

# Developing a Virtual Training System in Aeronautical Industry

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## Abstract

*The paper deals with the developing of a virtual training system to be implemented in an aeronautic company. The strength of the training method based on the use of Virtual Reality is the high degree of interactivity that it is possible to obtain in a virtual environment. In fact, unlike the traditional methods based on classroom lessons supported by slides and videos that only allow a passive participation of the users to the training, Virtual Reality, with its immersive environments, allows the students both to visualize realistically the contents of the lesson, and to interact with the represented objects. According to that, thanks to the collaboration with Alenia, one of the most important Italian companies in the aeronautical field, we elaborated an innovative virtual training methodology, named AVIRA, specifically dedicated to the users working with composed materials. For the development of this system we started from a real case regarding a particular production process of a specific component. The considered production process is the stratification/lamination of carboresin, used for the fabrication of aeronautical components of high technological content, that is currently active at Alenia Aeronautica in Foggia.*

Categories and Subject Descriptors (according to ACM CCS):

I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism - Animation and Virtual Reality

J.7 [Computers in Others systems]: Industrial Control and Process Control

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## 1. Introduction

In Virtual Reality (VR) the human being is immersed in an artificial environment generated by a computer that gives him visual, auditory and tactile feelings. Since the obtainable degree of interactivity in immersive environments is high, it is possible to develop virtual training methodologies that allow the operators to improve the learning process and the successive performances, transferring the operations to carry out from the virtual world to the real one. Although this technology, from some points of view, still presents large limits, the considered studies have demonstrated that in a training carried out with the adoption of VR, a reduction of 30% of the time necessary to reach prefixed objectives can be achieved, [STO01].

## 2. Virtual training systems

A training system based on Virtual Reality can be generally structured in interactive subsets suitable for the management of logical linked operations. A first phase of job plan-

ning is necessary in order to generate training plans according to prefixed target and to the operator's training profile. Subsequently a simulation system generates virtual scenes, that may be immersive or not. At this point, according to the planning phase, the generation of the training actions to carry out takes place and, through an automatic monitoring and data collection system, necessary information, messages of warning and error or specific recommendations for each user are provided to operators. To obtain an intuitive interaction system, the interface must be able to comprise and integrate the various user actions by receiving and analyzing data coming from the sensors in order to store and to coordinate them, [LYDS02]. Immersive systems guarantee a complete interaction with the virtual environment. Therefore we must support all our senses, not only sight, hearing and touch but also those we are not used to consider, such as sense of direction. All that is extremely advantageous in a factory training process. In fact VR allows to operate adequately on structures before these are installed, moreover it

allows to familiarize and to interact with the working environment before becoming effective.

### 2.1. Fields of application for virtual training

Various are the fields where it has already been experienced the employment of VR for the training process. In particular its benefits and limits, now, can be adequately illustrated. An ideal example, that demonstrated the effectiveness of VR in the training process, was presented by Motorola, in collaboration with Adams Consulting Group in the USA, regarding a factory that employed human operators for the supervision of industrial robots. Other studies in the industrial field were lead by Ford's Vulcan Forge in Dearborn, Michigan, [STO01]. Another example of virtual training application regards a MCNC (Machine Computerized Numerical Control) functioning. The research was carried out in order to better understand which were the perception similitude and differences in virtual and real environments, [DS00]. In the medical field, the presence of a virtual MIST (Minimally Invasive Surgical Trainer) system was experimented from the clinics of the entire world, [STO01]. With respect to the training area in the field of spatial operations, the best survey was carried on by the Virtual Environment Laboratory Technology, in association with the University of Houston and the NASA Johnston Space Centre. Using as main application the NASA Hubble Space Telescope, VELT team performed an in-depth series of analysis of data provided from 38 operators who directly lived the immersive experience, [STO01]. Recently the Applied Visuals Ltd. (a VR company in UK) led a research on a virtual training system for the Real Ship Flight Deck for the helicopter Lynx, [STO01]. These are only some examples, many other research works have been carried in different fields, from the aeronautical field to the services agencies, from training of submariner to firemen, [STO01] [DS00].

