly work, which includes work in small spaces (holes, spaces below or above) where the operators have to perform basic assembly operations. This means having to adopt risky postures – exaggerated stretching and twisting, working above shoulder height, crouching or kneeling – as well as remaining in static positions for long periods of time (fig. 4-1).

a. b. and c. Cramped spaces involving postural constraints at stations 3 and 4; d: Poor visbility at station2;
e. Demanding work for upper extremities at station 1.

Figure 4-1: Examples of postural constraints

The installation of various parts requires the use of many vibrating tools (drill, riveter, countersinker) such that the assemblers are exposed to vibrations during various stages of assembly. In addition, efforts that may involve either specific body parts to operate tools or the whole body to handle the drilling templates or parts, compound the other physical risk factors. One particular type of effort often mentioned and observed – that we could call a "restrained effort" – consists of the assembler having to make a sometimes substantial effort to drill a part, but without "denting" or losing control of the momentum so as to avoid damaging hidden rear parts. Lastly, other factors that add to the complexity of the assemblers' work or make it more demanding include, among other things, working in poorly lit areas, working on fragile or soft parts, and the presence of hidden rear parts.

The operators assemble parts of varying sizes and shapes to make up the aircraft structures. To do so, they perform the operations usually associated with assembly work: drilling holes in the various layers of the parts, countersinking holes so that the fasteners can be properly inserted, and riveting the rivets (flattening the rivets). Another part of their work involves doing layouts and fitting the parts so that the assemblies respect the tolerances specified in the engineering plans. This might mean trimming to make parts thinner, adding sheets of metal to fill spaces and obtain the right thickness, or transferring drilling patterns onto parts. In addition to these two major sequences of operations – drilling-countersinking-riveting and fitting – a series of other operations are carried out: controlling and verifying, cleaning the structures to remove assembly debris, performing administrative tasks to complete the aircraft documents, or applying the various substances needed to ensure the adhesion or electrical insulation of parts. This brief list does not describe all the operations performed by the assemblers, but provides an accurate picture of their main tasks.

4.4 Activities prior to implementation of job rotation

4.4.1 Potential changes for preventing risks

Prior to implementing job rotation, it was decided to try to reduce risks at the source. Potential changes were identified for this purpose (Table 4-14). They involved, in particular, the most physically demanding stages or those for which the learning process was deemed difficult (e.g. a stage that few assemblers were familiar with or agreed to carry out). The purpose of the changes was therefore to reduce the physical risk factors and improve the learning opportunities.

Table 4-14: Potential changes

Problematic phases or tasks	Difficulties and risks	Changes retained
Assembling splices during stage 6 at station 1	Jig: adopting constraining postures (arms upward, twisting positions); no hole located: risks of major errors; difficult access, little visibility	Carry out this stage at station 2 to facilitate access (less cumbersome jig)
Trimming skins during stage 2 at station 1	Constraining postures to trim excess material; applying major force to install/remove parts (back-and-forthing); high risk of error	Reduce quantity of excess material during manufacture of skins to reduce time and effort needed for trimming
Drilling skins during stage 2 at station 1	Applying major force; constraining postures.	Manufacture a new drilling template adapted to shapes of parts
Other problems: inadequate lighting, defective support stands for tools.		Purchase new lights, install a shelf

4.4.2 Determining job rotation assignments

We asked a working group to plan a job rotation scenario for the assemblers at stations 1 and 2, taking into account the 14 rotation units identified. Table 4-15 summarizes the assignments planned for each assembler for two job rotation cycles, with each cycle involving 10 cockpits.

Table 4-15: Planned assignments for job rotation trial 1 for first 20 cockpits

Assembler	1st job rotation cycle (1st to 10th cockpit)	2nd job rotation cycle (11th to 20th cockpit)
1. Experienced – coach	**A** Stage 3 – station 2 Stage 4 – station 2 Stage 7 – station 2 (half) **Coaching**	**E** Stage 6 – station 1 Stage 7 – station 1 **Coaching**
2. New recruit	**B** Stage 1 – station 2 Stage 2 – station 2 Stage 5 – station 2 (half)	**A** Stage 3 – station 2 Stage 4 – station 2 Stage 7 – station 2 (half)
3. Experienced – coach	**C** Stage 1 – station 1 Stage 2 – station 1 Stage 3 – station 1 **Coaching**	**B** Stage 1 – station 2 Stage 2 – station 2 Stage 5 – station 2 (half)
4. Inexperienced	**D** Stage 4 – station 1 Stage 5 – station 1	**G** Stage 6 – station 2 (evening)
5. Inexperienced	**E** Stage 6 – station 1 Stage 7 – station 1	**C** Stage 1 – station 1 Stage 2 – station 1 Stage 3 – station 1
6. Experienced – coach – team leader	**F** Stage 5 – station 2 (half) Stage 7 – station 2 (half) **Coaching**	**F** Stage 5 – station 2 (half) Stage 7 – station 2 (half) **Coaching**
7. Inexperienced	**G** Stage 6 – station 2 (evening)	**D** Stage 4 – station 1 Stage 5 – station 1

A job rotation plan for trial 1 was proposed for the first 20 cockpits. Stages were combined to form blocks of around three days' work per assembler to respect the production cycle at these stations. For the first ten cockpits, the work performed resembled that usually performed by the assemblers. The job rotations were to take place starting at the eleventh cockpit (the first ten cockpits served as the baseline for monitoring purposes). We noticed that the assignment blocks often included subsequent stages to maintain the production logic in the assemblers' eyes; also, some stages were divided in two. It was planned that there would be seven assemblers in total for this trial, three of whom would have coaching tasks.

During the group work, we paid close attention to the selection criteria used by the participants to define the job rotation scenarios. The first criterion applied to choose the stages was related to the stage's degree of complexity, depending on the assembler's experience. In other words, the job rotation scenarios were determined on the basis of the difficulties in the learning process, with this criterion taking precedence over alternating between risky and less risky stages. Other criteria were also applied, such as maintaining the production logic, because certain stages could not be dissociated from each other. Efforts were always made to keep an experienced assembler or coach close to an inexperienced assembler.

4.5 Conducting and monitoring the job rotation trials

4.5.1 Trial 1

In December 2012, it was decided to proceed with implementing a first job rotation trial as planned by the working group. The researchers monitored this trial over three days. While the researchers observed that the requested changes had not always been made, the organization – management, union, and workers – still wanted to go ahead with the implementation, insisting that the minimum conditions needed for the trial to succeed were in place (e.g. the presence of a coach to train the new recruits).

4.5.1.1 Actual assignments

Our first observation was that the actual assignments differed from the planned assignments (Table 4-16). Also, since the time of the preliminary analyses (spring 2012), major changes had taken place in the assembler population at stations 1 and 2: there were many more new recruits and inexperienced workers, and overall, less expertise at the stations. This situation was attributable to several phenomena. First, during this period, the company obtained new contracts and several experienced workers were transferred to the new projects. Second, the cockpit production pace accelerated, going from four days to three. To offset the faster pace, new recruits were added, such that there were more inexperienced workers, including some with only a few days' experience. The implementation conditions needed were therefore not in place.

Table 4-16: Assembler assignments for trial 1

Assembler	Planned assignment	Day 1	Day 2	WKD	Day 3
Experienced – coach	<u>A</u> - **Coaching**	Cockpit -1	<u>A</u>, B	<u>A</u>, B	Absent
New recruit	B	Station 3	Station 3	Station 3	Station 3
Experienced – coach	<u>C - **Coaching**</u>	<u>Coaching</u>	<u>Coaching</u>	<u>C</u>	<u>C</u>
Inexperienced	D	C	C	C	C
Inexperienced	<u>E</u>	Cockpit -1	C, <u>E</u>	Station 3	Station 3
Experienced – coach – team leader	F - **Coaching**	Absent	Absent	Absent	Absent
Inexperienced	<u>G</u>	<u>G</u>	B	B	Do not know
New recruit	-	G	A	A, G	F
New recruit	-	E	C	Station 3	G
Experienced, temporary assignment	-	Team leader, coaching	Team leader, coaching	Team leader, coaching	Team leader, coaching
Experienced	-	Station 3	Coach	Coach	Absent

<u>Underlining</u>: planned assignments that coincided with observed assignments. -1 = before monitoring.

To illustrate this drop in expertise, we produced a variety of data for the whole department (Table 4-17). We observed a marked decline in the personnel's experience, with cumulative experience dropping from 23 to 12 years. Looking at the assemblers' expertise at the time of trial 1, we saw that the required number of assemblers was not attained. The ratio was six assemblers for the two stations, with one experienced assembler counting for one full worker, a coach not working full-time equating to 0.5, and an inexperienced worker, in terms of staff, counting for only a fraction of an experienced worker. Thus, taking into account the fact that there were many inexperienced workers, the optimal ratio of six assemblers was far from being attained.

Table 4-17: Expertise during trial 1

	Spring 2012	Trial 1, December 2012
Cumulative expertise in the department	23 years	12 years
Cumulative expertise in the plant	108 years	81 years
Seniority in the plant	From 13 to 23 years	A few days to 23 years

The fact of having a less experienced population caused difficulties in terms of the learning process, making it impossible to apply the planned assignments. To describe this phenomenon, we documented the coach/assembler interactions (Table 4-18). The difficulties in the learning process were indeed real; we observed a total of 117 coach/assembler interactions, 106 of which were related to the learning process. The cumulative duration of these interactions was 467 minutes, which was a significant amount of time and explained the delays in production. It appeared that 96 interactions involved two assemblers: one assembler who was in the process of learning and one coach. Ten other interactions involved a third person such as another assembler, another team leader, or the supervisor. A total of six individuals acted as coaches, but the vast majority of the interactions were carried out by three coaches (103/106); the three other coaches interacted only once each.

Table 4-18: Coach/assembler interactions during trial 1

Type of interaction	Number	Total duration	Average duration	Median
Teaching/learning	106	467 min	4 min 23 s	2 min
Quality	7	69 min	9 min 51 s	8 min
Critical situation	3	77 min	25 min 40 s	30 min
Other	1	4	-	-
TOTAL	**117**	**617 min**	**5 min 16 s**	**2 min**

It was further apparent that the requested changes had not yet been implemented. During this trial period, major quality problems were observed, primarily with peeling paint. These quality problems disrupted production because they mobilized assemblers, the supervisor, and engineering or quality assurance representatives. Production was thus compromised. Whereas four cockpits should have been produced at the two stations during this period, in actual fact only one cockpit was.

4.5.2 Trial 2

After discussion with the follow-up committee, another date was proposed for a second trial under more suitable conditions. This trial took place in March 2013. Again, the actual assignments differed from the planned assignments (Table 4-19). As described in the following paragraphs, the team leader could not really plan the assignments; he managed and adjusted them in constant response to unforeseen variables that arose, mainly quality problems and unforeseen tasks.

Table 4-19: Assembler assignments for trial 2

Assembler	Planned assignment	Day 1	Day 2	WKD	Day 3	Day 4	Day 5
Experienced	A - **Coaching**	Cockpit -1	Cockpit -1	A, B	B Cockpit -1	B, F	B, E
New recruit	B	Cockpit -1	A, B	A	B	B, C, F	G
Experienced	F	Cockpit -1	Cockpit -1	-	Cockpit -1 F	E	E
Experienced	H[1]	Cockpit -1	Cockpit -1	-	C	C, D	E
Experienced	C - **Coaching**	Absent	Absent	Absent	Absent	Absent	Absent
Inexperienced (evening)	E	C	C	-	Absent	C, E	Do not know
Inexperienced (evening)	G	Cockpit -1 (day)	C	-	F	E	Do not know
Inexperienced (evening)	D	Cockpit -1	C	-	C, F	D, E	Do not know
Team leader	Coaching, managing team and production	Team leader, quality	Team leader, quality	-	Team leader, quality	Team leader, quality	Absent

Underlining: planned assignments that coincided with observed assignments; [1]: this assignment should have been determined on the basis of a faster cycle time. -1 = before monitoring.

Regarding the assemblers on the shop floor, the situation differed from that in trial 1. Table 4-20 shows the changes in the assembler population at stations 1 and 2 during the project. As was seen earlier, during trial 1 there were many inexperienced workers and the overall level of expertise was greatly diminished. The situation was different during trial 2; there was a high level of expertise on the day shift, but there was now one evening shift with three inexperienced workers subject to less supervision. This had repercussions on the day shift as observed during our monitoring of trial 2.

