ABSTRACT

One of the facilities available at ALTEC S.p.A. is a Neutral Buoyancy Test Facility (NBTF), in which reduced gravity conditions can be simulated from the operational point of view. The term “Neutral Buoyancy” is used to describe something that has an equal tendency to float as it does to sink. Persons and items / elements of equipment that are configured to be neutrally buoyant (which is accomplished with a combination of weights and flotation devices) result to “hover” under water. With the application of the neutralization techniques, the level of buoyancy can be trimmed and set according to the specific test needs (e.g. for simulation of zero-gravity, Moon and/or Mars gravity environments).

While this facility has been utilized as a support to the design development and verification tests of the ESA Laboratory of the International Space Station, Columbus, its utilization has been indispensable to verify the feasibility of fundamental system flight operations developed by the industrial team.

The appreciation for the utilization of such a facility during the design phase of manned modules has been at the basis of the choice to use the NBTF also for the verification of the design and of the operational scenario of the EUROBOT System (developed by Thales-Alenia Space Italy (TAS-I)) using, as a test article, a dedicated Wet Model.

In particular and relevant to the in subject Symposium on Artificial Intelligence, Robotics and Automation in Space field of interest, it is noteworthy to describe the underwater test developed in the ALTEC NBTF utilizing an EUROBOT Wet Model – EWM (designed and produced by a consortium led by TAS-I including EADS Astrium) the aim of which was to conduct functional tests in Neutral Buoyancy conditions.

The NBTF has been recently inserted by the European Space Agency (ESA) in the list of Ground Based Facilities (GBF) which are made available through ESA to the European scientific community, on the basis of an open tender, which provides funding and accelerated procedures (refer to the following site: http://www.esa.int/esaMI/HSF_Research/SEMXT6UXSG_0.html)

Purposes of this paper are: i) to present the NBTF, highlighting the components and major characteristic and potentiality with respect to, in particular, its application in support to robots and automation devices design and performances as well as in support to train personnel for human-artificial equipment collaborative tasks; and ii) to provide some snapshots of the EUROBOT Wet Model performed tests be considered as a successful approach.

1 INTRODUCTION

The scope of the paper is to provide: i) the description of the ALTEC NBTF, ii) a short description of the EUROBOT Wet Model developed and build by the consortium led by Thales-Alenia Space Italy (TAS-I) including EADS Astrium utilized for the functional tests performed during the two developed test campaigns, iii) the tasks performed by the ALTEC NBTF Team inside the facilities during the performed tests campaigns and
iv) the advantages in support to space robots design and operations description.

2 NEUTRAL BUOYANCY TEST FACILITY DESCRIPTION

The Neutral Buoyancy Test Facility (NBTF) incorporates:
- a water tank
- a control room
- a meeting room
- a medical room
- handling & lifting system
- support systems
- subject (diver) equipments

Water Tank

The Neutral Buoyancy Tank (see figure 1) consists of an octagonal 340,000 liters (75,000 gallon) water tank 5 m (16.40 ft) deep by 9 m (30 ft) between two opposite walls (see figure 2 for layout and overall dimensions). The NBTF Tank is constructed by eight iron vertical rods that support eight walls; four lateral walls are iron reinforced panels, while, the remaining four are Plexiglas panels (156 mm thick). The later permit the observers placed outside the pool, from inside the control room and from the public area to follow the execution of the test.

Control Room

Engineers direct NBTF activities from a control room located adjacent to the tank (see figure 3). The control room includes consoles for three participants, TV monitors that provide two views of the tank interior, direct communications with the subjects, and audio/video recording capabilities.

Meeting Room

Close to the control room, and with direct access, a meeting room is available with the possibility to accommodate up to 15 people.

Medical Room

A small medical team is present to monitor the
condition of all the divers. A dedicated room is available, at water level, for medical pre- and post-dive check and resolution of emergency problems, if occur.

Handling & Lifting System

The NBTF is equipped with one mobile crane for lifting of a complete mock-up. Equipment is lifted from ground to the top of the tank and into water using an up to 12.5 ton hoist.

Support Systems

Audio System:

The main audio system (see figure 4) consists of a one-way network (from Control Room to tank) in case of use of standard scuba equipments utilization and a two-ways network in case of LAMA helmet utilization (refer to “Subject Equipment” paragraph for more details on this item). The audio is patched to 2 underwater speakers in the tank to allow all divers to hear the communication from the control room. The meeting room, the water level and the public area are provided with speakers that permit the test attendances to hear the communication between the control room and the tank.