### 3. The case study in Alenia

Thanks to the collaboration with Alenia, one of the most important Italian companies in the aeronautical field, currently partner of Boeing in innovative aircrafts production, we have identified a VR use of strong corporate interest: training of the operators assigned to the operations of lamination and stratification of composite material components. In particular Alenia, using virtual training techniques, was interested in the delivery of specific formative courses to insert young newcomers and to adapt the competences of the already occupied human resources, with the aim to guarantee a good level of operating autonomy about new generation instruments and methodologies. For this aim we have elaborated an innovative methodology of virtual training, specifically dedicated to the workers assigned to the new composed materials processing. In fact new and actual Alenia projects have highlighted the primary role that composed materials

will have for the new aircrafts design. Thanks to the manufacturing nature, of high technological content, of the production process of carbon elements, the role of the laminator/manufacturer worker acquires a central role as first guarantee of product and process qualities. It's necessary, therefore, to focus the attention on the actual workers training process as well as on the development of possibilities connected to the employment of Virtual Reality techniques for personnel training with the aim to fully understand the peculiarities of the proposed methodology.

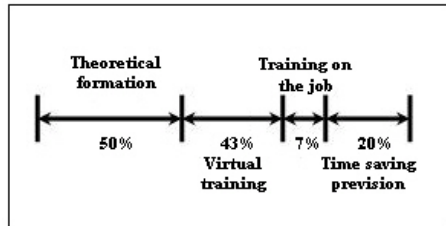
#### 3.1. The workers formative course

The aim of the training course is to provide the students of know-how and operational abilities, necessary to play the role and to carry out the relative tasks. The worker, besides knowing product technical characteristics, processes, fabrication and assembly methods, needs: personal efficiency, efficiency in organizational sphere, good relational gifts, tendency to improvement, aptitude in communicating and transferring his/her own abilities to performance/manuality, availability to operate in context where analysis ability and productive problems resolution are needed, ability to characterize the improvement areas of workers' resources and to propose organic interventions. The formative course is currently articulated in two phases: base modules to provide theoretical formation within the classroom and specialized modules carried out by training on the job. During the theoretical course development in the classroom, specific didactic material for the topic, is provided to all participants. To verify the effective learning level of treated subjects, at the end of the course, a questionnaire is submitted to every component of the class. Then this monitoring previews the rework of collected data and the evaluation of results. After theoretical formation a phase of practical training on the job follows, where the newcomer is supported by a more expert worker in the application of all the fabrication techniques learned. The phase of theoretical formation of the workers is preponderant (85% of time) if compared to the supported one (15% of time).

#### 3.2. The adoption of Virtual Reality in laminator/manufacturer operator training

A more active and effective learning in factory training can be obtained with the use of Virtual Reality. Virtual simulation guarantees an active learning as well as it allows the user to act on the phenomena he/she causes and to observe the consequences of his/her actions ensuring a complex multi-sensorial experience more meaningful than a simple theoretical lesson, [PP04]. The primary aim to reach is the increase of the quality level of training. The actual course for the laminator/manufacturer operator, as mentioned above, includes a theoretical module followed by a phase of supported practice. This methodology highlights two fundamental limits: the learning passivity during classroom and the annoyance

induced to the expert operator during the supported phase. With respect to these aspects, the adoption of Virtual Reality can produce significant improvements introducing, as hypothesized, after theoretical formation, a practice module that includes a training with virtual simulations, [Gar00]. A reduction of 20% of the total hours is foreseen thus reducing considerably the time dedicated to the training on the job and to the classic theoretical teaching. In figure 1 is reported a possible alternative configuration of the formative course.