Given their minimal seniority, the evening-shift assemblers made errors, which then had to be corrected by the day-shift team. In order to limit errors and the consequent work overload for the next day shift, the evening shift team was given the easiest operations. This in turn intensified the work for the day-shift workers, who had to focus their energies on the most difficult stages. During monitoring, we observed major quality problems; the “regular” problems were compounded by problems stemming from the inexperience of the evening-shift assemblers. The company’s data showed that the quality problems due to human error for stations 1 and 2 totalled n=14 for the year 2012 compared to n=23 for the period from January to March 2013 alone. The team leader therefore had to manage assignments largely in response to quality problems.

Table 4-20: Changes in assembler population at stations 1 and 2

Conditions	Spring 2012	Trial 1, December 2012	Trial 2, March 2013
Level of expertise in the department	High, stable 23 years	Reduced 12 years	High, day shift: 20.5 years Low, evening shift: 1.5 years
Number of assemblers	6 to 7 on average	5 to 8	7 to 8
Cycle duration	4 to 6 days	3 to 4 days	3 to 4 days
Number of assemblers on the evening shift	0	1	3

An unforeseen situation also prevailed during our monitoring of trial 2 and hindered the application of the planned assignments. There were several assembled cockpits on the floor for which the customer had requested changes. Assemblers from stations 1 and 2 were assigned to making these changes, which in turn hampered production of the new cockpits. Whereas four cockpits should have been assembled during our monitoring time, only one cockpit was in fact completed at station 1 and only half a cockpit at station 2.

The prevailing situation led us to describe the team leader's work, as it became clear that he did not have the organizational conditions required to plan the assignments according to the job rotation scenario proposed by the working group. The team leader has multiple roles: he has responsibilities related to monitoring production, which implies interactions with representatives of the quality assurance and methods departments. He also has to rectify quality problems on occasion, which sometimes requires using highly specialized techniques that necessitate company and worker certification. From time to time, he helps with off-line assembly at workstations other than his own. He also has to perform various tasks at the stations he is responsible for: assisting with riveting (working in pairs), coaching assemblers on new tasks, administrative tasks (meetings, monitoring production, monitoring quality problems, etc.). In addition, he has basic tasks of managing and motivating the team of assemblers and overseeing production.

As we did in trial 1, we also documented coach/inexperienced worker interactions during our monitoring of trial 2. The results are shown in Table 4-21. Interactions were observed, but were much less frequent than during trial 1, a fact attributable to the presence of a more experienced workforce during the day shift. At the time of trial 2, the requested changes had still not been implemented.

Table 4-21: Coach/assembler interactions during trial 2

Type of interaction	Number	Total duration	Average duration	Median
Teaching/learning	19	53 min	2 min 47 s	2 min
Quality	5	54 min	10 min 48 s	8 min
TOTAL	**24**	**107 min**	**4 min 28 s**	**3 min**

Table 4-22 summarizes the conditions that were present during the two trials and that caused difficulties in implementing the planned job rotation.

Table 4-22: Conditions observed during the two implementation trials

Conditions during trial 1	Conditions during trial 2
Three major changes not made	Three major changes not made
Unstable and very inexperienced workforce	Unstable and inexperienced workforce
Recent acceleration in work pace	Injured workers (absent and on temporary assignment)
Major quality problems	Additional workers added to evening shift, little supervision
	Major difference in levels of expertise between day and evening shifts
	Changes requested by customer on already-finished cockpits

4.6 Actions taken by the company

Given the data collected during the first two trials, the company, which was aware of the conditions needed to foster versatility, became more actively involved in the project, and the role of the research team became more that of project advisor and support. A working group (in-house ergonomist, representatives of the training department, supervisor, head of assembly, and the research team) held a series of meetings beginning in May 2013, and an action plan was drawn up by the team leader, training specialist, and in-house ergonomist to improve the new recruits' learning process and integration. This plan included medium- and long-term objectives. In the medium term, five main steps were retained:

- training two coaches (2 days): what information to pass on and how, etc.;
- developing pedagogical material to support the coaches in teaching/learning situations with the assemblers: documents for each rotation unit identified at stations 1 and 2;
- identifying training scenarios to guide the coaches: using a participatory method, reflecting on the deployment of versatile workers at stations 1 and 2;
- supporting and monitoring the learning process at the workstations (coach/assembler interactions).
- implementing a job rotation trial.

In the longer term, it was planned to deploy the job rotation and versatility project throughout the department under study, to identify indicators for use in monitoring project performance, to develop a training course on specific technical skills (so-called level two), and to offer it to all the assemblers in the department. Concurrently with these discussions on the main steps in the action plan, a number of conditions that had to be respected were discussed repeatedly during meetings of the working group. The purpose of implementing these conditions was to support this change project. The conditions included defining the coach/assembler ratio (one coach for a maximum of two or three assemblers), stabilizing the personnel in the department (limiting interdepartmental personnel movements), and "protecting" the department (limiting major quality errors that could destabilize production).

5. DISCUSSION

The aim of this study was to identify the prerequisite conditions for implementing job rotation in an aircraft assembler population working at a company in the aerospace industry. The company specifically wanted to prevent the MSDs that affect this population of workers, who – while not very old (± 40 years) – had performed this work for over 15 years on average. The results obtained regarding pain and MSDs were comparable to those in other studies conducted in this sector (Nogueire et *al.*, 2012; Menegon and Fischer, 2012). An underlying objective was to develop the assemblers' versatility so as to give the company greater flexibility in assigning personnel. This adaptive capacity had become an organizational priority and was cited as a solution for managing absenteeism and meeting ad hoc demands in various assembly departments to keep pace with fluctuations/unforeseen events in production. A window of opportunity for developing this adaptive capacity presented itself with the recent hiring of assemblers and the upcoming production of a new model of aircraft that would involve competent resources.

Four themes are covered in this discussion. It begins with a look at the methodological issues related to the analysis of the job of assemblers (sub-section 5.1). We will attempt to show that the main literature on the job rotation question neglects to explore dimensions that proved critical in our study and that in fact obliged us to innovate in our process and our data collection tools. Then, beyond the physical demands – which incidentally are well recognized by the stakeholders in the company – we will discuss the issues of the learning process and assembler expertise, both necessary to meet the high quality standards of the industry (sub-section 5.2). We will argue that the high quality requirements are a driving force behind the need to develop versatility among the assemblers and to implement job rotation. This will be followed by an assessment of the conditions that were identified and appeared essential to implementing job rotation (sub-section 5.3). These include aspects of training deriving logically from the preceding point. The focus will be on the organizational issues posed by the implementation of these conditions. Lastly, given the complexity of the problem in which numerous factors interact – including psychosocial aspects related to the ideas and beliefs of various stakeholders – we will emphasize the fact that job rotation cannot be implemented in an improvisational manner, but rather must be tackled as a structured organizational project (sub-section 5.4).

5.1 Methodological issues and need for innovations

In most of the literature consulted in preparing for this research project, job rotation was presented as the alternation between different, successive jobs, a sort of alternative to scientific management (also called Taylorism). Characteristically in Taylorian organization, work is divided up and simplified, with the predominant configuration being characterized by the job/person/task trio. The cycles last from a few seconds to a few minutes. A job rotation project therefore consists of analyzing a certain number of these jobs – including the tasks involved – and defining a strategy that specifies how the workers will move from one job to the other, most of which are located in physically distinct areas. This reality is very different from that observed in the company that requested our study. The differences obliged us to adapt both our process and our data collection tools, mainly at three levels:

Jobs with unclear boundaries: The department under study was configured in such a way that only four jobs (or stations) were initially available for the job rotation (see Table 2-1). Several assemblers simultaneously assembled different sections of the cockpit and were assigned to one or another of these stations. The first interviews with the assemblers, combined with our preliminary observations of the assembly activity, convinced us that we could no longer think in terms of jobs – but rather in terms of stages of assembly – which thus became the "rotation units" between which job rotation could take place. Seemingly insignificant, this restructuring in fact obliged us to follow a certain logic that was not always readily grasped by all our contact persons.

On the one hand, the distinction between the different possible assignments for job rotation was not physical in nature – a job whose boundaries could be clearly defined in order to form a clear picture – but rather an assembly sequence characterized by a beginning and an end that were sometimes only vaguely defined at the start of the project. Furthermore, some of the organization's stakeholders perceived all the assemblers as essentially doing the same thing, give or take a few minor details, and therefore saw no relevance in this distinction. Lastly, 37 rotation units were identified: rarely can job rotation include this many possibilities, which was one of the reasons why we carried out our trials on fewer than half of the units (n=14). And such a large number of "jobs" to be performed further complicated the presentation of our analyses, and consequently, the understanding and assimilation of the problem by the stakeholders. We therefore attempted to develop materials (see summary sheets in tables 3-1 and 3-2) compiling a range of information but in simple (e.g. strips indicating level of intensity) and visual (e.g. colour code, drawings) format. The idea was not to oversimplify but to make the complexity intelligible.

Cycles lasting days: This was the greatest difficulty we had to contend with throughout the project. While it was not easy to analyze the work activity carried out over such long cycles, it was mainly the risk factor dimension that was hard: overwhelming amounts of data were collected quickly. We were obliged to change our strategy after analyzing the first two stations. While this method yielded interesting results, it proved poorly suited to work involving long cycles and far too demanding in terms of analysis time[4]. For example, the continuous analysis of postures for five body regions meant viewing more than 100 hours of videotape five times.

The alternative method we developed did not allow for such a nuanced analysis, but offered a number of interesting advantages. First, it allowed us to triangulate our data – a form of internal validation – since several data collection tools were used. We were thus able to cross-verify the perceptions of several assemblers, but also to cross-verify their perceptions with our own observations and with the information contained in the assembly specifications. Even if we used essentially qualitative data collection, we have total confidence in the results obtained precisely because the cross-verification of the various data sources provided us with a coherent and convergent picture, one that was also validated by all the assemblers. Second, one irrefutable advantage was that of being in sink with the work: the risks were related to certain critical operations in the stage of assembly, which gave us a better understanding of the activity and opened doors more readily to possible changes. It was easier for the stakeholders to assimilate

[4] Only the PATH method (Buchholz, 1996) is better adapted to long cycles; it provided us with inspiration when we were developing our alternative method of risk assessment.

our data because they were able to see the connections with their daily work. By looking at what we called “aggravating factors”, it was also possible to establish links with the activity and gain a better grasp of certain risks. Thus, while the notion of effort was primarily examined from the perspective of maximum efforts, our analyses made it possible to identify so-called controlled (or restrained) efforts in which the assembler had to restrain his efforts so as not to damage parts behind or near the work area. Lastly, we also found empirically that the time spent with the assemblers during the individual interviews and the group validation meetings induced them to reflect on their work, to examine it with a critical eye, and to compare their viewpoints with those of their coworkers. We believe that the visual material developed to facilitate verbalization (photographs of the stages, postures) helped cultivate this awareness: without exception, the assemblers continually looked at the photos and referred to them regularly to support what they said. They did not hesitate to comment on, for example, the fact that a given assembler did not often perform such and such a stage of assembly (i.e. why was he chosen?), or that such and such a photo was not representative of the work they wanted to talk about.

Complex assembly work due to the high degree of variability: Anyone watching the assemblers in action for the first time would be hard put to contest the widely held view in the organization that they all do the same thing[5]. The “basic” operations were, in this case, the same from one station to the other – drilling, countersinking, and riveting – only the proportions varied. Subsequent analyses of the assembly activity revealed, however, that despite apparent similarity, each assignment differed in terms of the parts to be assembled (e.g. size, shape, thickness, contours), the fasteners used, and the physical location where the parts had to be installed (interassignment variability) in or on the cockpit. Another source of previously underestimated variability concerned the fact that any given part was never identical from one cockpit to the next: this is where the play within tolerances is a factor. Though the tolerances may be tiny for any given part, they are important during the assembly of dozens of parts, all with variations: the skill of fitting these parts and of properly anticipating the tolerances thus becomes key (interassignment variability). It is this facet of the work that Buchmann (2013) was referring to when he used the expression “industrial craftsmen” to describe assemblers.

