ACCESSIBILITY AND MAINTAINABILITY STUDIES THROUGH DIGITAL HUMANS IN A DIGITAL MOCK-UP CONTEXT

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Abstract

This paper addresses conceptually, and through some practical example, how and why Digital Humans would be useful in a digital environment. The focus is on the implementation of accessibility and maintainability from the very beginning, during the preliminary design.
For the conceptual parts, are addressed the different stages at which the tools are especially helpful. Examples are then given specifically relating to a conceptual design exercise of a trainer jet and space transportation system study.

1 General Introduction

New tools have been developed over the last few years to aid the designers and the various specialty engineers in their tasks. Among others there are the humanoids or Digital Human Models (DHM) and the Digital Mock-Up (DMU).
This work represents the excerpt from a wider research aiming at increasing knowledge and cross culturing between the general design field (both aero and space) and the ensemble of the advanced software tools for support (CAD, DHM, DMU, etc.).

Some product features, need to be pursued from the very beginning of the design phase. Neglecting them would lead us into the risk of wasting money and time in successive stages of the design to correct the mishaps, or even worse letting a product out of the production line without the proper level of, say, maintainability and accessibility. The experience coming from previous works in the field of both space and aeronautics [1], [2], [3] have lead us to select some of these new tools to enhance our methodologies and obtain better results in the implementing of desired features.

Among others of the cited tools, we have already used digital mock-ups. DMU has allowed to better visualize some products or parts. It allows to detect product defects as early as possible in the product lifecycle. DMU combine advanced 2D and 3D visualization with robust analysis of large product assemblies. Among other features we recall: dynamic interference checking, cross sectioning, advanced 2D and 3D viewing.

Stepping up we have targeted a product of the DHM group and we have applied our previous knowledge to it. The results are specific analysis aiming at improving the accessibility and maintainability in different stages. In particular we underline the importance of the tools not only for designing maintainability, but also for designing adequate procedures so to assure that both during the initial production stages as well as the subsequent, the humans interacting with the machines are assured the best possible interfaces and procedures.

The aim is to acquire specific knowledge on the capabilities of the humanoids in the design fields and evaluate where and how to support the design process with this tool.

Preliminary results are presented here. Deepening into the following stages of the research we will focus especially on the higher level methodology for use of DHM. At the same time, in cooperation with experts in human modeling, we will highlight the limits of the DHM so to avoid the description of procedures severely impacted by the difference between a human and a DHM.

2 What is a Digital Human Model?

In design teams today collaboration between the professions is the key element that results in appealing and functional user-centered products and procedures of high quality that are safe to use or carry out.
Assessing requirements can be time consuming, costly, and variable in their results. In recent years it has become easier to visualize, evaluate, and quantitatively analyses human characteristics, behaviors, and interaction in the digital environment.
Important issues such as fit, stress, comfort, fatigue, and collision detection are only a small sampling of the many capabilities effectively employed through the use of Digital Human Modeling (DHM) software tools [4].
A DHM manikin allows the designer to represent a human through numerous variables such as height, somato (body)-type, gender, age and garments. These types of models are important when evaluation and analysis of human characteristics and actions are relevant to the design process and when it may be impossible to actually test real people in a particular situation.

In its basic realization the DHM is based on the schematics of a human skeleton. Bones are represented by segments and joints to allow simple movements. Figure 1 shows the particular type of schematics used for Jack, the DHM we have used for our analysis described later on. Thus movements follow the basic framework schematization of the human body.