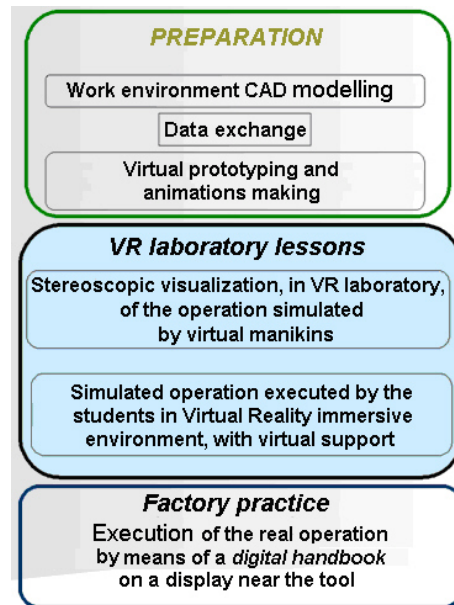
**Figure 1:** An alternative configuration of the formative course of a laminator/manufacturer worker

The main advantages that it is possible to obtain with this approach are substantially two: to create an active learning of the concepts exposed during the theoretical lessons and to reduce the annoyance induced to the expert operator during the supported phase. With respect to the first point, the operator, after the training course, can guarantee a greater efficiency thanks to the higher quality of the knowledge and of the operating abilities required. Moreover, the virtual training allows to reduce the time required for supported training. All that can be seen as a better performance of the same operator and, therefore, a lower amount of defects of the manufactured parts, smaller costs of reworking of the not compliant components and a saving on the manufacturing rejects.

#### 4. Architecture of AVIRA

In collaboration with Alenia Aeronautica we started the training methodology called SAVIRAĬ, Virtual Training in Alenia, (in italian Addestramento VIRTuale in Alenia). The project, oriented to the formation of industrial workers, is based on the simulation, in Virtual Reality environments, of the worker's operation. Figure 2 shows the architecture of AVIRA. For the implementation of such virtual training system a real case was examined that is a particular production process of a specific component. The production process considered is the carboresin stratification/lamination, used for the manufacturing of aeronautical components of high technological content, that is currently active at Alenia Aeronautica in Foggia.

The component chosen for this study is the inboard upper panel, that is the superior panel of a flap next to the fuselage of an airplane (Figure 3).



**Figure 2:** Architecture of AVIRA.



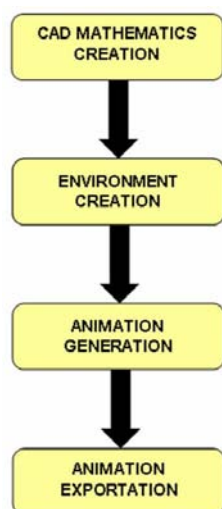
**Figure 3:** Complete representation of the flap.

The choice of this component has not been unintended, but finalized to the description of some fundamental stratification-lamination operations.

##### 4.1. Preparation of the virtual simulations

AVIRA previews a first phase dedicated to the preparation of the simulation. The work environment is modelled with a CAD system and, after appropriate procedures of data exchange and virtual prototyping, the simulations and the animations of the operation are performed. The main steps of this process have been highlighted in figure 4.

The first part of the work has been preceded by the study of the production process attending to the manufacturing of the panel in the clean room of Alenia Aeronautica in Foggia. The starting point of the work has been the development of CAD mathematics and in particular the working tool for the panel. Digital models of this tool, in fact, have not been created and so, before modeling, it was necessary a measurement of the tool in order to obtain a realistic reproduction.



**Figure 4:** The first phase of AVIRA method.

In order to render the scene as much realistically as possible, we have reproduced the whole work environment (Figure 5).

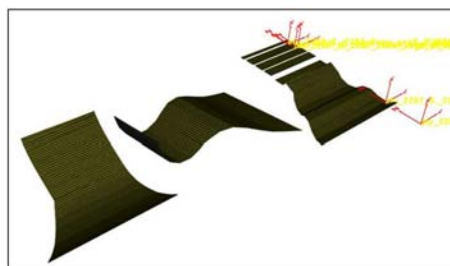


**Figure 5:** Work environment and tools modeling.

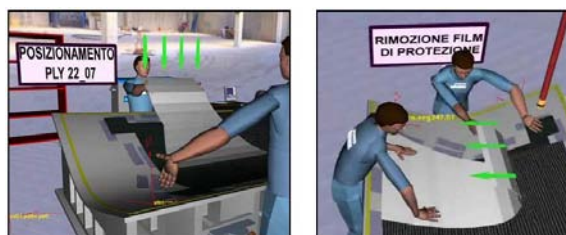
The software we have used for the creation of CAD mathematics was Catia by Dassault Systemes. It allowed to export the digital models in VRML format supported by the simulation software JACK 5.1 by UGS. On the other hand, the problem that we have found with these software was the modeling of deformable geometries like the carboresin ply used in the process. To make up for this problem we have discretized deformable geometries in a certain number of parts. In order to guarantee the continuity of these geometries the adjacent parts have been connected by spins and contact ties. In this way, during the simulated operations of material stratification, it has been possible to show the material deformability (Figure 6).