We then faced the challenge of characterizing each stage in terms of learning issues. Contrary to the more conventional situations studied and reported in the literature on job rotation, we found that the main distinction between the various assembler assignments concerned less the tasks or even operations to be performed and more the variability of the parts having to be assembled and the conditions under which they were assembled. In a more standard job rotation context, the tasks and operations are often different from one workstation to the other and form the backdrop against which the necessary skills are defined. In our case, as mentioned above, the difficulties in the learning process concerned less the mastery of tasks and operations (which were quite similar from one stage to the other), and more the ability to deal with the variability in the parts, fasteners and physical configurations of the jigs on which the parts were installed (e.g. cramped space and poor visibility, working at arms-length, near fragile parts). The main challenge for the assembler was that of resolving the motor skill problems imposed by the variable constraints of the work environment in order to deliver a defect-free product. To take into account these specific aspects, we developed an original grid for characterizing the issues associated with

[5] Could long cycles downplay the differences more than short cycles? Is it easier for stakeholders in the company to see differences in the work with short cycles?

learning how to perform assembly work (Appendix B). While tested in one department only, we believe this grid can be generalized to all the assembly tasks in the aerospace industry. However, this still needs to be validated.

To conclude this discussion of methodological questions, we will briefly cite the issues associated with assessing the interventions. As intervention specialists, we are aware of the importance of clearly defining the impacts of changes implemented in workplaces, given workplace expectations in this regard in order to justify a return on the investments made. The field of evaluative research is prolific. There is a wealth of literature on the topic and assimilating it is a complex process. Our intervention context also had a variety of characteristics that made the assessment process difficult: long cycles, circular (rather than linear) causality, multiple changes, more than 20 workers impacted, and so on. We nonetheless tried to define indicators to use in monitoring the job rotation implementation trials: the workers' perceptions of the difficulties experienced, consequences for production, impact on errors (e.g. number, nature), reporting of pain and MSDs, etc. We remain mindful of the challenges posed by this aspect of research and make no claims to have innovated in this respect. Rather, we are much more concerned about these questions and prefer to ask for the expertise of specialists who could assist us than to make recommendations to readers.

5.2 Quality as a defining variable in the learning process

As was the case in our risk analysis, triangulation of the data obtained from observations, the company's internal records on errors (NCRs), and interviews with the assemblers and quality assurance officers highlighted the overriding presence of the quality issue and its impacts on the assemblers' work activity (see Gonella et *al.*, 2013, for additional information). We would like to illustrate the defining nature of the quality requirements in the development of versatility in the assemblers and how it could hinder the implementation of job rotation if its impacts are overlooked. To do so, five aspects will be discussed.

Quality goes hand in hand with competence: Many demands were associated with the quality requirements and were concretely assessed on the operational (i.e. motor), cognitive, and affective levels (e.g. fears) through the assemblers' discourse. Based on excerpts from the interviews – partly validated by our observations – we identified a vast spectrum of planning and work organization strategies, as well as more refined methods of working used to achieve the desired quality. Our analyses do not allow us to be 100% affirmative, but we can put forward the hypothesis that, contrary to many predominantly manual trades, assemblers do not appear to develop automatisms (unconscious behaviours) (Leplat, 2005) due to a complex combination of variability and quality requirements that demand constant adjustments and sustained attention. The assemblers emphasized this need to be constantly vigilant, to anticipate, and not to fall into the pitfall of routine behaviour in their work. Coupled with the physical demands of the job (postures, efforts, vibrations), the quest for motor efficiency – characteristic of motor learning (Sparrow and Newell, 1998; Delignières, 1991) – is thus compromised. Regardless, a first finding was that the quest for quality is not improvised; rather it involves a series of actions planned by the assemblers and learned over time. The fact of facing the same problems relatively often thus ensures that learning takes place.

Identifying "tricks" for handling the difficulties faced and making them readily available to new assemblers would be a very useful means of transferring knowledge to them and would contribute positively to their development of versatility (Aubert, 2011; Beaujouan et *al.*, 2013). For the time being – apart from the transfer of knowledge among the assemblers themselves – the assembly specifications are the only tool available to them, but these documents are rarely consulted because they are not totally up-to-date. In fact, only certain pages are consulted; in many instances, they are ripped out and posted within plain sight at the stations, with handwritten notes added here and there to fill in any missing information or highlight any critical information that may otherwise go unnoticed. As part of the project set up by the company following the two job rotation implementation trials, a technician from the training department began the task of developing highly visual information sheets in collaboration with experienced assemblers, to offer adapted material to the new assemblers[6] (see Appendix K for an example of this type of document for one operation). This work has only just begun, and the experience of the department studied is sure to be beneficial for other departments facing the same problem.

Non-quality as a source of stress: Our analysis of the interviews conducted with the assemblers from the standpoint of the relationships between the learning process and the search for the required quality revealed to what degree the quality requirements were a major source of stress for all the assemblers, as small errors can have enormous consequences (e.g. costs of replacing parts, production deadlines, dismissal for camouflaging). The complexity of assemblers' work, compounded by demands related to both the physical layouts of the workstations and the organization of lean production, generates frequent errors despite all preventive efforts. The assemblers absorb the effects of this constant quest for quality, as well as the repercussions that go hand-in-hand with making errors. Several of them were marked by previous non-quality events in which they were involved and which affected their openness to job rotation. As interviewers, we were amazed to find that some assemblers, despite having many years of experience, seemed to have a low sense of self-efficacy usually related to the memory of a significant failure that left them with a bitter aftertaste.

A second finding was that the assemblers must be placed in situations where they will succeed in order for them to develop a sufficient level of confidence[7], a prerequisite to enlisting their willingness to participate in job rotation. Yet the learning process requires relative stability in a work situation if they are to develop the necessary confidence in their abilities through a sufficient number of achievements and successes. The process of learning the new stages must take place at an appropriate and planned pace, and our trials allowed these parameters to be defined at least in part, given that we did not have sufficiently robust theoretical guidelines. Along the same lines (even though we only touched on this issue), the way in which the situation is handled by an assembler following an error might warrant review. We heard about cases in which the assembler felt isolated after making an error. Depending on the situation, he might actually be excluded from the error correction process in full view of the entire work team, and sometimes even subjected to ridicule. In addition to this feeling of discomfort, an assembler sidelined in this way does not benefit from the error resolution process that could in fact help him in his learning process. Despite these occasionally humiliating situations, the work team remains a safe refuge.

[6] In our view, an assembler who is assigned to a stage of assembly that he has never or rarely performed could be qualified as "new" and therefore benefit from this support material.

[7] The active experience of mastery is one of the strongest sources of belief in self-efficacy (Rondier, 2004).

The work team as a protection factor: Continuing with this idea, the support role of the work team appears to be a major and positive prerequisite, not to completely eliminate the fear of making errors, but at least to help manage this fear. While direct collaboration is a somewhat rare occurrence when job rotation is involved, it is required in assembly work, for example, when riveting or handling parts. The assemblers help each other out, frequently communicate, share information, and so on. Despite the seemingly individualistic nature of this work, collaboration among the assemblers was found to be the rule rather than the exception[8]. Again, a thematic analysis of the interviews with the assemblers regarding their views of their social environment was highly informative. They saw a clear separation between “them” and “the others”. The others – referring to all the people or entities outside their own department (e.g. other assembly departments, engineering, methods, subcontractors) – were seen as being removed from their reality and as making decisions the assemblers did not always understand. This perception increased their feeling of belonging to their own group, to their “gang”. Their team, characterized by camaraderie, joking around, and a friendly atmosphere, constituted a protective social group, a tightly knit group where everyone looked out for one another. In fact, conversation was easy, they could talk about work, and there were no taboos.

Assisting each other is a concern and a responsibility shared by all: they support coworkers in difficulty. Whether a coworker is late or in a risky situation, the team members help their coworkers at the other stations as needed, and occasionally, even prepare the work for others. In addition, the work team takes charge, either formally or informally, of the new recruits. They find ways to help them get organized, give them tips, alert them to the risks of errors at the workstations, pass on knowledge, assist them through their learning progression to give them confidence, protect them, or help them manage their worries and fears. They can never really see themselves as alone since, although they each work at their own stations, all the assembly work is interconnected and everything must be sequenced; there is a great deal of dependency in production and they have to pull together. Moreover, the team leader and the assemblers with the most seniority assume the role of leaders in this microcosm. They take turns assisting, motivating, guiding, or coaching, and always in a spirit of unity within the department. Solidarity is clearly the keyword for protecting oneself against the risks associated with the work, but also for sharing a sense of pride in work well done and the pleasures of camaraderie.

A third finding is that it is in this team’s best interests to remain as stable as possible during implementation of job rotation because the work team constitutes a resource essential to the learning process and helps build a feeling of confidence. Yet, particularly at the end of the project, the opposite happened: the work team changed regularly and substantially because experienced workers were called to other workstations or were absent due to injury, and new recruits appeared here and there, “disappearing” into the evening shift as soon as their brief integration period was over. Production demands and compliance with the collective agreement dictated personnel turnover and assignments.

Quality as a key consideration in the organization of the work: The impact of the quality requirement is also felt indirectly by the assemblers in the way the work is organized within the department. In fact, the team leaders too have to deal with the quality issue in their daily work, as evidenced in their assignment of the assemblers to the various stages of assembly (“rotation

[8] The way in which the work was organized in the department, where several workers were assigned to the same stations, further reinforces the notion of the teamwork aspect of assembly.

units”), in their management of the delays caused by cumulative errors, etc. A particularly noteworthy finding mid-way through the study clarified the role played by the ways in which the work was organized and quality requirements were taken into account. A brief analysis of the records of all the errors made in the department under study revealed that the number of errors reported during the first three months of 2013 was double the number for the whole of 2012. At the end of 2012, the time allocated for assembling a cockpit went from four days to three. To cope with this faster production rate, new assemblers were assigned to the department and an evening shift was introduced. For reasons related to the collective agreement, the new assemblers soon found themselves on the evening shift after spending only a few weeks on day shift learning the rudiments of the assembly procedures in the department. On the evening shift, they were left more to their own resources with minimal supervision and no access to the resources who could have helped them assimilate what they had learned only recently. This partly explained the escalation in the number of errors, with work team instability and a faster production pace as possible contributing factors. During the interviews with the team leaders, we learned that to cope with situations of this kind and limit error frequency, they had the assemblers specialize in certain stages. Depending on the new assemblers’ skills or lack thereof, they were asked to carry out certain stages and only those. The most talented assemblers were gradually exposed to the more difficult stages, but under close supervision. As a case in point, when the team leaders had to deal with the increased number of errors on the evening shift, it was decided to assign the simpler stages to the new assemblers, and conversely, the more critical stages to the more experienced assemblers on the day shift, which intensified their workload. Clearly this way of organizing the work ran totally counter to the goal of developing the assemblers’ versatility, but possibly it constituted the only means of control whereby the team leaders could deliver on time. These contradictions must be discussed within the organization in order for appropriate solutions to be found.

Errors as a vector for learning: It is easy to understand why errors are perceived negatively within the company studied. They are a source of disruption, incurring costs and delays, among other things. Errors are meticulously documented, but for the time being, these records are used for administrative purposes only, which, moreover, are consistent with the high normative and traceability requirements of the aerospace industry. We firmly believe that the error databases could serve other purposes as well. For one thing, an analysis of these errors could help determine their main causes and ways of reducing them at the source. Where do the errors occur? What is the proportion of so-called “normal” errors compared to that of more problematic errors? For example, we know that the source of some defects in the assembly is attributable to other departments that supply the cockpit assembly department. Such analyses would help improve the organization of the work and the production process as discussed earlier.

Second, the errors could be used for teaching purposes. An error constitutes a divergence from the established norm and is generally ascribed a negative value, thus calling for a sanction or penalty. Under the impetus of work done by a number of researchers, such as Jean-Pierre Astolfi (1997), errors have slowly gained the status of learning resource. A better understanding of the apprentice assemblers’ main errors would provide direction for teaching and for the feedback to be given. Practical workshops could also be designed to simulate the working conditions at the source of the most common errors. Given that learning time costs the organization money, a better understanding of the errors made would also provide clearer focus for the learning process and establish training priorities so as to enhance efficiency. While one might hope that the entire assembly process could be covered in training, it may prove sufficient – and strategically appropriate, given the realities faced by companies – to concentrate primarily on learning under the working conditions that are the most problematic for the assemblers and consequently the source of non-quality. During training, errors would be permitted and would be instructive for the learner, contrary to the current situation where the essential learning takes place directly on the job.

5.3 Prerequisite conditions for job rotation

We have produced a summary table of the conditions we regard as prerequisites for implementing rotation in the company where this study was carried out (Table 5-1). In addition to listing these conditions (first column), the table specifies how taking these conditions into account benefits and contributes to job rotation (second column), as well as the issues observed and difficulties faced by the company in trying to introduce them (last column). This list emerged during the data collection process, with elements added even after the second and last rotation implementation trial. Their application in other cases (i.e. other companies or departments) in the aerospace industry would allow us to verify whether these conditions can be generalized. Some of them come up quite systematically in the literature on rotation. For example, allowing a sufficient length of time for the learning process and putting certain conditions into place (e.g. coaching) are not new ideas, nor is the fact of identifying changes that need to be made to the workstations. Other conditions are more specific to the industry, such as managing quality-related technical problems, and to a lesser degree, the desired stability of the work team. Without going into the details of each condition, two aspects in particular should be emphasized.