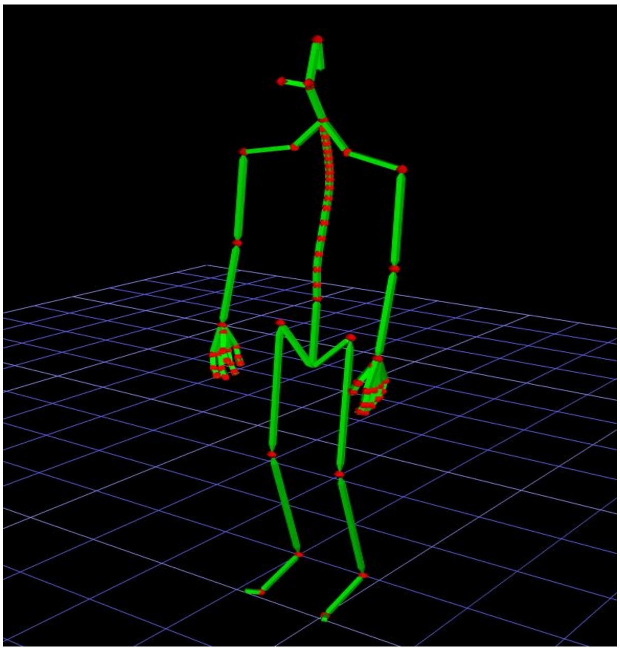

Figure 1: Jack’s skeleton

The model is so structured to allow only acceptable postures and real human movements. Body joints such as hands and fingers are the most complex. Due to the above mentioned basic scheme, errors in the analysis of the movements and postures during maintenance actions are induced. The cognitive aspects are, for the moment, resolved by the DHM operator/engineer. Detailed analysis regarding these limits have been carried out, but they are presented in different works. Interesting feature is that, normally, the DHM are based on anthropometrics databases, so it is possible to choose what type of human we are considering, and moreover it exists in some models the possibility to alter proportions among body parts. Figure 2 represents a screen shot from this feature as manageable in Jack. On this basic framework making up the skeleton are than added the muscles, by dedicated geometries so to have a complete body, as shown in figures 4, 6,7. Different postures are donated to the DHM by indicating angles of the different joints and imposing constraints, such as foot on ground, etc.

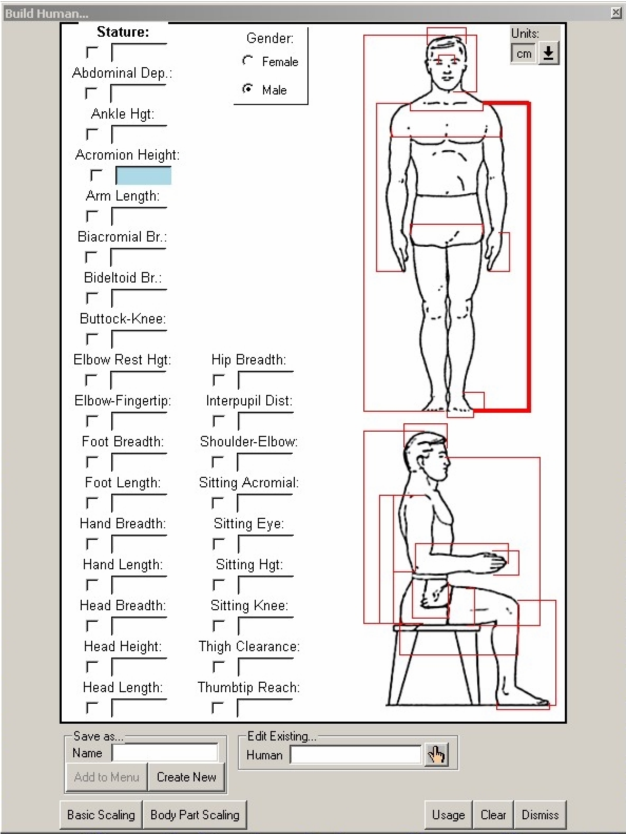

Figure 2: Anthropometrics data settings for Jack

2.1 Overview of existing DHM for engineering purposes

Here is a brief description of the main type of existing models, used for industrial purposes:
1980s Jack created by Badler et al was a NASA-supported effort in conjunction with the University of Pennsylvania. Derived from the Tempus model, Jack became a scalable linkage and hominoid model with flexible spine and limbs that could be articulated through inverse kinematics. Jack can be positioned for reach analysis and visual interference analysis as well as strength, posture, and motion analysis.

1984 Safework was developed at the Ecole Politechnique in Montreal, Canada. The model has 6 default manikins and an anthropometrics module to create human beings from any population anywhere in the world. Safework performs extensive ergonomic analysis. A unique boundary manikin ensures designers accommodate their entire target population using a minimum of manikins. It incorporates inverse kinematics methods with a fully enfleshed human graphic, which integrates with CATIA CAD software capable of handling complex geometry.

1998 TechMath's Ramsis and Anthropos are human modeling systems for ergonomic analysis, design, and visualization. Ramsis is used extensively in the automotive interiors and cockpits designs. Anthropos is a plug-in for 3D Studio with excellent visualization and ergonomic analysis and simulation abilities.