On the other hand the discretization has increased the number of degrees of freedom needed to control the movements of deformable parts. So, in order to simulate realistically these movements, it has been necessary to assign laws of motion for each degree of freedom (Figure 7).

Subsequently it has been created a virtual environment as

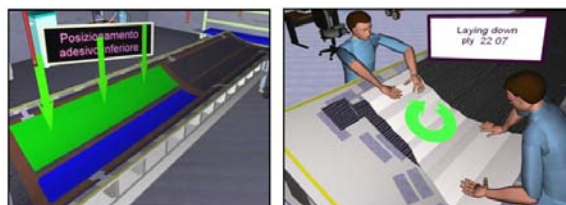


**Figure 6:** Deformable ply created by joining discretized in-deformable elements.



**Figure 7:** Using deformable ply in virtual environment.

much similar as possible to the real one. We have added to the predefined objects bookcase of JACK a new set of mathematics, created ad hoc to set up and represent the different environments used for each production phase. With the aim to create a real digital handbook it has been decided to introduce, in the scene, a series of elements that could make it easier understanding the animation, highlighting at the same time the executive modalities of the most delicate operations. Therefore digital models of arrows, informative billboards and positioning shapes have been introduced (Figure 8), [BC03].

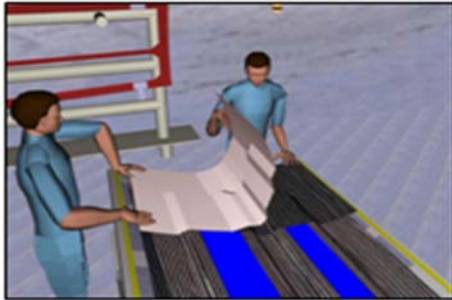


**Figure 8:** The arrows indicate the adhesive positioning.

After the conclusion of the environment reconstruction, the simulation of the productive operations, through the use of JACK 5.1 animation module, has started. The problem that we have found in this phase has been the simulation of the deformation of all the flexible elements to lay down on the tool (Figure 9). In fact, as already illustrated, each deformable element (skins, filler ply, honeycomb, detacher, bag) has been created by defining appropriate connection

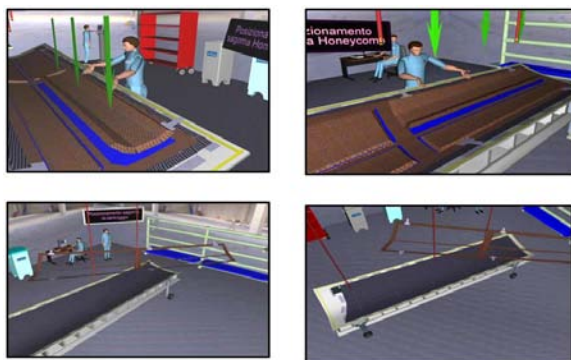


joints between the segments of which it is made up. The simulation of deformation has been rendered by assigning, step by step, the right values to the parameters controlling the angular position of the joints. In this way the correct representation of the deformation caused both by gravity and by the operations of stratification (air elimination below the skin) has been implemented.



**Figure 9:** The hand of the operator helps the movement of the skin.

The tasks that require the motion of the skins, of the honeycomb and of the adhesive have been implemented by imposing relation ties among the moved object and the upper limbs of virtual manikins. In particular, a posture compatible with the operation to be executed by the commands that regulate the movements of the human model has been initially assigned. Subsequently, it has been inserted a kinematic relation of dependency between the segments of the manikins and the moved element (Figure 9). After the allocation of the described instructions, the choice of best shot views has been made. In fact different frames of the same scene can allow to highlight the phases of greater interest for the represented operations (Figure 10).