Video System

One of the primary sources of test data at the NBTF is videotape of the test activities. Currently there are 2 underwater color video cameras in operation (refer to figure 4): 1 wall mounted and 1 swim camera. The wall-mounted camera has remotely controlled focus, zoom, iris and pan & tilt units. The swim camera is operated by a diver who closely follows and documents the execution of the test. Two monitors are located in the control room (one each camera), one in the meeting room, one at water level and one on the public area. Two video recorders are available, one in the control room and one in the meeting room. The PALS standard video signal can be recorded.

Electrical System:

The NBTF provides the user with 220 single phase VAC and with 380 tri-phases VAC provided in the control room and in the meeting room.

Network Interfaces:

The NBTF provides the user with network interfaces in the control room as well as in the meeting room.

Subject Equipment

The subject will wear, with the exclusion of the mask and the regulator, standard SCUBA equipment composed of:

- Wet or dry suit (dry gloves are also available)
- Air tank
- Buoyancy Compensator Device – BCD
- Weights

3 EUROBOT WET MODEL SHORT DESCRIPTION

In 2003, the European Space Agency proposed to develop an EVA assistant robot. This assistant would save EVA sortie time. This could be achieved by:

- Enabling to better prepare the sortie by performing at the intended worksite close up inspection, initial preparatory work
- By preparing the EVA sortie work in transferring tools and equipment needed at the worksite prior the sortie.
- During the EVA sortie, by assisting the astronaut during the work itself providing addition support restraints, viewing & lighting capabilities or powering means.
- After the EVA sortie by cleaning the worksite, storing away tools and equipment

While EUROBOT can support the EVA sortie, it can also perform in automatic mode small equipment exchange. To obtain an early feedback on operations / interaction aspects, an early prototype of EUROBOT capable of operating in a wet environment has been developed for ESA by a consortium led by Thales-Alenia Space Italy (TAS-I) including EADS Astrium.
The EUROBOT Wet Model – EWM (Figure 5) mobile segment is similar in size and configuration to the intended Flight Model. It consists of a central body structure with three identical arms, each with 7 joints are mounted.

![EUROBOT Wet Model](image1)

**Fig. 5:** EUROBOT Wet Model

The arm length (1.2 meter) and strength (100N in a stretch configuration) are similar to those of a human. All arms are equipped with cameras and end-effectors. The EUROBOT Wet Model end-effectors are simplified and capable to grasp an EVA hand rail shape only (see Figure 6). A head camera on a pan & tilt mechanism provides a global monitoring view of the worksite. The EUROBOT wet model has been made neutral buoyant such to simulate the real operative environment.

![EVA Handrail](image2)

**Fig. 6:** EVA Handrail

The EWM was provided with an emergency stop button, operable by the divers, such to enable the complete shut-down of the model in case of emergency.

4 PERFORMED TESTS

4.1 First Test Campaign

4.1.1 Purposes

Purposes of the first tests campaign were to check the water proof of the EWM, to perform the tuning of the model neutralization and to execute first set of functional tests (vision capabilities and limited movements).

4.1.2 Test Set-up

The test set-up consisted in a very simple structure provided with two portions of an EVA handrail, placed orthogonally one to each other, and a box (see Figure 7).

![First Test Campaign Set-up](image3)

**Fig. 7:** First Test Campaign Set-up

4.1.3 Performed Tasks

During the first test campaign the following tasks have been performed:

- For the water proof test, aimed to verify the capabilities of the sealing items, the EWM was kept submerged into the water, restrained by the mobile crane, for 4 hours. No human intervention inside the water pool was required for such an operation.
- Even if the wet model has been made neutral buoyant already during the manufacturing process, a fine tuning of the neutralization was performed by installing, mainly within the main body volume, positively buoyant (specific gravity less than that of water) items (i.e. polystyrene). This task has been performed by the ALTEC NBTF team.
- A first set of functional tests, aimed to verify the robot performances for what concern the vision capability, the movements control and the
The EWM was commanded to perform the functional tests sequences by operators located in the control room (see Figure 8) which also supervised the correct execution of the movements with respect to the preliminary performed simulation.

The ALTEC NBTF team intervention during these tasks was limited to the set-up of the EWM on the submerged test bench at the beginning of the tests sequences (morning) and the removal of the model from the pool at the end of the tasks (evening).

4.2 Second Test Campaign

4.2.1 Purposes

Purposes of the second tests campaign were to perform a set of functional tests in the field of the locomotion capability of the model along pre-defined paths and the removal of a box.