It was not in the purpose of this study to compare different tools or benchmarking different capabilities, so we have focused only on one type of DHM, Jack.

Hereafter are listed some of its main features:
Jack is based on body dimension measurements taken from the 1988
Anthropometrics Survey of U.S. Army Personnel (ANSUR 88).
Jack human figures have 69 segments, 68 joints, a 17-segment spine, 16-segment hands, coupled shoulder/clavicle joints and 135 degrees of freedom.
Jack obeys joint limits derived from NASA studies (Anthropometrics Source Book, Vol. 2: A Handbook of Anthropometrics Data, Technical Report NASA RP-1024) and can be represented as stick figures, wire-frame, shaded, high-resolution or transparent model.

3 Using DHM in the context of an advanced design methodology

Systems engineering covers several aspects; among them there is preliminary design of an airplane. Preliminary design has the power to deeply influence most of the subsequent choices that will affect the life of an airplane. Being such a critical phase new methodologies have been devised to increase efficiency of the design process. Aside from this, the last years have seen a proliferation of new or revised tools that can be used in support of the design activities.

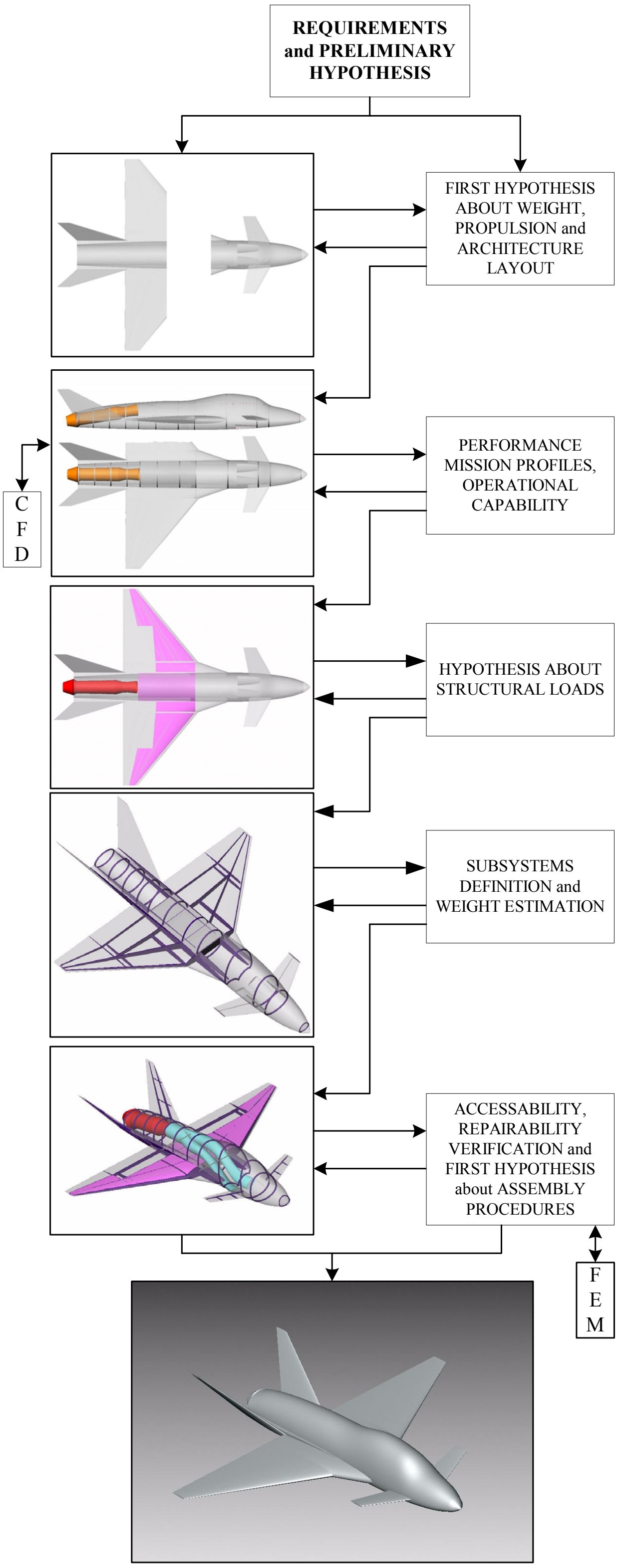

Figure 3: Design methodology flow

An advanced design methodology would incorporate all these and obtain the maximum in terms of performance and quality of the design.
A general scheme, developed by the Aerospace Systems working group of Politecnico di Torino is shown in figure 3 as already presented in other works [1] [2] [3].
It was used to develop the preliminary design of the SCALT project (an academic exercise concerning the development of a high performance trainer, the same we used to perform our maintainability evaluations for the present work). We recall here some of the main results achieved, so to highlight the areas were DHM would come into play (both the ones explored and the remaining ones still to look at).
CAD has proved to be extremely useful if used as a complete tool to manage the development of the various arts. The results have been assessed and presented elsewhere so will pass it on here.

Using DMU, starting from conceptual level allows us to improve the overview of the system layout by means of:

- verify the actual possibility of the airframe to contain all systems foreseen and check the right positioning of each equipment;
- allowing a accurate and easy estimation of the center of gravity and geometrical quantities;
- allowing preliminary studies of maintenance characteristics;
- studying the interface between equipments and structural elements.

On top of this DMU represents a very good mean to integrate the Conceptual Design with a methodology [9] oriented towards Reliability, Availability, Maintainability and Safety.

The technical activities are mainly the conceptual design and the development and definition of the support system.
In particular we have seen how useful can be the DMU tools in support to the classical analysis in this domain. We remember here only the Preliminary Failure Modes and Effects Analysis (PFMEA), useful for performing the Safety and

Reliability project design; the Reliability Centred Maintenance (RCM), useful for optimizing the Maintenance program; and the Maintenance Process Failure Modes and Effects Analysis (MPFMEA): i.e. FMEA performed on the succession of operations of a maintenance process in order to prevent critical situations or probable mistake sources.

Critical area to be worked with particular r attention during this phase, but presently out of scope, are essentially connected to fluid dynamics, thermodynamics and similar in the design flow.

3.1 Scenario definition and potential development

