MODUS: Space Shuttle for Deepwater Interventions

Abstract
This paper presents MODUS (MOBILE Docker for Underwater Sciences), a specialized ROV for deployment, recovery and servicing of heavy sea bottom stations, e.g. scientific observatories for deepwater application (depth rated 4000 m). Developed, built and tested as part of the EC funded project GEOSTAR (GEophysical and Oceanographic STation for Abyssal Research), the new ROV-system includes the operating vessel with winch and umbilical and the versatile ‘space shuttle’ MODUS for handling the bottom station with modularized payload.

The paper focuses on aspects of the development as well as open water trials and missions. Results from hydrodynamic analyses are presented to illustrate design studies for minimized structure drag and therefore minimized power requirements for thruster driven horizontal movements. Motion analyses comprise the dynamic behavior of the ship and the entire deep dived system considering hydroelastic effects. Due to the direct coupling, vertical excitations of the ship in the prevailing sea are substantially transmitted along the submerged umbilical to the ROV, causing potentially harmful slack cable situations. Results from numerical simulations illustrate the dynamic response of the system due to ship oscillations in random seas and the associated downtime of MODUS operations.

The paper presents the latest technological and scientific applications of MODUS during its first cruises: Reaching depths of 3700 m within the EC funded projects GEOSTAR and BIODEEP (BIOtechnology from the DEEP) in the Mediterranean Sea demonstrates its high availability with reliable performance and low costs.

Introduction
The conquering of deepwater – or inner space – is technologically mainly driven by exploration and exploitation activities of the Offshore Oil and Gas industry. Key tools permitting and supporting these interventions are Unmanned Underwater Vehicles (UUV) comprising both Autonomous Underwater Vehicles (AUV) and Remotely Operated Vehicles (ROV). Consequently, during the last 25 years standard ROV technology evolved to a reliable everyday tool, used in all fields of oceanographic engineering [1]. This growing ROV market initiated numerous theoretical investigations and sea trials covering the entire scheme of static and dynamic problems during operation. Vertically tethered as well as towed body systems are characterized by hydroelastic effects, influencing the safe and reliable overall performance. These systems consist, in general, of an operating vessel, a tether, umbilical or towing cable and the suspended or towed sensor carrier, respectively. The tethers or umbilicals connecting the ship with the submerged sensor carrier enable the system to stay underwater almost without time restrictions. Because MODUS as a flexible inner space shuttle can operate various sea bottom stations and support deep sea missions the system opens a wide spectrum of activities, fully controlled by the operator on board the ship.

Fig. 1-GEOSTAR main components: Vessel with winch and A-frame, multifunctional umbilical, MODUS and Bottom Station
A major problem is the coupling of heave and pitch motions of the vessel and the subsequent oscillations of the suspended carrier system. Due to the transmission of wave induced ship motions along the submarine umbilical, the dynamic behavior and stability of the towed or suspended carrier becomes a critical aspect during operation. Depending on geometric configurations and operational conditions, the motion and acceleration amplitudes may increase significantly. Due to high inertia and drag forces the dived modules may not follow the umbilical oscillations, resulting in harmful slack cable conditions [2, 3, 4]. During these short moments the cable tension decreases to zero and the motions of the ship and the submerged structure are decoupled. Large snap loads and erratic motions of the carrier system may occur due to independent oscillations with different amplitude and phase of the upper cable suspension point and the deep dived module. Simulations in time domain regarding non-linear cable dynamics, sub-sea current and irregular seastate confirm these observations and allow the determination of expected downtime for such carrier systems [5, 6, 7].

The development of the MODUS system started with the EU funded feasibility study DESIBEL [8]: In the mid 90s four different deepwater intervention concepts have been investigated with the intention to develop economy priced deep sea stations and operate networks for long-term observations and allow the determination of expected dynamics, sub-sea current and irregular seastate confirm these observations and allow the determination of expected downtime for such carrier systems [5, 6, 7].

The development of the MODUS system started with the EU funded feasibility study DESIBEL [8]: In the mid 90s four different deepwater intervention concepts have been investigated with the intention to develop economy priced tools that are easy to handle and capable to carry loads up to 30 kN to a predetermined location. The GEOSTAR [9] shuttle concept derived from that study (Fig. 1) is designed to handle deep sea stations and operate networks for long-term measurements in deepwater for all purposes.