**Figure 10:** Different frames make it easier understanding represented operation.

#### 4.2. Lessons in immersive virtual environment

The second phase is dedicated to the frontal lessons in laboratory. At the beginning the students, wearing glasses for stereoscopic visualization, attend the simulations created by virtual manikins while an instructor comments the operations (Figure 11).



**Figure 11:** Stereoscopic visualization, in the virtual reality laboratory, of operations simulated by virtual manikins.

The program of the lessons relative to the fabrication process of the flap, structured as virtual animations, has been divided in four "lessons" that show, step by step, the operations that the user has to carry out to create the component:

- LESSON 1 :** Ply stratification: layers positioning and de-tacher film removal.
- LESSON 2 :** Filler Ply stratification: filler Ply positioning and positioning of a whole Ply.
- LESSON 3 :** Honeycomb core stratification and employment: centering shape positioning, adhesive film positioning and honeycomb elements positioning.
- LESSON 4 :** Vacuum bag use: positioning of a whole Ply, nonstick film disposition, bases valves positioning (under the bag), bag preparation for vacuum and pumping circuit connection.

The first lesson explains how practically to execute the stratification of a complete covering Ply and the operation of removal of the non-stick protecting film before stratification (Figure 12). In the lesson it has been emphasized the importance to not omitting such operation to avoid the rejection of the entire panel. In fact the presence of small protecting film borders cause not only the rejection of a very expansive element but, in the worst case, it could lead to a behavior non compliant to the plan directions and compromise the whole system it belongs to. The second lesson, instead, shows how to stratify the filler plies, that are the ply of filling (Figure 13). They are first applied to fill up the spaces between two "honeycomb cores" and, then, as "blocks" for the honeycomb during the successive stratifications that require a partial cover of the same core.

The third lesson shows the operations carried out for the stratifications of lightened and strengthened elements by the honeycomb core overlapping. A centering shape is placed on the tool to make quick and precise positioning of bi-adhesive and honeycomb core layers upon the previously stratified carboresin ply. Once the bi-adhesive is opportunely moulded

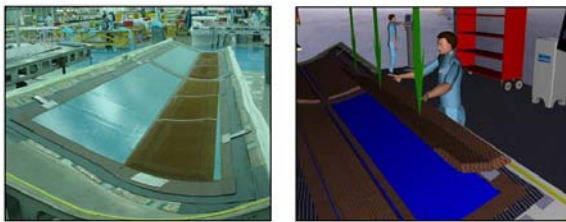


**Figure 12:** The ply kit components positioning and the protecting film removal.



**Figure 13:** Filler ply stratification and immobilizing action on the honeycomb cores.

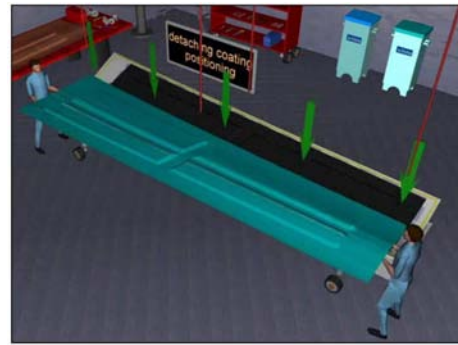
in the spaces that the shape left empty, the cores are placed on the bi-adhesive in order to arrange them. Then another layer of bi-adhesive is laid on the core before the stratification of a complete covering ply (Figure 14).



**Figure 14:** Core positioning in the centering shape on the adhesive.

The fourth phase implies the creation of the pre-vacuum, by the vacuum bag technique. This fundamental operation is approximately repeated both every two or three layers and always after a total covering layer. This pre-vacuum phase, preceding the high vacuum phase and the autoclave, is necessary either to remove the air bubbles caught among the stratified plies, or to guarantee a contact without movements between the layers. The disposition of the stamina mastic on the perimeter of the tool is followed by a placing of a detaching film on the whole tool, within the area defined from the mastic (Figure 15).