We have so far seen the flow of design activities as per the latest design methodologies. We have also noticed that some advanced software tools have been already incorporated and their value assessed. Now we move a little bit farther on and we identify a few areas where a preliminary study of specific features, supported by the use of a DHM would be extremely interesting.
The basic idea behind this activity was to point out, at two levels, the main advantages of using a DHM: at conceptual or methodological level, identify which areas are most worth or most suitable to investigation or analysis using the DHM; at lower or operational level, identify which are the main constraints still limiting the use of a DHM in a more consistent and structured way.
Taking from the scheme in figure 3, we focused for this research (partially explained in this work) specifically on:

- The general layout of the internal accommodation as support to interfaces and compatibility with human users.
- The subsystem definition especially in support of the future maintenance operation. This needs to be borne in mind since the very beginning, to avoid affecting drastically the future phases of the life of the item. During this phase, specific training procedures can be also developed as the configuration is frozen; This would be particularly valuable in case of systems with peculiar need of support, such as special ops or off shore. Of course this is part of the typical realm of DHM, i.e. accessibility studies.
- Accessibility and assembly procedures would gain a lot in long term decision if the DHM could verify early the choices proposed. The idea is to expand from simple accessibility to a complete maintenance study.

Of course all this can be done later on if it was forgotten in the initial phases, and this would repair errors and further established the value of theirs tools as powerful in repeating real conditions and evaluating possible solution to fix problems. Everything would have to be carried out under the development of operational scenarios.
So far we found that the use of the DHM could be well pushed beyond its actual use, especially in some industrial areas. But, remaining in the aerospace field, we prepared a basic subdivision of the macro areas. Users (pilots and passengers) are on one side, maintenance and assembly operators are on the parallel branch. For the first category, very similar for some aspects as they are far apart in operational needs, a lot of work have been traditionally going on in most of the industries human engineering departments. The other group, as we envisioned it, should in the end greatly benefit of the efforts during design. The leap ahead would be done by putting DHM at work not only during the analysis phase, as we show here, but also in developing complete scenarios. These scenarios would be used for establishing real worlds connections with the DHM and in so doing assuring complete models for production, maintenance and any other action involving humans having specific knowledge. Moreover whenever the same scenarios could be redefined for expertise at different levels, the DHM would come the original utility, analysis, by suggesting areas of improvement or critical resources needs.
In order to really expand the capabilities of these tools, some basic questions need to be

asked during the modeling on the computer. For example in the case of passengers, how they would react to specific situations or external stimuli. In other words we are already exploring the capabilities jack would need to receive implemented in order to develop his cognitive capabilities. As of now this is done trusting the judgment of the operator who puts him in different situations. The need is now to write paradigm of these situations and apply them to the mannequin.