Table 5-1: Prerequisite conditions for implementing job rotation and organizational issues

Prerequisite Conditions	Benefits and Contribution to Job Rotation	Issues for the Company That Could Limit Its Ability to Act
Human dimensions		
Group stability	Group stability fosters the transfer of skills between the coaches and apprentices. It also promotes collaborative work and increases the new recruits' self-confidence.	Having to meet unforeseen demands (loaning personnel, ensuring just-in-time delivery) Managing personnel absences and movements Orienting new recruits (aging workforce, mobility, increased production)
Release coaches and make them available	The coaches must be available, have time, and be physically close to the apprentices to assist them in their new assignments. They play a dual role of controlling quality and mentoring the learning process.	Coaches' multiple roles make it difficult to release them: - mobilized for highly technical assemblies - not recognized as coaches - less present on the evening shift
Organizational dimensions		
Train assemblers before they go on the job	Prior training (other than at the workstations) on the basic operations would help reduce the risks of errors on the assemblies. It would facilitate the acquisition of skills on the job and speed up integration into new assignments. It would reduce the control exercised by the assemblers.	Orientation training for assemblers is currently very general and offers little recognition of expertise (underestimation of skills required) Developing a more specific training program would require major investments: defining objectives and pedagogical methods, providing support materials for the learning process, training coaches (teaching methods to be used), releasing personnel, simulating jobs/workstations (developing workshops, finding rooms for practicing, etc.)
Management, local responsibility	The team leader plays the role of "orchestra conductor" in the department; he both manages and controls variability; he also referees situations, establishes assignments and priorities, and is the one who manages rotation on a daily basis.	Work overload for team leader Multiple role poorly understood Heavy dependency on team leader when internal mobility of personnel
Technical dimensions		
Reduce and control problems with technical quality	Reducing the problems of technical quality (e.g. peeling paint) would help stabilize the assignments and create an environment conducive to learning (increased presence of team leaders, fewer difficult situations).	Certain recurrent problems difficult to control (e.g. parts coming from subcontractors) Other problems require major investigations to identify the source
Make changes to the workstations	The changes would help reduce the risk factors for the onset of MSDs. They would also increase the opportunities for more workers to learn certain tasks and for task rotation.	Change processes in the aerospace industry are long and complex, given the high quality requirements Difficult to modify work environments without modifying manufacturing processes It is more difficult to change "old contracts".

The learning process is indispensable: While it may be relatively commonplace to talk about the role that training can play when it comes to job rotation, in the context studied, this aspect was particularly important. In many cases involving manual work organized on a Taylorian basis, a structured learning process directly on the job may be adequate. However, in our context, training that allows a transition from the assemblers' initial training to actually performing the job is anything but a superfluous condition. Our data in fact confirms the vast range of expertise needed by the assemblers to meet the quality requirements inherent in this particular activity sector.

For now, we infer that what is learned at the assemblers' initial training school, as well as during the orientation training for new recruits, does not adequately prepare them for the real assembly work performed in the cockpit assembly department. For example, during the orientation training given to new assemblers, they practice the basic skills (approximately two hours), but on flat steel plates (i.e. no curvature) positioned vertically in a vice at waist height. Based on our observations, this type of configuration of the work situation – the simplest possible from a motor skill perspective – represents less than 5% of the situations actually experienced. This means that only when they are actually on the job do they learn to use these basic skills in real conditions: at arms' length, near sensitive and fragile parts, in a precariously balanced position on a jig or stepladder, or under time pressure, etc. Moreover, although they are still learning on the job, errors are no longer permitted. If we accept the premise that errors can serve a purpose in learning because they help in diagnosing the learners' difficulties, the fact of being limited to learning only on the job deprives them of this source of knowledge. In addition to training prior to actually working on the job, the availability of a coach, the development of support materials, and – more indirectly – team stability and management of the job rotation by the team leaders all converge to foster learning and a gradual increase in skill and autonomy. This poses a major challenge for the organization.

The impact of errors on a "just-in-time" type of organization: another dimension – even more problematic in our view – consists of having to find solutions for implementing job rotation within a form of work and lean production organization where many non-quality events occur. The two trial implementations carried out in this study – and which ultimately proved highly instructive regarding these "organizational" issues – stand as evidence, and in our opinion, were the only way of identifying them. It was during these trials that the coordination role of the team leader stood out so significantly. The trials also cast light on the difficulty of ensuring the smooth flow of the planned cockpit assembly sequence when quality-related errors occur, particularly major errors. In fact, the most common "toolmark" type of errors, for example, can generally be repaired during the assembly hours planned in the prescribed organization of the work, provided they do not occur too frequently. It is assumed they will happen – zero errors being utopia – and there is some leeway for dealing with them. They are accounted for to a degree in the production deadlines and require no or little involvement of stakeholders outside the department, such as Quality Assurance officers.

The situation is quite the opposite when more serious errors occur and require unplanned partial cockpit disassembly operations, the presence of Quality Assurance officers to diagnose the situation so as to identify the problem(s), the mobilization of more experienced assemblers – in addition to team leaders – who are called upon to repair these errors and to monitor the repairs made as well as their conformance with the identified procedure, etc. This is aside from the delays caused by waiting for new parts to replace damaged parts, and the fact that these cockpits take up extra space that clutter the department. It is these errors that disrupt the normal assembly cycle and require – reactively and often urgently – sometimes major adaptations. At such times, the team leaders have to “improvise” and rethink their production plan because the task of repairing these cockpits is in addition to normal production, causing delays and bottlenecks. As the experienced assemblers are monopolized to perform these urgent repairs, they are contributing less to normal production, which is also delayed, creating a vicious circle that can take a long time to emerge from.

It is precisely to prevent the occurrence of these situations causing a disruption of the normal cockpit production flow that the team leaders have the assemblers specialize. Even if errors can always be anticipated, one can at least hope they are minor, infrequent and manageable within the planned time parameters, which is virtually impossible in the case of major errors. In fact, the latter types of errors (e.g. peeling paint, a machined part that was damaged) were observed during our two trials and obliged the team leader to rethink the assembler assignments that had been predetermined to allow us to monitor the job rotation. The priority then became that of “getting the cockpits out” of the department to restore the normal flow and not create undue wait times in the subsequent departments that work on the assembled cockpits (e.g. electrical components, paint). One might well wonder whether there is not some way for companies subject to major changes in production to develop both job rotation and specialization systems that would have to be adapted on an ongoing basis in keeping with the production context, composition of the assembler teams, etc. First and foremost, the adjustments the team leader has to make to manage errors have to be taken into consideration. While far from exhaustive, our implementation trials enabled us to identify various issues faced by the organization in the concrete implementation of this job rotation project. Clearly the implementation of job rotation and development of versatility are difficult to improvise and must instead be the focus of a concrete organizational project involving the parties concerned. While some stakeholders saw these trial implementations as failures, notwithstanding their mixed results, the trials involved true hands-on management of the project by the organization, given that the decision makers were the only people with real control over what was acceptable or not in terms of production issues.

5.4 Implementing job rotation: an organizational project

Throughout the research project, the stakeholders in the company – both employer and union – demonstrated a collaborative spirit and level of involvement reflecting the importance they placed on this new form of work organization: job rotation. This collaboration was evidenced primarily in their positive responses to most of the requests we made in order to come up with our diagnosis and report on the progress of our work: observations at the workstations and unlimited videotaping, significant releasing of workers and management personnel from their duties, unlimited access to internal documents, planning of steering committee meetings with senior executives present, etc. Sometimes the department was virtually emptied of its workers and production was suspended so that we could hold a group validation meeting, which is no small gesture and illustrates the full means put at our disposal. The company never skimped on offering us resources to help us clearly delineate this complex problem of job rotation.

Despite this excellent collaboration, production realities quickly caught up with us during the trials when non-quality events occurred. The variations in production, largely attributable to the so-called major errors, did not allow the company stakeholders to maintain the conditions conducive to the job rotation trials despite all their best intentions. We could not help but observe the great efforts made by the assemblers and team leaders to stay afloat and get over the hurdles. We therefore felt that this complex issue was being approached as a true company project and that the organizational issues discussed in the previous section were going to be debated – by some at least – within the organization. A formal project management process was put in place by a member of the training department (see Daniellou (2004) for an interesting text on this issue) and a budget and resources were allocated. We assisted this group for a few months and observed the enormous challenge facing them, despite the participants' energy and good will. We stopped our involvement in this group since we had already extended the deadlines for the official end of the project, which was a source of frustration for the group as they were unable to see the outcomes of our process. Expectations had most definitely been created in the assemblers, but we have no idea how they were subsequently managed.

Like Coutarel et *al.* (2003), we became firmly convinced that implementing job rotation and developing the versatility it requires are complex issues that must be treated very seriously. In our particular context, this finding appeared to be reinforced if one considers the high quality requirements and the just-in-time mode of work organization. While interesting from the point of view of preventing MSDs and enhancing worker skills, job rotation may also – if the prerequisite conditions described in this report are not given their just due – increase the likelihood of the onset of the very health problems we want to prevent. First, many conditions must be taken into account in order for job rotation to achieve its full potential. Second, implementing these conditions poses a challenge and raises questions about the feasibility of such a project in the current context. It must be remembered that at the beginning of the project, the aim was to identify conditions conducive to implementing job rotation in the company concerned and not to carry out an implementation project. The pursuit of such an objective might have led us to carry out our intervention differently and specifically as a formal project-management undertaking. We would nonetheless like to draw attention to a few particular aspects of the intervention approach we adopted and that contributed positively to the achievement of our aim. In addition to the information collected in this study and provided by the stakeholders to guide the actual realization of the job rotation project, three other factors pertaining to our way of carrying out the intervention warrant attention.

A participatory process: The involvement of most of the stakeholders in the process definitely strengthened general support for the project, particularly from the workers – assemblers, team leaders and supervisors – who were going to be impacted directly. Their participation was not limited solely to collecting information from them, but also included asking their opinions about certain issues, validating the information collected, and keeping them informed of the project progress and goals chosen. The year and a half devoted to collecting data gradually helped us define the boundaries of this major organizational change, giving greater confidence and control to those who initially might have had concerns. An atmosphere favourable to job rotation gradually settled in as the project progressed, despite a small decline toward the end that, in our view, was attributable to the imminent approach of the end of the project rollout and to a sense of exhaustion given the length of the process. At the end of the project, the company was also faced with new challenges that interfered with the job rotation challenge: the faster production rate, hiring of new personnel, and instability in the assembler team, with an overall loss of expertise, significant internal movement of the first-level supervisory staff, and so forth.

A joint employer/employee process: The employer and union parties saw us – and rightly so – as a neutral player in this intervention. This fact was stated openly, particularly by the union representatives, as an essential factor in ensuring its and its members' collaboration in this project, which generated concerns. The good employer-union agreement was therefore beneficial in terms of both the participation of all the stakeholders and in the constructive discussions held within the steering committee. In all honesty, and without denying our own expertise, this neutral player status constituted our main asset because the requesting company was aware of our position as researchers with all the ensuing consequences: the longer time it required compared to consultation mandates due to efforts made to generalize our results and that implied more data collection; and the importance of the quality of the data collected, which implied a triangulation process and validation meetings, among other things.

Change as a means of understanding: learning from errors: Implementation trials became a necessity very early on in the project for a number of reasons. The first had to do with internal pressure – from both the decision makers and the personnel on the floor – to get on with things and see the outcome of our work. We agreed to carry out such trials, not only to satisfy this request, but because we believed that the fact of concretely testing job rotation would give us an understanding of some of the determinants. This proved to be so. We came to realize that it would be difficult to put in place several of the conditions we had identified as prerequisites for job rotation because they were incompatible with, if not contradictory to, the contingency management process and production fluctuations. The role played by errors, especially those that were difficult to rectify, clearly emerged at this point. We had already assessed their impact on the assemblers, whether in terms of their openness to job rotation or of learning issues (described in subsection 5.2). However, we had underestimated their role in the organization of work on a daily basis, particularly when it came to major errors, which – if they are to be corrected within reasonable timeframes – require urgent adjustments that disrupt the normal assembly dynamics.