At this point the bases of the valves, that will be coupled later with the valves, are placed on the detaching film (Figure 16) and a large polyethylene film, that contains the whole surface of the tool, is placed. This transparent polyethylene layer is the bag and it guarantees, with the mastic and the surface of the tool, an airtight environment (Figure 17). The vacuum, that can be more or less high according to the re-



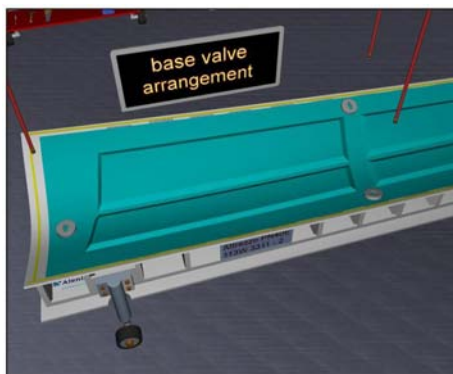
**Figure 15:** Detaching film positioning.

quired operation, is obtained by coupling the bodies of the valves with the base-valve and by connecting the bag to the pumping system (Figure 18).

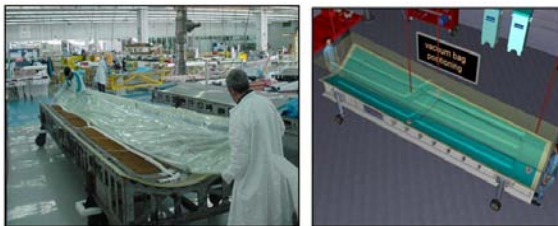
#### 4.3. Simulation of the operations in immersive environment

The simulation phase of the operations in immersive environment, still in progress in the VR laboratories of the University of Naples Federico II, consists of a period of active training where the student/worker, wearing sensors for point of view and body tracking, will have to perform in first person the operations learned in the previous phase supported by a virtual instructor present in the environment (Figure 19).

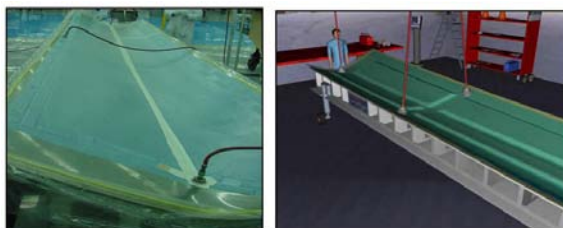
The interaction among the virtual operator and the objects in the immersive environment can be delivered in two different ways: through the use of virtual manikins or through a directed manual interaction approach. The adoption of the virtual manikins allowed, in the first phase of the training, to simulate the work environments, the machines and all the operations that the worker has to carry out. However, this experience has highlighted some limits of the software based on virtual manikins that have oriented the second phase of development of the AVIRA methodology towards the use of the directed manual interaction approach. In particular the chosen software was an in-lab-developed system, named ViRstperson, born thanks to the collaboration between the University of Naples Federico II and the CIRA (Italian Center of Aerospace Researches), The first limit of JACK consists of the necessity to trace the position of all the parts of the operator's body, in order to create the correspondence between the user and the virtual manikin. To date, it is possible only through tracking systems (i.e. VICON) not available at our VR laboratories. The direct interaction between user and virtual object in the ViRstperson environment, instead, only requires the tracking of the position of the point of view and of the hands of the operator in order to obtain the correspondence between the hands of the operator and



**Figure 16:** The placing of bases valve.

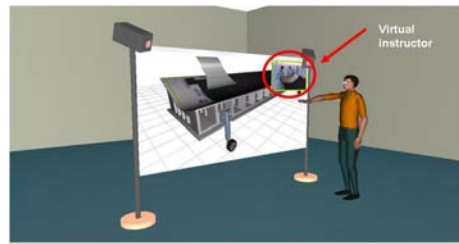


**Figure 17:** The closing of the bag.



**Figure 18:** "Vacuum bag" connected to the pumping circuit.

its virtual avatar. Other limits of JACK are both the level of realism in the representation of virtual environments and the interaction with the objects. In a Virtual Reality immersive simulation, instead, visual realism and simulated world behavior realism cannot be ignored, [LDA04]. As far as visual realism in a virtual environment is concerned the ViRst-person software introduces the possibility to insert real time shadows. Shadows are very significant, not only in order to elevate the acceptability threshold of the immersive experience, but also to perceive the spatial relations between the objects of the scene, as necessary, for example, in the carbonesin filler ply deposition. On the point of view of the realistic interaction with the objects, the ViRstperson allows the reproduction of real physics, with the introduction of gravity and friction forces. The objects in the virtual environment show reactions as much possible similar to that they would have in the reality, both in the direct interaction and in that deriving by forces transmission through collisions and preset