4 Preliminary results and evaluations

4.1 Space Tourism

A said earlier previous studies have defined a preliminary configuration for a Space Tourism aircraft. The basic requirements were: reusable, operating ceiling 100 km, 1 pilot and 3 passengers. The DHM has allowed us to integrate in the preliminary design phase the internal accommodation for the pilot and the passengers.
The first point was to evaluate the internal dimensions minimum to configure the seats.
Two possible configuration have been evaluated as possible: T configuration (pilot in front row, passengers in back row), double tandem, car style (pilot and one passenger front seats, two passengers back seats). Figure 4 shows the two layout.
The two configurations have been influenced by several considerations, but typically we have considered the layout of the windows. It is assumed to be a commercial tourist flight, so passengers expect to see what they pay for, they would not be happy just floating in space.
The double tandem layout allows to have a leaner cross section in the passengers area. The three passengers will have different degrees of accessibility to the external view. In particular one will have the side window view plus a much wider front view through the pilot windshield.
The pilot is on one side of the panel (as in commercial and transport airplanes), so has direct access only to side instruments.

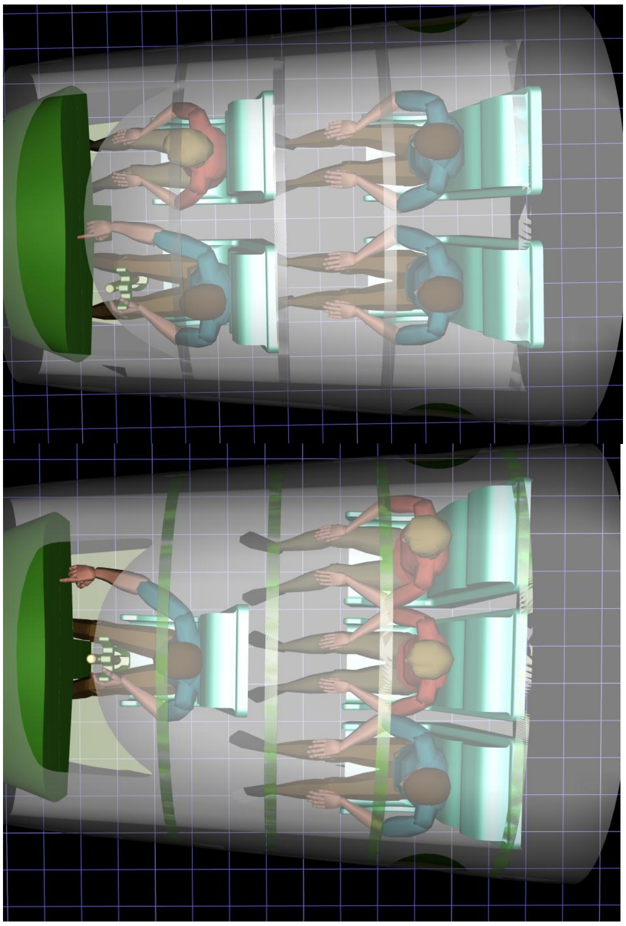

Figure4: Visualization of seats layout

The T layout presents the distinctive advantage of having the passengers arranged together and the as far as possible from the cockpit, without having bulkheads or separate areas. This definitely increases the level of safety in case of passengers interference with the pilot.
Major disadvantage is that the one central passenger will not have direct access to the window, unless a window is positioned on the roof. Moreover this configuration leads to sequential access from the 3 passengers, which assuming bulky or specific garments might lead to impeded movements.
This is supposed to be a very cheap system (high affordability) and we assumed that the passengers would fly into space with little or no specific training. Due to this no bail out possibility have been evaluated. That is the seats are standard, space qualified seats, no ejection capability or anything. This feature allows to put the seats as close as possible, compatible with a

minimum of movements allowed to the passengers. No free areas around the seats rails or anything.