These trials were highly instructive, among other things because they shed light on previously underestimated phenomena, thus helping bring about a change in the internal stakeholders' perceptions. In fact, one unexpected outcome of these trials was our finding that they elicited reactions and led to an internal assumption-of-responsibility process. We believe that this process will enable the stakeholders in the company concerned by these issues of job rotation and versatility to collectively find solutions in order to put in place the conditions identified in this study and summarized in Table 5.1. For instance, the creation of a training course to be given before the assemblers start their jobs will require the company to find a large enough space for the course, retrieve "used" parts on which the assemblers could practice the basic operations under spatial conditions resembling the realities at the stations as closely as possible, identify in-house trainers or hire new ones, define the objectives of the training course and its content, estimate the training time needed, and so forth. All this requires financial and human resources as well as preparation in the form of formal project management (e.g. schedules, responsibilities). This is why we stress the fact that the implementation of conditions conducive to job rotation must be tackled as an organizational project. As we have just shown for pre-job training, providing each of these conditions itself implies a number of concrete steps. It is easy to say that work team stability is needed to facilitate job rotation but harder to actually achieve it because, for now at least, personnel movement serves as an effective strategy for coping with fluctuations in production. What should be done to ensure this stability, while maintaining normal production? The company stakeholders will have to grapple with these types of questions because a formal project management plan involving all those concerned offers the best chance of finding realistic solutions within reasonable timeframes.

6. CONCLUSION

The particular context of this study and its realities had impacts on three groups of stakeholders, from those furthest to those nearest the work situations: the team of researchers, first-line supervisory staff, and the assemblers. Each group faces specific issues. First, the researchers had to deal with methodological questions. The discrepancies between the scientific literature on job rotation and the reality observed in the requesting company led to innovative methods of studying both the complexity of the work and the associated risk factors. We believe that these tools – and the process in which they were used – were successful and generalizable to other assembly situations in the aerospace industry. We hope to have the opportunity to confirm these assertions in a future study.

The first-line supervisory staff (supervisors and team leaders) and the decision makers were each faced with organizational challenges in their efforts to implement job rotation. While the prerequisite conditions for job rotation identified in this study were within reach, their implementation posed a challenge. This challenge can only be met if the questions of job rotation and versatility become the focal point of a real organizational project conducted in the form of a project management plan with sufficient resources provided. The main challenge of this process will be to find solutions to the existing paradox between effective ways of developing versatility and the current mode of work organization and production. Here, the correction of major errors and their impacts on the assembly dynamics in the department will need to be a focus of discussion. Regardless, it is recommended that job rotation be managed as closely as possible to the shop floor and with sufficient leeway for adjusting the plan in the event of unforeseen events in production: there must be room to adjust production dynamics so as to manage the occurrence of errors and defects during assembly.

Lastly, and of prime importance, the learning issues faced by the assemblers must be fully appreciated. Despite their label of “manual workers” and the ideas associated with that label, they have considerable technical expertise, not to mention adaptive motor skills. First, even if the assemblers are totally open to job rotation, some of their apprehensions will have to be factored into the implementation process. Second, recognizing that the learning process takes time and requires a degree of stability (in assignments, in the work team), experiencing a sufficient number of successes, and having access to external resources (coaches, learning support) are absolute preconditions for enabling learners to develop both their skills and their feeling of self-efficacy. Recognition by the organization of the assemblers’ expertise is an essential condition and key to the eventual success of the change represented by job rotation.

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APPENDICES

APPENDIX A: QUESTIONNAIRE ON ASSEMBLERS' PERCEPTIONS OF JOB ROTATION

Questions 1 to 6 will allow us to do statistical processing and give us a better understanding of your working conditions.

1. Are you … □ Male? □ Female?

2. How old are you? ___________ years old

3. At which station in the assembly department do you work?

____

4. How long have you worked …
   a) in the company? _________ years b) at your current job? _________ years

5. What is your current employment status?

□ Regular employee □ Temporary employee □ Other __________

6. Does your work place any particular demands on you? (several answers possible)

□ Major efforts (forceful exertions) □ Fast pace □ Stress/Monotony

□ Constraining postures

□ Other ____

____

7. If the conditions needed were put in place (e.g. training for the various jobs, adapted work team, adjusted cycle times, etc.), would you be prepared to do job rotation?
□ YES □ NO □ I don't know

Please explain.

____

____

8. Do you think that job rotation would be feasible in the plant if sufficient training was given?
□ YES □ NO □ I don't know

Please explain.

____

____

9. Do you think that job rotation would be good for your health, that it could reduce your pains?
□ YES □ NO □ I don't know

Please explain.

10. Or, do you think that job rotation would be bad for your health, that it could increase your physical problems?
□ YES □ NO □ I don't know

Please explain.

11. Do you think that job rotation could be good in terms of reducing the monotony of your work?
□ YES □ NO □ I don't know

Please explain.

12. Do you think that job rotation could lead to problems with quality?
□ YES □ NO □ I don't know

Please explain.

13. Do you think that job rotation would be a source of stress?
□ YES □ NO □ I don't know

Please explain.

14. Do you think that job rotation could make your work more interesting?
□ YES □ NO □ I don't know

Please explain.

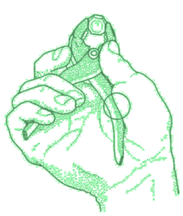
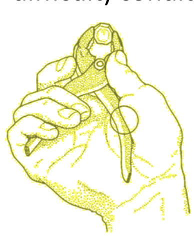
APPENDIX B: CLASSIFICATION GRID FOR TASK COMPLEXITY

The classification covers three main dimensions:

- Basic skills
- Fitting
- Sequencing

Basic skills: These are the basic operations that must be mastered to do the assembly, and essentially consist of drilling, countersinking, and riveting. One particular requirement of an assembler's job is that of having to properly position the tools in relation to the work surface. The assembler has to find the perpendicular between the tool and the surface: the workers talk about finding "a flat surface" or "feeling your angle". This requirement demands many postural compromises on the part of the assemblers.

The basic skills can be classified as manual know-how. Mastering these skills requires time for practice under the real conditions where they will have to be applied. Of particular importance here are fine motor skills and hand-eye coordination. Sense of touch and application of force are also aspects to be considered.

Variables	Criteria/definitions
Basic operations carried out under neutral conditions 	The conditions do not hinder, or only minimally hinder, the assembler's work; he is not limited or hampered in achieving the required quality. It is easy to find "a flat surface" (i.e. the perpendicular) and no postural compromises are required. For example: easily accessible work zones, work surfaces in front of the assembler or on a vertical surface, nearby access zones (i.e. work close to the body), adequate lighting, etc.  
Basic operations carried out in the presence of an aggravating (≈ difficult) condition 	Aggravating conditions hinder the assembler from achieving the required quality; it is hard to find "a flat surface" (i.e. the perpendicular) with the tools. Here are some examples of aggravating conditions: <u>Intervention in demanding work zones</u>: The assembly is carried out in corners or spaces (access holes, around the jig, above the head) that require the assembler to adopt constraining work postures to physically support his movements and/or to make the actual movement. It is essentially the workstation layout that obliges the worker to make one or more postural compromises, as illustrated in the following examples: • Difficulty maintaining the **overall stability of the body** (maintaining good balance): The assembler may have to stand on one foot, lean forward to reach the work zone, crawl on something, etc. Overall positioning of the body is hard, which affects the quality of the physical support available for

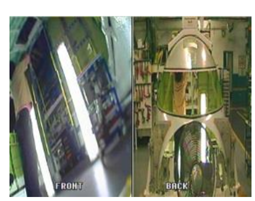
the movement to be made: the person is less stable.

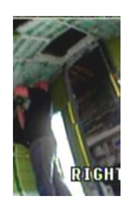
- Difficulty **positioning the upper extremities**: In this instance, the postural comprises involve the back or the upper extremities, shoulder, elbow, and/or wrist height. The assembler must practically do contortions to align himself properly, creating the impression that he is all “crooked.”
- Upper extremities **positioned away from the body**: The work has to be performed at arms-length; there is a significant distance between the eyes and the task, making it more complicated to control movement and vision. It is harder to apply force in this position.
- **Work performed with two hands**: Both hands are used simultaneously to perform the work: they have to be coordinated. Sometimes two-handed work is necessary to apply greater force, control the tool, for greater precision, etc. This makes it impossible or difficult to use the hands for additional support.
- **Major efforts (forceful exertions)** required to perform the operation and/or to **control the effort** to be applied: This refers to all conditions requiring the application of greater effort: bigger rivets, thickness of the parts, etc. Sometimes the effort to be applied on unfastened or softer parts has to be “dosed out,” that is, exactly the amount of effort needed is applied but no more, meaning that the worker has to hold back.

Overall stability of the body

Positioning of the upper extremities

Upper extremities positioned away from the body





Work performed with two hands

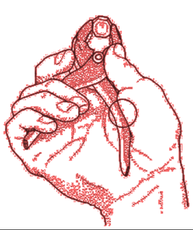
Major efforts (forceful exertions)/controlled efforts


Intervention near or on parts whose integrity is critical: Assembly operations are performed near or directly on parts that must not be damaged; the risk of direct or collateral damage to the parts (e.g. machined parts) is high. This demands even greater attentiveness than normal. In addition to the physical consequences, closer attention and vigilance (concentration) are required.

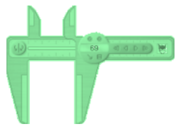
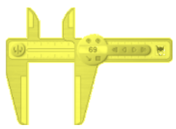
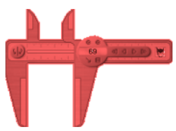
Work performed on or near the sill

Intervention on fasteners that are small or placed nearby: The assembler is cramped in small work spaces, working on small items (e.g. small rivets). Great movement precision is required. It is also harder to find “a flat surface” because the tool used (the head) is smaller and finer.

Basic operations performed in the presence of two or more aggravating conditions



<u>Fitting</u>: This dimension concerns aspects related to the assembly's spatial presentation, to understanding the play within tolerances that makes it possible to anticipate how to assemble the cockpit, and spatial awareness. Fitting combines manual know-how (trimming, fitting) and knowledge (required tolerances). Great precision is required, and poor fittings have heavy consequences (e.g. costs, production delays).

Variables		Criteria/definitions
Holes and predefined locations/ part-to-part fits, fitted parts		All the holes have been located beforehand. The assembler installs the parts and they fit part-to-part; no fitting is needed. If applicable, a drilling template indicates or clearly identifies the location of the holes.
Mixed situation: some holes are defined while others are not; some parts have to be fitted		The locations of some holes are indicated, but not the locations of others. The assembler therefore has to take certain measurements and fit the pieces (layouts, trimming etc.).
No holes are predefined and the parts have not been fitted		The assembler has to do all the fitting and identify the hole locations (measurements, layouts, trimming, etc.). The parts have to be machined in order to be assembled and tolerances must be respected.

<u>Sequencing</u>: Sequencing refers to assembling the parts in the right order. Several factors have to be taken into account, such as the number of parts to be installed, the complexity of the order of the assembly operations, and the location of the parts on/in the cockpit. Sequencing is essentially a matter of knowledge: you simply have to know the sequence.

Variables	Criteria/definitions
Few parts, large parts 1, 2, 3 …n	The location and positioning of the parts are known or can be easily identified. There is a low risk of error, and the assembly sequence is easy to remember.
One condition that can increase the risk of error 1, 2, 3 …n	Conditions that can increase the risk of error: • <u>Number of parts to be installed</u>: more than x number of parts… • <u>Installation sequence (specifications)</u>: there are many steps required in assembly (e.g. pre-assembly on the bench, installing one part before another part, etc.). • <u>Positioning/angle of the parts</u>: The parts must be installed in a specific position (on the right or on the left, inside or outside, at a 30° angle, etc.).
Two or more conditions that can increase the risk of error 1, 2, 3 …n	

APPENDIX C: QUESTIONNAIRE ON COMPLEXITY/TRAINING

Introduction to the interview

The interview will cover learning and training issues related to the job. Questions will be asked about the skills needed, difficulties encountered in the learning process, the number of things to be learned, and variations in the work. We will look at a variety of factors: tasks to be performed, tools/equipment/machines (instruments), products/basic materials, instructions/procedures to follow, spatial environment (layouts or work premises), issues and expectations, time frame and deadlines, work disruptions, and lastly, coworkers (social structure).

1. Worker identification

1. How old are you? ____________ years old
2. What qualifications/training do you have? Are they related to the work you are doing?
3. What is your official job title? *And the unofficial title?*
4. How long have you worked …
   a) in the company? _________ years b) at this job? _________ years
5. What path have you followed in the company (different jobs held, how long)? Or in other companies?