4.2.2 Test Set-up

Due to the increased test objectives, the set-up of the work bench was improved in terms of dimensions and items; indeed (see figure 9) other than the already installed box, this implemented a higher number of EVA handrails portions such to allow more complex movements paths and another tool box with the capability to be opened by means of a hinging cover.

4.2.3 Performed Tasks

During this second test campaign the following tasks have been performed by the ALTEC NBTF Team:

- On a daily basis the set-up of the test environment was needed. Such set-up consisted in installing, evening, to remove it from the water and place it on the supporting structure.
- Still on a daily basis the neutralization of the model was checked and eventual corrective actions were put in place.
- During the main activities, in selected time slot during the test days, ALTEC NBTF team members acted as support to the EWM in receiving from, and giving back to, the model tools.

It is important to notice that during the tests sequences that foresaw the involvement of ALTEC NBTF team members as divers, according to the ALTEC NBTF safety utilization rules, two divers were present into water, one acting as main diver and the second as safety divers, and a medical representative was present such to immediately intervene in case of emergency.

5 ALTEC NBTF ADVANTAGES IN SUPPORT TO SPACE ROBOTS DESIGN AND OPERATIONS

There are many advantages provided by the ALTEC NBTF utilization in support to space robots design and operation and these can be categorized in two main fields:

- Relevant to the facility
- Relevant to the ALTEC NBTF personnel
5.1 Advantages relevant to the facility

The main advantages of the ALTEC NBTF are relevant to the fact that it is the only one available worldwide completely out-of-ground (see Figure 1), it foresees transparent walls from which the complete scene inside the pool can be followed from outside (see Figure 10), the control room is located adjacent to the pool in correspondence of a transparent wall (see Figure 11) and, in addition, the length of the needed umbilical for the control of the submerged models can be reduced at the minimum (see Figure 12).

Another aspect of importance is that, due to its reduced dimensions, the utilization costs of the ALTEC NBTF are significantly less than those required for the utilization of the other available on the market; indeed, for example, the quantity of water contained into the pool is less than that present in other (bigger) facilities and, therefore, the required energy consumption for the warming is reduced.

5.2 Advantages relevant to the ALTEC NBTF personnel

It has to be noted that during the lifetime of the ALTEC NBTF the following tests have been performed:

- Two test campaigns in support to the development of the Columbus module design
- One test campaign in support to the verification of the Columbus module design
- One test campaign aimed to the development of the internal (IVA) and external (EVA) OPS procedures for the Columbus module
- One test campaign aimed to the verification of the internal (IVA) OPS procedures for the Columbus module
- Two test campaigns on the EWM

In performing the above listed activities, the ALTEC NBTF team gathered significant experience in working in reduced-g simulated environment acquiring also particular skill in the neutralization techniques that are mandatory for a correct development of NBTF tests. It has to be noted that the level of buoyancy can be trimmed and set according to the specific test needs such to simulate not only reduced-gravity, but also the gravity level experienced on Moon and/or Mars.

6 CONCLUSIONS

The ALTEC NBTF can be of a great support in the field of the design and verification on earth of robots to be used in the Space (reduced-g level).

This can be acquired by manufacturing wet test models (compatible with the water environment) and implementing neutralization techniques that allow setting the level of the simulated gravity in the range needed by the specific test.

The intrinsic characteristics of the ALTEC NBTF, the main being:

- completely out-of-ground
- presence of 4 transparent walls
- position of the control room with respect to the water basin

allow to perform the required tests in an environment
that ensures the full visibility of the items under test and allow also the optimization of the supporting equipments.

Its dimensions permits to optimize the costs associated to its utilization.

Having performed several reduced-g simulation activities inside the NBTF, the ALTEC NBTF team gathered significant experience in working in reduced-g simulated environment acquiring also particular skill in the neutralization techniques that are mandatory for a correct development of NBTF tests.

The ALTEC NBTF and its associated team is now available on the market for further utilization in support of the design and verification on earth of robots to be used in the Space (reduced-g level), and for other industry or science oriented applications; the NBTF has indeed been recently inserted by the European Space Agency (ESA) in the list of Ground Based Facilities (GBF) which are made available through ESA to the European scientific community, on the basis of an open tender (CORA) which provides funding and accelerated procedures. So the NBTF is now at disposal of the European science community as a powerful tool to carry out also research on physiology and neuroscience studies on topics like equilibrium, locomotion, perception of space, posture, control of physiological parameters, decoupling of visual and proprioceptive cues in perception of gravity, gravity models, underwater medicine and other.

For more information on the ALTEC NBTF and access processes of CORA consult the CORA / GBF Facilities web pages at http://www.esa.int/esaMI/HSF_Research/SEMXIT6UXSG_0.html