To assess the compatibility layout-passengers we have defined the windows position as taken from the CAD model and confronting them with the sighting capabilities of the passengers. These are given by using jack view cones. Particular attention was given to the pilot as safety criteria influence his ability to see outside.
The main guideline was to allow external vision without structural modifications. In order to assure structural continuity and ease of modification, the CAD models were developed using the UG WAVE control structure.
Using WAVE, allows to take into account the position of the structural bearing frames, while building a series of CAD parametric models within which the position of the windows can be displaced without the risk of interruption of a structural element.

Taking advantage of the control structure it has been easy to realize two different lay out of the same cabin. The difference is the seats arrangement and the initial position of the windows.
The first level of analysis has dealt with the comparative evaluation of the two layout described earlier, T and double tandem
The main criteria followed were:
Room available for each passenger
External view for each passenger
Seats accessibility and hatch positioning

Final choice has privileged the double tandem configuration
After the layout has been decided we have run an optimization analysis for position and dimension of the windows. The process has been carried out through a series of iterations, complex and time consuming. The main hurdle to overcome has been the still far from complete integration between the CAD environment and the DHM tool. Due to this we have been forced to follow over and over the loop shown in figure 5. the main draw back of this process is that the loop has be run manually. That is to say each step is controlled by the operator and is run independently. No automatic tasks.

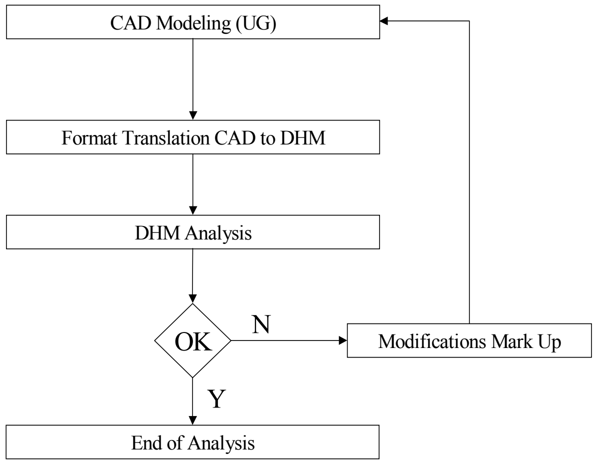

Figure 5: Jack analysis loop

By using Jack we have identified the position, that were deemed to be the most natural. The evaluation was not based on numerical analysis but only visual compatibility.

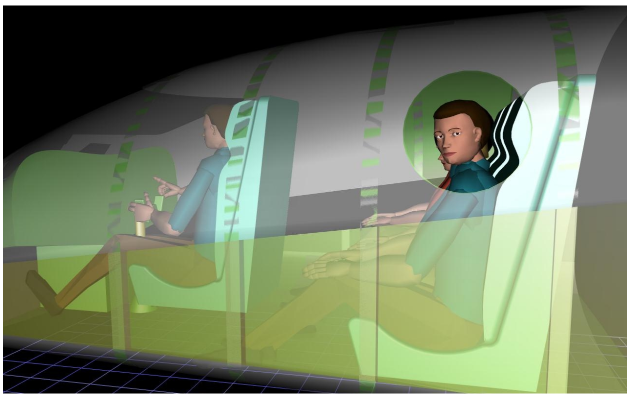

Figure 6: Posture analysis image

From this basic example a few evaluation have come out. Using a tool like DHM during the preliminary design, requires a rethinking of the conceptual design procedure. The use of DHM must be foreseen from the beginning and appropriate analysis devised in order to better take advantage of the tool.
The analysis we have carried out were exclusively of static type, which is the level of accu-

racy sure is not adequate to a real product design.
We have discovered a remarkable limit doing these analysis: the results suggest if the position allows a certain angle of vision or postural problems (see figure 6), but nothing gives us indication about the possibility to hold position for short or longer times.

Whenever the full integration would be reached, the problem of modification management would be reversed on the CAD system. It should anyway be able to deal with the changes and allow easy transport in and out the DHM environment.

4.2 SCALT

In a previous conference [4] we presented a work summarizing the experience of our research group concerning the use of DMU for the definition of maintenance procedures.
The work was specifically targeted on the secondary power unit of the SCALT. SCALT is a project developed by the research group down to the end of the preliminary design.