2. General questions

6. What level of knowledge is needed to perform the work involved in this job?
A **minimal** level of knowledge
A **relatively good** level of knowledge
A **good** level of knowledge
A **high** level of knowledge

7. How long does it take to:
a. be able to do/perform the job? b. be good at the job?
8. Of all the things that have to be done in the job, what is the most difficult thing to learn?
9. Do you feel that you are continuing to learn in your work?

3. Tasks/operations

Based on the chronological workshift-task description, prepare an overview*:*
- describe the sequence of operations/tasks
- list the operations/tasks
- provide photographs of the operations/tasks.

10. Encourage the person to talk about/confirm: the accuracy, completeness, variability, discrepancies, precision, etc., of what you have presented.
Does it provide a good description of the tasks/operations you have to perform? Does it cover everything? If not, what is missing? What aspects of your job are subject to change and under what circumstances? Do you sometimes have to perform different tasks at the same time? Do you perform your tasks in a certain order or does the order vary? Do you perform the same tasks every day?

11. Of all the tasks/operations described above, which one takes the most time to master or learn; which one takes the longest time in terms of developing the necessary skills to do the work? In what way does it take more time, and for what reasons?
12. Generally speaking, how long does it take to be good at performing the tasks described above?
13. Of all the tasks/operations described above, which one(s) is(are) the most difficult to master or learn? For what reasons?

4. Tools and equipment used

Based on the chronological workshift-task description, prepare an overview:
- list and describe all tools used that have been identified
- identify the primary tools versus the secondary tools
- show photographs of these tools.

14. Encourage the person to talk about/confirm: the accuracy, completeness, usefulness, necessity, etc., of what you have presented.
Does it provide a good description of all the tools/types of tools used? Are some of them primary tools and others, secondary tools? Which ones are the most useful? How frequently do you use each tool/type of tool?
15. Of all the tools described above, which ones take the most time to master or learn? Which one takes (or ones take) the longest time in terms of developing the necessary skills to use them properly? In what way does it (or do they) take more time, and for what reasons?
16. Generally speaking, how long does it take to be good at using all the tools described above?
17. Of all the tools described above, which one(s) is (are) the most difficult to master or learn? For what reasons?
18. Generally speaking, regarding the tools discussed above (Yes/No): a. are they well adapted to the work? b. are they well maintained/do they work well? c. are you responsible for their maintenance? d. are they sufficiently available to allow you to do the work? Please explain.

5. Basic materials: parts and fasteners

Based on the chronological workshift-task description, prepare an overview:
- describe the basic materials identified (list)
- show photographs of the basic materials.

19. Encourage the person to talk about/confirm: the accuracy and completeness of what you have presented.
Does it provide a good description of the basic materials you use?
Which ones do you use the most?
20. Do the basic materials change a lot?
21. Are the properties/characteristics of the basic materials mentioned above constant over time?
22. Do some of the basic materials cited above pose particular problems/specific difficulties? Please explain.
23. Are there particular/specific things you have to know about and/or to do with the basic materials cited above?

6. Instructions/procedures

Based on the documents collected, prepare an overview:
- summarize the instructions.

24. Encourage the person to talk about/confirm: the accuracy and completeness of what you have presented. Does it provide a good description of the instructions you receive? Are there other instructions as well and how do you receive them?
25. In what ways are these instructions useful to you? Are they easy to memorize, to learn? How long does it take to thoroughly understand them and know them? Please explain.
26. Do these instructions often change? Please explain.
27. Is it possible to veer away from these instructions? To take a distance from/diverge from the instructions?
28. Generally speaking, are the instructions you receive clear (Yes/No)?

7. Spatial context

Based on the chronological workshift-task description, prepare a plan of the premises:
- list and describe the premises/work spaces identified
- Show photographs of the premises/work spaces and changes in layouts.

29. Encourage the person to talk about/confirm: the accuracy, completeness, etc., of what you have presented.
Does it provide a good description of all the premises, work spaces, and layouts? Are some more important/more used than others?
30. Of all the premises and spaces described above, which ones pose the most difficulties? In what ways and for what reasons?
31. Is it important to have a good knowledge of these premises, spaces, and layouts? Why? What are the important things to know? How long does it take to know them well?
32. How do you move/change (transition) parts/jigs/assemblies between premises/work spaces/layouts?

8. Issues/expectations

33. Would you say it is important that you do things well in your work or that you do them quickly?
34. a. In more general terms, what are your priorities, what is most important (what do you have to focus on) in your work? b. And for your coworkers? c. And for the company?
35. Regarding the points discussed above, do they change/evolve over time (why)?
36. Do you manage to do what is needed to reach/meet expectations? Do you succeed in doing the work that is asked of you? Please explain.
37. Could an error in your work result in (Yes/No): a. consequences for quality? b. financial impacts for the company? c. risks for people's safety? d. sanctions/reprimands? Please explain.
38. As things progress, do you learn whether your work was well done/done properly (on time, with good quality)? How can you find this out/obtain this information (feedback)?

9. Time frame

39. Do you have the impression that you have enough time/that you are given enough time to do your work properly? Do you feel that you have time constraints in your work?
40. Do you have to follow an imposed work pace or can you decide your own work pace?

41. Do you have the impression that you are able to manage your time as you see fit (preparing, anticipating, planning)? Are you free to manage your own work time? Can you vary the order of the operations you perform?
42. Are some steps in your work harder to organize/plan?
43. If the time limits/deadlines represent the amount of time available for doing a job that has a beginning and an end, is it important to respect these deadlines/time limits? Do these deadlines come up (Yes/No): a. daily? b. weekly? c. over longer periods of time? d. are there consequences if you don't meet these deadlines?

10. Disruptions/changes

Based on the chronological workshift-task description, prepare an initial overview:
- give examples of the types of disruptions: incidents, interruptions, variations, anomalies, malfunctions, etc.
- show illustrations.

44. Encourage the person to talk about/confirm: the accuracy and completeness of what you have presented. Does it provide a good description of the changes/interruptions you sometimes face?
45. Can you give some examples of things that interrupt/hinder you in your work?
46. Do these disruptions/changes happen often? Please explain. Do they occur under particular conditions? Please explain.
47. Of the examples discussed above, are some more difficult to manage than others? Please explain.
48. Have there been a lot of changes in your work recently or is it relatively stable work that does not change much? If any changes have occurred, please explain.
49. Do you have any ways of preventing/anticipating these disruptions so they won't happen (opportunities to foresee rather than acting reactively when incidents occur)?

11. Social structure

50. Do you have to interact with a lot of different people? Different groups of stakeholders? How many and who? What form do these interactions take: periodic discussions/occasional meetings, collaborating actively/working together?
51. Do these people/groups of stakeholders with whom you have to work change often?
52. Do you have to synchronize with/work in sink with other people to do your work?
53. Are there any times/circumstances when you can talk with/benefit from the experience of others (knowledge sharing)?

APPENDIX D: VARIABLES AND CLASSIFICATION CRITERIA FOR THE THEME OF QUALITY

Themes/sub-themes analyzed

Risks of error (potential)

Category that touches on the assemblers' ability to anticipate or foresee errors. May involve the assemblers taking action, reflecting or, or projecting about the possible consequences of errors.

Potential consequences

Statements and descriptions of the potential, negative consequences of the assembly operations (use of tools, basic operations, etc.), of methods of organization (integration of new recruits, work shifts, etc.), and of risks run (defective parts, overtime, etc.).

Caution, foresight

Assemblers' reflections on how to prevent, control, and reduce the risk of non-quality.
Expression of the need to be constantly on the lookout, alert, and attentive in order to control risks.

Fears

Ultimate fears of the assemblers, often related to a past experience of their own or to a witnessed experience. These fears can lead to avoidance strategies regarding certain tasks, cause anxiety, or have an impact on their activity and their choices.

Physical protection of the assemblies

Means used by the assemblers to protect the assemblies and nearby parts; for example, placing a metal plate behind the work zone to protect the parts during drilling; applying protective tape to prevent making toolmarks.

Control

Personal or administrative measures put in place to guarantee the required quality.

Verification, inspection

Personal initiatives or mandatory controls regarding certain operations/stages of assembly.

Administrative procedure

Interventions and inspections performed by the quality assurance department.
A series of administrative procedures launched following the detection or identification of an error or damage.

Actual errors

All errors and instances of non-quality identified by the assemblers. The assemblers describe the type of errors observed, experienced, encountered.

Non-conformance reports (NCRs)

Symbolic significance of the NCR, the administrative report is described as an entity in itself. For the assemblers, the NCR, over and above its administrative nature, comes to represent the error.

Past events involving damage

Frequent mention or memories of defects that were experienced in the past and are still present in the assemblers' minds.

Techniques for identifying errors

Sensory identification (visual, tactile, etc.) following an incident involving damage (toolmarks, hole size, etc.).

Requirements and demands

Normative requirements (or prescriptions) to be followed in assembly and implications for working methods needed.

Required tolerances

Technical specifications spelling out the fitting tolerances and intervals allowed by the methods department.

Precision

Descriptions of the working methods and of the assemblers' knowledge guaranteeing the accuracy of the operations performed, e.g. choosing the right tools, following the correct assembly sequence, precision work, etc.

Fitting

Frequent mention of the demands related to fitting operations, e.g. parts with no obvious locators vs part-to-part fits, reaction of the materials, etc. The assemblers describe themselves as fitters.

APPENDIX E: METHOD OF RISK FACTOR ANALYSIS USED FOR STATIONS 1 AND 2

The material analyzed consisted of the videotapes of a complete cycle at each of the stations, with each tape approximately 50 hours long. The videotapes were made using a “quad,” i.e. four cameras showing different views of the workstation, in 30-minute segments.

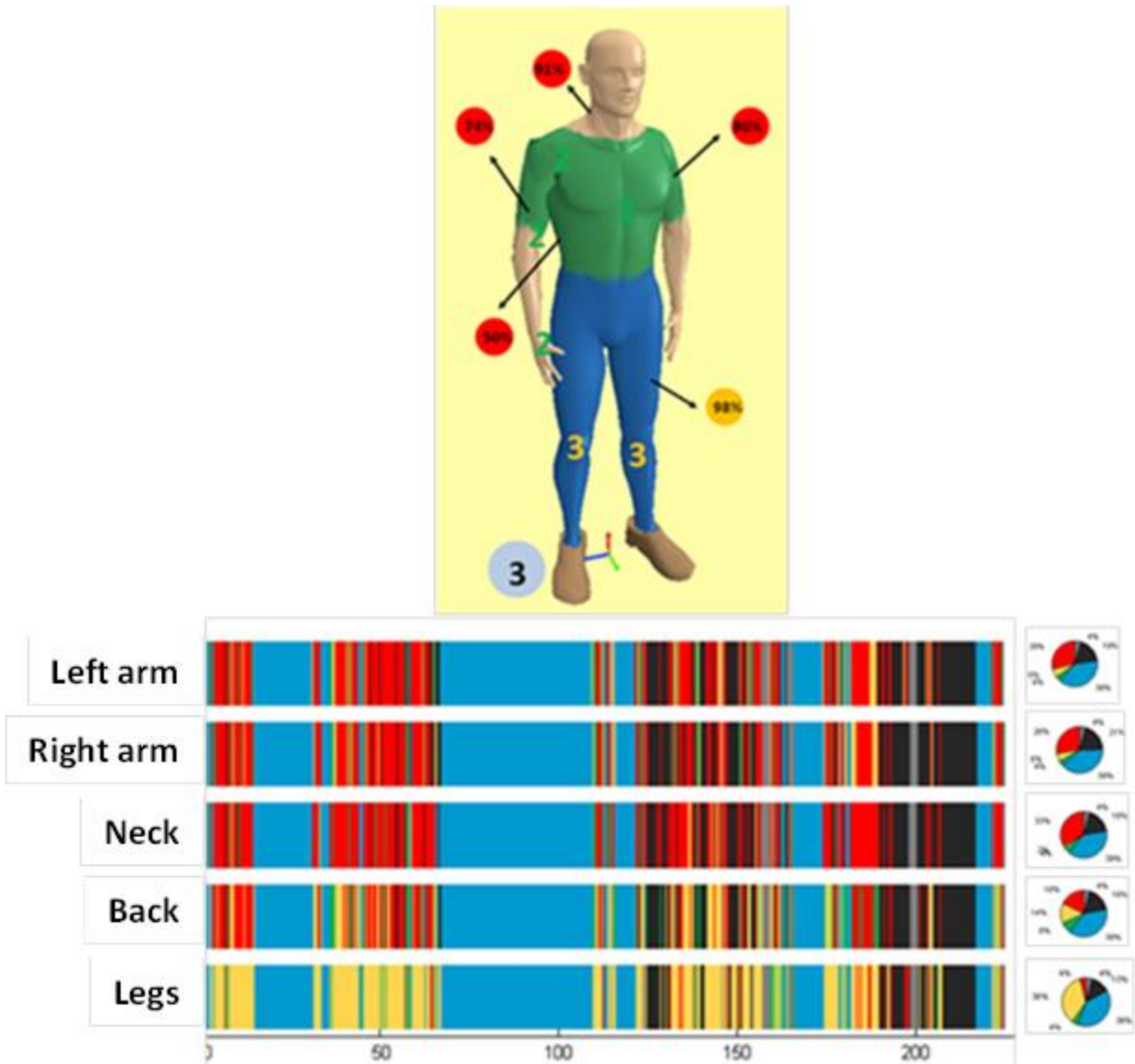
VEA software (Chappe, 2006) was used for the risk factor analysis. Work postures for four body regions (neck, back, right and left arms, and legs) were analyzed on a continuous basis. Three levels of risk were used to describe the postural constraints observed during the work: green, for neutral or undemanding postures; yellow, for constraining postures; and red, for very constraining postures at the extreme ranges of motion of the body region. The posture categories used were based on ergonomics literature (REBA, OWAS, RULA, EN-1005-4). The data obtained from the videotape analysis were exported in order to build a database describing the posture for each body region every 15 seconds.