**Figure 19:** Simulation of the operation in Virtual Reality immersive environment.

Kinematic chains, [DL05]. After all, the directed manual interaction will be able to guarantee the user to execute in first person the operations learned in the first training module by verifying, interactively, through the movement of the hands, the level of comprehension of learned operations. The obvious advantage of the directed manual interaction, therefore, is the immediate correspondence between the wished check and the relative carried out action, that makes the learning phase natural, intuitive and, therefore, also faster. The adoption of digital human models allows, however, to estimate visibility, reachability and grasping modalities of the components during the operations. Moreover, it allows to calculate the necessary time and efforts for the execution of the same operations, to preview the possibility for the workers to bear the consequent solicitations, on the base of their subjective anthropometric characteristics, to make ergonomic analyses of the posture assumed during the activity, until evidencing possible risks of damaging for the vertebral column during an action of raising. All these functionalities are precluded by the directed manual interaction. Since the use of digital human models is however foreseen in the first phase of the training, all these evaluations can be carried out, if necessary, during this phase.

#### 4.4. Training on the job

After the phase of training in the virtual reality laboratory, the contact with reality and, therefore, with the difficulties to perform real operations, will become less traumatic by using, in the real work environment, a LCD touch screen display where a digital handbook of the operations is installed and where it is possible to see, even if not in stereoscopy, scenes and animations of the operation to carry out. (Figure 20). Concurrently the operations could be visualized, if necessary, on palm-top devices to be used by the staff to be trained (Figure 21).

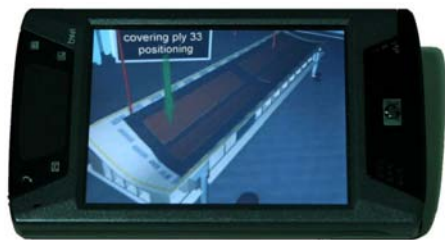
#### 5. Conclusions

In this work we have highlighted how it is possible nowadays a didactic use of Virtual Reality for all the operators not specialized in the use of virtual laboratories. The main advantages of the proposed approach are summarizable in





**Figure 20:** Development of the real operation with the aid of a digital handbook placed on a display near the tool.



**Figure 21:** Palm-top device for the visualization of the operation to perform.

the elevated degree of know-how supplied to the operators, in the reduction of the "supported time" and, consequently, of the direct (supported time reduction) and indirect industrial costs (a better production process understanding means a reduction of the errors). This Virtual Reality application can be extremely important for all those industries where a high degree of specialization of the staff, assigned to the production process, is demanded. Far from being exhaustive in the matter of virtual training the study carried out up to here wants to be only a first step towards the use of such methodologies. This kind of training, in fact, could be already improved by using, for instance, collision detection, in order to guarantee the right assemblage of the parts, or tracing features in order to show the movement to be performed during the operations. Of course a digital archives of all the work operations could be useful as well as the possibility to consult them on palm-top devices provided to the staff, or on touch-screen panels placed near the workspace (Figures 20 and 21).

## 6. Acknowledgments

The authors, who have equally contributed to this work, thank Alenia Aeronautica for the case study. Further the authors deeply thank Prof. Francesco Caputo, Dr. Anna Illiano and Mr. Vincenzo Turni for their helpful discussions and suggestions about future works and Engineers Francesco Sa-

viano, Antonino Gargiulo, Adelaide Marzano and Daniela Mistretta for their technical support. The present work has been developed with the contribute of POR Campania 2000-2006 - MIS 3.16, performing the activities of the Competence Center for the Qualification of Transportation Systems founded by Campania Region.

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