Now, with the support of the DHM tool the procedures have been analyzed to evaluate if they are all compatible with the limits of human operator performing the tasks
First step was to carry out an accessibility analysis. That is the limits given by the openings in the fuselage and the postures required to perform the tasks (see figure 7).

A first round analysis have brought to our attention that a simple task, as it is the replacement of an hydraulic pump, can become extremely difficult if the working volumes around the object are not preserved. After we have acknowledged the problem, which is not negligible, we have defined a paradigm of different solutions:
Repositioning of the whole hydraulic pump. This solution requires the overall review of the configuration of Accessory Gear Box, which is suppose to drive it. This solution is, of course the most expensive.

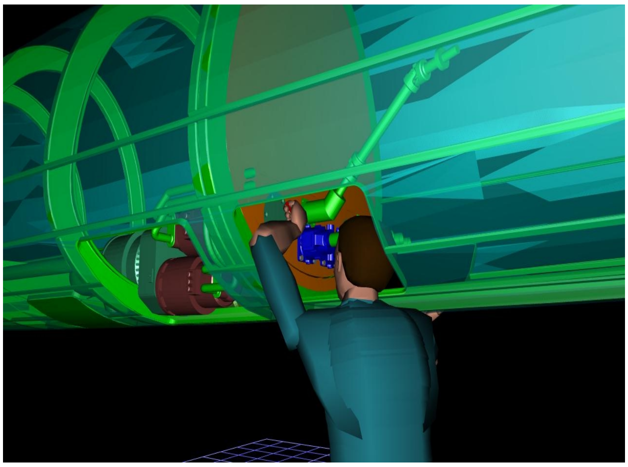

Figure 7: Jack at work.

Establish a disassembly sequence, affecting various elements, aiming at giving the operator enough room to operate. This choice implies several tasks, many parasite operations before we can do the desired one, high logistic impact due to longer down times.
Design and manufacture appropriate and specific maintenance tools to reach those areas or perform those tasks, precluded to the human being.
In the real world such a relevant problem as the impossibility to reach an element to be replaced, never happens at such low level of definition. We would expect it to be tackled and solved during the design of the aircraft subsystems.
Still open issue is the definition of the maintenance scenario. That is to say the complete definition of the maintenance procedure should be supported by a thorough knowledge of a model maintenance operator. The DHM allows the analysis of static postures as well as movement. But performing the second task of the above we encounter a new series of pitfalls. All of them are related to how the DHM operator, does the modeling of the human actions and transposes them into the software.
In this case the problems fall in two main categories:
At biomechanics level, we would like to have a DHM able to move smoothly and reflect as faithfully as possible the degrees of freedom of the human body.

Operational problem, means that we have to model the actions performed by the human handyman in the most compliant fashion. At present we have no clear catalogue of what the human would do in a situation like the one we rebuild in the digital model. The big gap is between the people at the consoles, programming the DHM and the maintenance operator. The gap should be filled as already stated pursuing two main ways: accurate definition and modeling of scenarios, and increase knowledge of real world procedures.

4.3 Application to space

Specific and very preliminary evaluations have also been made regarding space operations either on ground and in orbit.
Satellites and manned permanent structures are growing in complexity and they undergo an extensive series of operations and testing on ground and for some of them in orbit too.

The analysis have been carried out on potential on orbit assembly operations and ground assembly. The on orbit operations as of today imply basic maintenance on satellites in Low Orbit and assembly operations of the International Space Station (ISS). But in the near future, some satellites might be integrated in orbit.

As far as our DHM is concerned, we have benefited from some support from Alenia Spazio Torino. As we can see from figure 8, we have dressed Jack with a space suit and we have evaluate its movements. Having no embedded limits for this postures we have based the movements on our experience and sensibility.
For this type of application the use of DHM can be seen as a bridge between the present use of neutral buoyancy simulators and the, still some how at large in the future, virtual reality training environment.