A variety of situations were documented during analysis: during work on the cockpit, during related work performed outside the cockpit or during breaks, during discussions with the team leader or another contact person, and when the assembler was not visible on the videotape.

Variables observed for the initial method used at stations 1 and 2

Variables	Levels of physical demand	Classes of observables
Neck posture	1 - green	Neutral
	2 - orange	Neutral combined with twisting or lateral flexion
	3 - red	Extension – Flexion – Extension combined with twisting – Flexion combined with twisting or lateral flexion
	Do not know	Work outside cockpit – Discussion – Work not visible
Back posture	1 - green	Neutral – Flexion between 0° and 20°
	2 - orange	Extension – Flexion between 20° and 60° Neutral combined with twisting or flexion
	3 - red	Flexion between 20° and 60° combined with twisting or flexion – Flexion > 60° and/or combined with twisting or flexion
	Do not know	Work outside cockpit – Discussion – Work not visible
Right and left arm posture	1 - green	Neutral
	2 - orange	Neutral combined with abduction
	3 - rouge	Flexion between 45° and 90° – Flexion > 90° – Flexion between 45° and 90° combined with abduction – Flexion > 90° combined with abduction
	Do not know	Work outside cockpit – Discussion – Work not visible
Leg posture	1 - green	Walking – Moving – Sitting
	2 - orange	Standing on both legs – Standing with weight on one leg
	3 - red	Squatting – Kneeling – Crawling Lying on back – Lying on stomach – Lying on side
	Do not know	Work outside cockpit – Discussion – Work not visible

To supplement the observations, three assemblers at stations 1 and 2 were asked to complete a questionnaire. It concerned the body constraints they experienced during each stage of assembly, as well as the perceived effort (exertion) involved in the operations they regarded as the most difficult to perform at the workstations. It was decided to represent the results of each rotation unit in two different ways (see figure below).



Example of mannequin and colour bars: station 1/stage 3

First, the data were presented in the form of a mannequin incorporating both the results of the videotape analyses according to the three levels of risk and the answers obtained on the questionnaire on body constraints and efforts (exertion). For each body region analyzed (neck, back, right/left arm, and legs), the mannequin shows, in percentages, the highest amount of time spent in one of the risk levels. The denominator used to calculate this percentage was the amount of work time. In other words, periods when no work was performed (breaks, activity unknown, work at another workstation, etc.) and discussion periods were not factored into the calculation.

A second way of presenting results was developed to show the changes in demands during the job rotation unit and the alternation between time spent on assembly, discussions, and breaks. For each body region, a colour band was generated to represent the amount of time spent on each rotation unit. Among other things, this visual depiction made it possible to estimate exposure time to high demands and the alternation between easy and more difficult periods. This form of representation is very interesting because it gives an idea of the recovery time available during the operation under study.

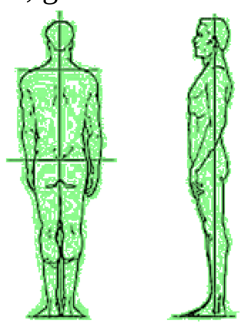
While offering highly informative potential, this first method of analysis was deemed too costly and poorly adapted to long work cycles.

APPENDIX F: VISUAL CLASSIFICATION GRID FOR ADAPTED METHOD OF RISK FACTOR ANALYSIS

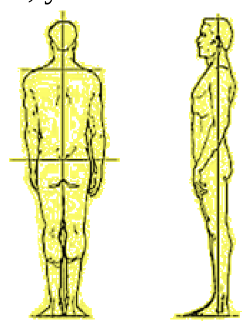
POSTURES

GENERAL POSTURE, risky postures: static standing position, crawling, crouching, kneeling, lying down

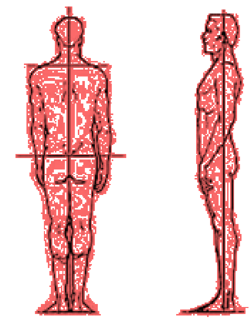
Risky posture between 0% and 30% of the time
Level 1, green



Risky posture between 30% and 50% of the time
Level 2, yellow



Risky posture > 50% of the time
Level 3, red

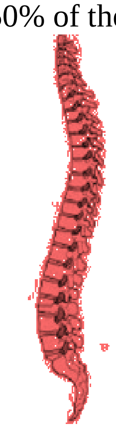


BACK, risky postures: extension, flexion, twisting

Risky posture between 0% and 30% of the time
Level 1, green

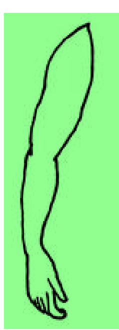
Risky posture between 30% and 50% of the time
Level 2, yellow

Risky posture > 50% of the time
Level 3, red

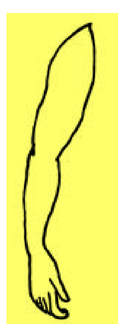


UPPER EXTREMITIES: extended away from the body or upward

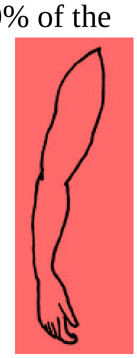
Risky posture between 0% and 30% of the time
Level 1, green



Risky posture between 30% and 50% of the time
Level 2, yellow

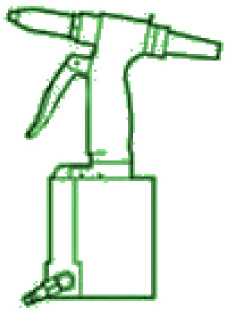


Risky posture > 50% of the time
Level 3, red

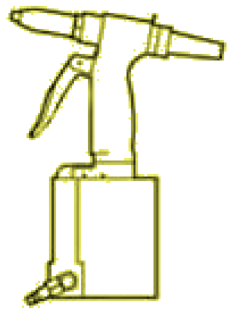


VIBRATIONS

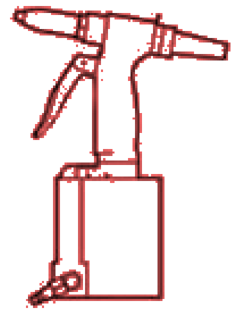
Exposure between 0% and 33% time
Level 1, green



Exposure between 33% and 66% of the time
Level 2, yellow

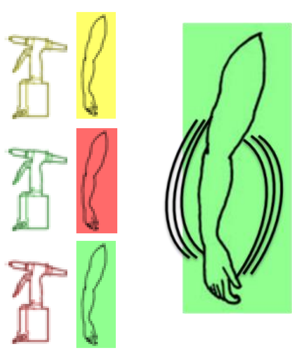


Exposure more than 66% of the time
Level 3, red

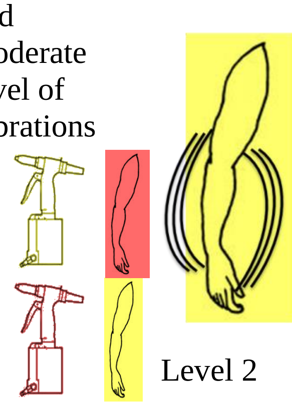


COMBINATION OF VIBRATIONS AND RISKY POSTURES FOR UPPER EXTREMITIES

Combination of vibrations and risky postures for upper extremities
Level 1

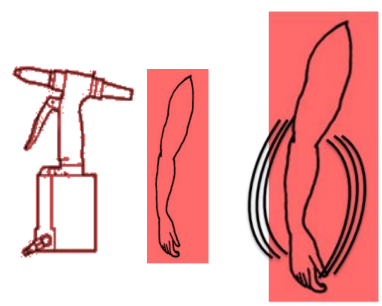


Combination of:
- Risky posture for upper extremity and high level of vibrations
- Upper extremity raised and moderate level of vibrations



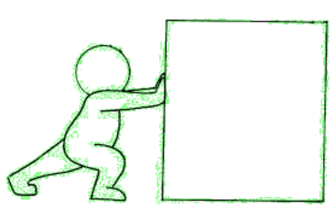
Level 2

Combination of upper extremities raised and high level of vibrations
Level 3

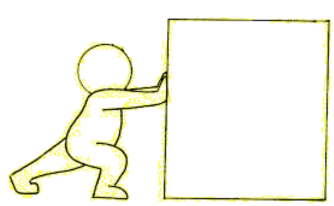


EFFORTS (EXERTIONS)

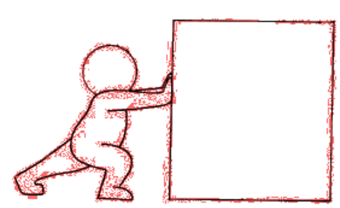
Level between 0 and 2
Level 1, green



Level between 3 and 5
Level 2, yellow



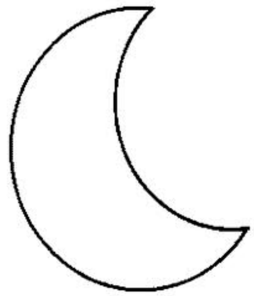
Level > 5
Level 3, red



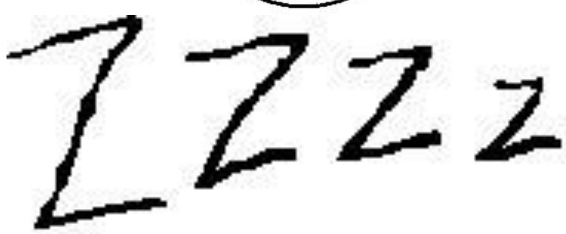
AGGRAVATING FACTORS

Small work spaces

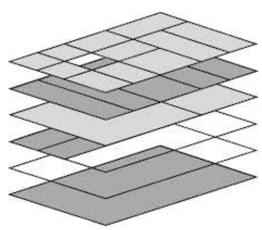
Poor visibility



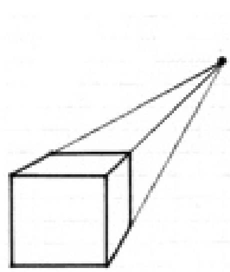
Little recovery time



Complex, multilayer parts



Hidden rear parts



APPENDIX G: QUESTIONNAIRE USED FOR THE ADAPTED METHOD OF RISK FACTOR ANALYSIS

Introduction to the interview
The interview concerns the risk factors associated with the job.
For each stage in the work, questions are asked about the context/work environment in which it is carried out, the postures adopted, the force applied, and the use of vibrating tools.

I. Identification of the worker and health status

1. How old are you?
2. Are you right-handed or left-handed?
3. Which stages of assembly are you currently working on (the past month)?
4. Do you feel any pain at the present time or are you injured? If so, please identify the body regions involved (on the diagram of the body).
5. Do you relate these pains/injuries to your work?

For each stage reported in question 3 above:

II. Context, work environment

Describe the context/work environment in which the stage is carried out.