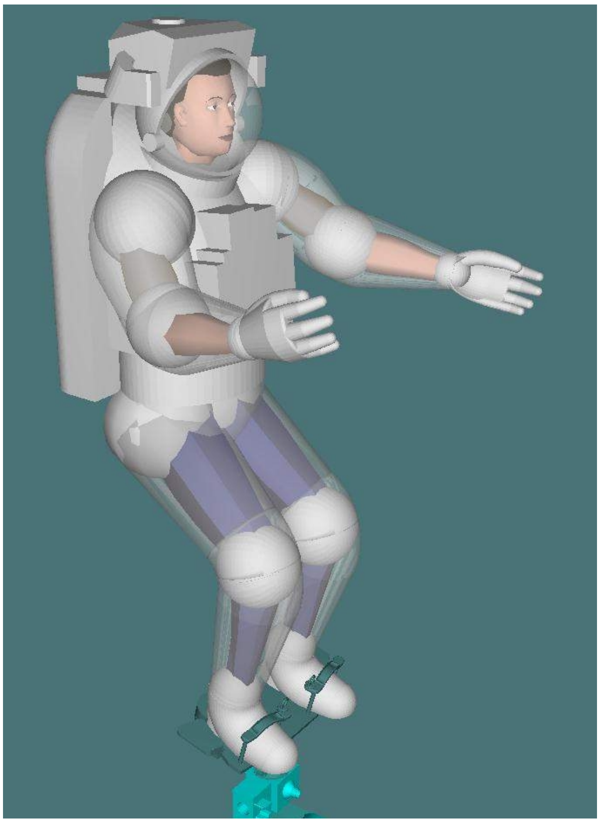

Figure 8. Jack dressed for EVA
(image courtesy of Alenia Spazio)

Different is the value of the DHM in ground operations. Analysis have shown clear limits, as in the SCALT, in some ground assembly operations for satellites. The tool would be used in this case in a similar way to the aeronautical use, and it should be clearly defined during the first steps of the project flow. A difference in this area would be in the case of developing training procedures for the personnel operating in ground assembly facilities. The time and effort spent in developing procedures very specific to one item might be a lengthy procedure and not worth while in case of procedures limited in time. An example of use of DHM for illustrating assembly procedures is given in figure 9. The basic concepts are now clear, but no usable results have been achieved so far.

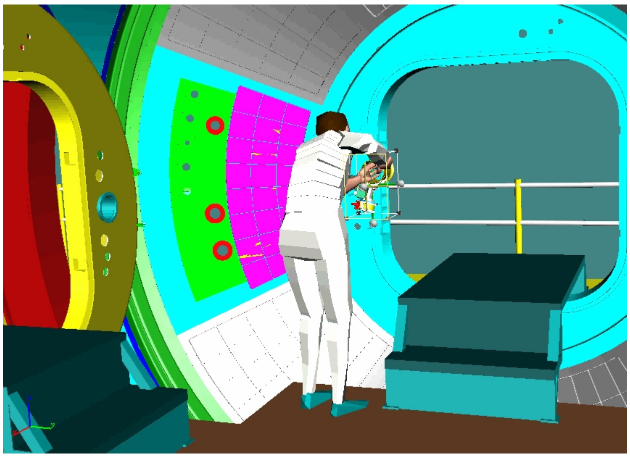

Figure 9: Jack at work in module
(image courtesy of Alenia Spazio)

5 Conclusions

This work is a first insight towards a complete methodology for the use of DHM in a wider field and more extensive way than at present. Our analysis have yielded some preliminary results which can be summarized in two main areas.
We have begun from some basics accessibility and maintainability analysis as a base start for a wider scope methodology. The use of DHM can be extremely valuable in many areas and different stages of product development, well outside its present domain. But the use in new areas requires the definition of a new paradigm. The main points still to be clearly defined are where to use it, that is at which point during the project flow; how to use, which means have clear I mind which are the results sought after. We have not done any economical assessment of the costs or returns, yet. But the acquisition has a cost (software and hardware) and the usage too. So improvements and paybacks need to be identified and quantified.

We have realized that the DHMs still miss fidelity at some levels. For example true correspondence with human postures is still down the road. It might be disregarded for some purposes, to some extent, but must be taken in account during the use or the analysis would be not completely reliable. Another miss is the possibility to evaluate if the movement are truly man compatible not only from a physical point of view. These aspects can be partially bypassed by having an expert of the field associated to the operator
Our experience directs us towards the software developers and human behavior experts. That is we would like to address the developer to have new modules (say capabilities). As for the other aspects we are now working towards giving the DHM some kind of cognitive capabilities.

The concept of application is now clear and needs only to be refined, tailored and targeted to the different phases or towards the different purposes we are looking for.

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