6. How long does it last? Can this time vary?
7. We identified several tasks performed during this stage. Can you validate or confirm this overview?
8. Which part of the cockpit do you work on during this stage?
9. During this stage, do you work in a small/confined space (inside the cockpit, cramped position due to the jig, in the access hole, etc.), or in a more open space (outside the cockpit)?
10. Do you have good visibility during this stage? Do you have a clear view of the work you are doing (your hands)? Do you have a clear view of the various parts to be assembled?
11. During this stage, do you have to adopt difficult postures (do contortions, stretch out, lean over, etc.) to reach the parts or obtain good visibility?
12. What type of surface characterizes the parts you work on during this stage (flat surface, surface with a double or triple curvature)?
13. During this stage, do you have to work on several layers/thicknesses of materials?
14. Which tasks during this stage require you to use vibrating tools? Please give an overall percentage for the amount of time that you use vibrating tools during this stage.
15. Do you feel tired when you have finished this stage (fatigue rating scale)?
16. Do you take time to recover during this stage?
17. Can you alternate between different operations during this stage? (for example, divide up the drilling and/or riveting sequence, work on the right side then on the left side)

III. Postures

We identified a number of tasks performed during this stage. Can you describe the postures you adopt to perform these various tasks?

We identified four overall body postures. Using the photographs provided, for each overall posture adopted when performing this task, can you explain how your upper extremities and back are positioned?

For each task identified above:

14. During this task, do you have to adopt a standing/crawling/sitting/kneeling/crouching/lying position?
15. What proportion of time do you spend in each of these overall postures during this part of the stage: 10%; 30%; 50%; 80%; 100%?

Based on the percentage indicated, confirm with the assembler the proportion of time (in hours and minutes) relative to the total duration of the stage.

16. When you are in this posture to perform this task, how are the following positioned:
    - Your upper extremities? Are they close to or far from your body? Are they extended upward or downward? *Proportion of time*.
    - Your back? Do you work with your back tilted backward or forward, or twisted (asymmetry)? *Proportion of time*.

IV. Physical requirements

You have described for us the postures adopted during the various tasks performed during this stage.

Referring to a perception rating scale, can you now tell us about the physical difficulties you experience during these tasks?

17. Do you have to use force during this stage? If so, for which tasks?
18. Using the perceived effort (exertion) rating scale, can you evaluate the level of effort needed to perform the tasks you reported as requiring force? Which body regions do you have to force (effort rating scale and on a mannequin)?
19. In your opinion, which aspects of the work might explain the efforts required?

20. To finish our discussion of this stage, can you suggest any potential changes that could be made to improve it?

Repeat these questions for all the stages carried out.

V. General questions

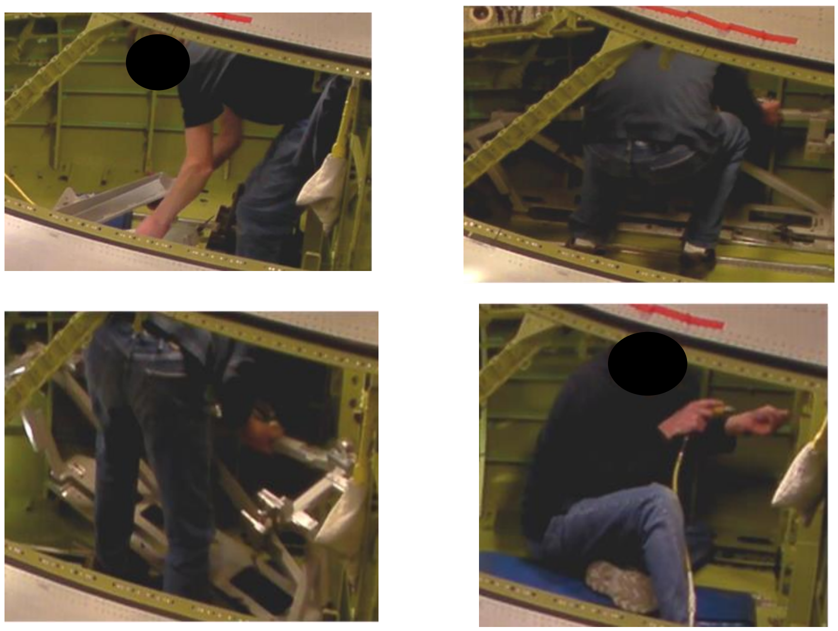
For all the stages:

21. Of all the stages of assembly you carry out, which one is the most physically demanding?
22. Please list the stages you carry out in order, from the least physically demanding to the most physically demanding.

APPENDIX H: EXAMPLES OF VISUAL DOCUMENTS USED DURING RISK FACTOR ANALYSIS INTERVIEWS

Examples of visual documents illustrating a work unit (station 4, stage 4)

Station 4 – Stage 4



Station 4 – Stage 4
Main tasks

1. Fit and install the drilling jigs in the middle, on the right, and on the left
2. Drill and locate the jigs

3. Drill and install brackets and nut plates: squeeze, rivet

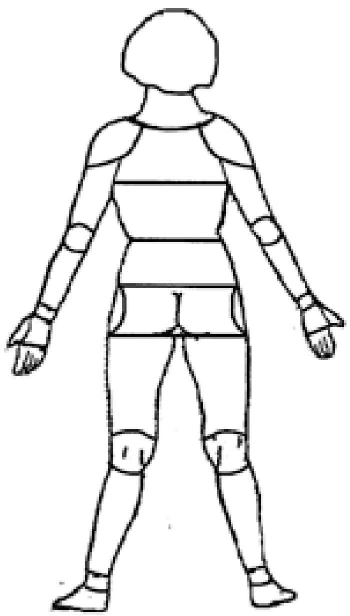
Examples of visual documents illustrating back postures

Back extended

Back twisted

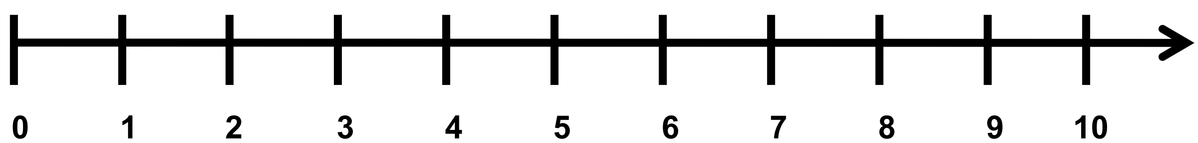
Back flexed

Examples of visual documents illustrating questions



Body diagram used to show location of pain

Perception rating scales used to describe levels of fatigue and effort



FATIGUE

0: No fatigue
0.5: Extremely low level of fatigue
1: Very low level of fatigue
2: Low level of fatigue
3: Moderate level of fatigue
4: Somewhat high level of fatigue
5: High level of fatigue
7: Very high level of fatigue
10: Extremely high level of fatigue

EFFORT

0: No effort
0.5: Extremely slight effort
1: Very slight effort
2: Slight effort
3: Moderate effort
4: Somewhat forceful effort
5: Forceful effort
7: Very forceful effort
10: Extremely forceful effort

APPENDIX I: EXAMPLES OF DETAILS CONTAINED IN AN ASSEMBLY SPECIFICATIONS DOCUMENT, INFORMATION USED FOR THE ADAPTED METHOD OF RISK FACTOR ANALYSIS

Assembly specifications are documents produced by the methods department and in which the assemblers can find brief descriptions of the parts and fasteners to be installed.

0021	B0206001AG5-2	ZHDW-003	BOLT, PROTRUDING SHEAR HEAD	8	/PC	GC219-3501	N/A
0023	B0206001AG5-4	ZHDW-003	PIN	7	/PC	GC219-3501	N/A
0024	B0206001AG5-4	ZHDW-003	PIN	8	/PC	GC219-1600	N/A
0025	B0206001AG5-3	ZHDW-003	PIN	6	/PC	GC219-1600	N/A
0026	MS20470AD4-3A	ZHDW-003	RIVET, SOLID, UNIVERSAL HD	4	/PC	GC219-3501	N/A
0027	MS20470AD4-4A	ZHDW-003	RIVET, SOLID, UNIVERSAL HEAD	21	/PC	GC219-3300	N/A
0028	MS20470AD4-5A	ZHDW-003	RIVET, SOLID, UNIVERSAL HEAD	5	/PC	GC219-3300	N/A

21 rivets to be installed

On this first figure, it says to install 21 rivets ("rivet, solid, universal head").

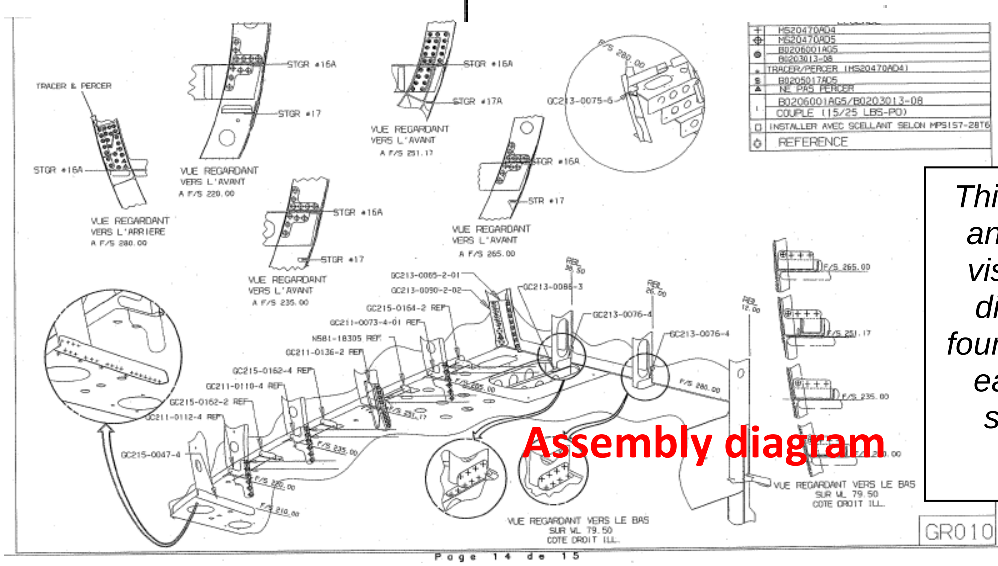
This second figure tells the worker to mark the location of and drill 13 holes ("mark and drill qty (13)3").

-LOCALISER ET SECURISER
LA PLAQUE AVEC L'ATTACHE A
FS 265.00,
-TRACER ET PERCER QTY.(13)
ET SECURISER AVEC LES CLECO
-DIA. #40

******* COMPOSANTS*******
LIGNE COMPOSANT QTY
007 GC211-0073-4-01 0
008 GC215-0164-2 0

0500 963 AGX320AA 0.000 0.000 0.000
0.000 0.000

13 holes located and drilled



This third figure is an example of a visual assembly diagram that is found at the end of each assembly specifications document.

APPENDIX J: OBSERVATION FORM FOR MONITORING INTERACTIONS BETWEEN A COACH AND AN ASSEMBLER

Date: ____ / ____ / __# cockpit in cycle: _____ official cockpit # _____________

Stage:

Station 1						
1	2	3	4	5	6	7

Station 2						
1	2	3	4	5	6	7

Point of time during the stage: ¼ - 25% 2/4 - 50% ¾ - 75% 4/4 - 100%

Stakeholders involved
Assembler __________________ Coach __________________ Other __________________

Schedule, duration of interaction
Start time: ___________ End time: ___________ Duration ___________

Type of interaction

☐ Coaching, teaching/learning ☐ Quality ☐ Other _________________

Description of the interaction

TAKE PHOTOS

Discussions (parts, working methods, tools), gestures, position in/on the cockpit, reference to assembly specifications or other training support materials, third party involved, learner's satisfaction/attitude, basic skills/fitting/sequencing.

____

____

____

____

____

____

APPENDIX K: SECTION OF A DOCUMENT INTENDED TO COMPLEMENT THE INFORMATION IN THE ASSEMBLY SPECIFICATIONS

	Étape	Points clés
4	**Percer les angles aux 4 coins des sills**	**1.** Sécuriser les angles en place. • Accoter correctement les 2 surfaces de contacts et maintenir un espacement pour les angles localisés en haut.   **2.** Percer 2 trous communs à la station 280 aux 4 coins et installer cleco. • Utiliser mèche 2½" sur corner drill, (attention aux marques d'outils).   **3.** Ouvrir 3 trous communs aux «sills», pleine grandeur aux 4 coins. • Percer #40 avec la bague et ouvrir 1/4 en protégeant avec la partie arrière avec la plaque de protection en titane.   **4.** Aléser les trous (0.265 – 0.272) et ébavurer avec le «stop csk».  

This document was written in French by the company. It is presented here in its original form.