**GEOSTAR-System Description**

The GEOSTAR prototype is designed to meet the requirements of a long-term ‘reference’ mission in the Mediterranean Sea, dedicated to demonstrate its technological and scientific abilities. Tasks to be accomplished by the different GEOSTAR main components are:

- safe deployment of a large multi-sensor benthic laboratory (the GEOSTAR Bottom Station) to a predetermined location in deepwater
- continuous measurement of seismic and magnetic parameters
- continuous measurement of physical and geo-chemical water parameters, e.g. 3D current profile in the seafloor boundary layer
- safe recovery of the BS after 3-12 months [10, 11]

To conform with these requirements the following main subsystems have been developed (for details see Tab. 1):

- the remotely operated MODUS deepwater shuttle for deployment, recovery and servicing of the Bottom Station
- the Bottom Station (BS) designed as autonomous, modular deepwater observatory for abyssal depths (6000 m), hosting scientific packages, data acquisition, data storage, energy supply and communication equipment
- the Scientific Packages for long-term geophysical, geochemical and oceanographic observations
- the redundant Communication System based on expendable pop-up data messengers and an acoustic telemetry link for near real-time mission control from shore stations

The modular character of the payload components is the key feature to use MODUS also for the BIODEEP mission (Tab. 1).

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### Table 1 - Main characteristics of MODUS and Sensor Modules

<table>
<thead>
<tr>
<th>MODUS</th>
<th>Scientific Payload Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep water</td>
<td>GEOSTAR 2 (Com.) systems</td>
</tr>
<tr>
<td>version</td>
<td>Autonomous unit for several multidisciplinary</td>
</tr>
<tr>
<td></td>
<td>long-term missions</td>
</tr>
<tr>
<td></td>
<td>Umbilical tethered Sensor and sampling Unit for</td>
</tr>
<tr>
<td></td>
<td>Brine water sampling</td>
</tr>
<tr>
<td>Weight in air [kN]</td>
<td>10.9</td>
</tr>
<tr>
<td>Weight in water [kN]</td>
<td>7.35</td>
</tr>
<tr>
<td>Total length [mm]</td>
<td>2878</td>
</tr>
<tr>
<td>Total width [mm]</td>
<td>2346</td>
</tr>
<tr>
<td>Total height [mm]</td>
<td>1700</td>
</tr>
<tr>
<td>Material</td>
<td>Aluminum, Stainless Steel, Titanium (grade 5)</td>
</tr>
<tr>
<td></td>
<td>Stainless Steel, Titanium (grade 5)</td>
</tr>
<tr>
<td></td>
<td>Aluminum, Stainless Steel, Titanium (grade 5)</td>
</tr>
<tr>
<td>Depth rated [m]</td>
<td>4000</td>
</tr>
<tr>
<td>Thrust horizontal [N]</td>
<td>4x700</td>
</tr>
<tr>
<td>Thrust vertical [N]</td>
<td>2x700</td>
</tr>
<tr>
<td>Positioning equipment and/or scientific payload</td>
<td>360° sonar, 325 kHz altimeter, LF transponder, 4x lights, TV camera (2x color, 2x b/w), analog+elect. Compass, x-y tilt sensor</td>
</tr>
<tr>
<td></td>
<td>Seismometer, magnetometers (scal., vect.), 300 kHz ADCP, transmission meter, water sampler, electro-chemical package, hydrophone, gravity-meter, single pl. Current</td>
</tr>
<tr>
<td>Communication (Com.) systems</td>
<td>Online data transmission during operation 3x P/T O telemetry</td>
</tr>
<tr>
<td></td>
<td>Data storage, redundant com. Channel, near real-time com. via buoy and satellite syst.</td>
</tr>
<tr>
<td></td>
<td>Water sampling rosette (various bottle volumes possible), CTD, color camera, light, altimeter, compass</td>
</tr>
</tbody>
</table>

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### Space Shuttle Concept

The deployment (and recovery) procedure starts with a bathymetric survey performed by the operating vessel. After determination of the selected landing location (or detection of the Bottom Station), the down-winching of the umbilical driven system starts its operation. With cable speeds up to 0.6 m/s the deployment missions down to 4000 m last around two hours.

In close distance to the seafloor the sonar at the bow of MODUS transmits reflections from the landing point, to prevent unwanted contacts with bigger obstacles or the BS,
respectively. The final touch down (or coupling) is conducted by two pairs of horizontally mounted DC-brushless thrusters and video guided by four pairs of cameras and lightning. During decoupling (or coupling) the docking pin on top of the Bottom Station structure is guided by the funnel-type docking cone out of (or into) the latch device in the heart of MODUS (Fig. 2). Automatic sensors indicate if the decoupling (or coupling) is executed.

MODUS—a versatile Shuttle for the Inner Space

Aim of the MODUS development is to establish a new deep water intervention technology supporting versatile research activities in water depths down to 4000 m. The MODUS shuttle concept consequently focuses on a modular design with the ability to adapt to a large variety of scientific applications like the remotely controlled deployment/recovery of large and heavy Bottom Stations (e.g. for GEOSTAR) or the exact operation of deep-sea sampling devices with CTD (Conductivity-Temperature-Depth) sensors (e.g. for BIODEEP).

Fig. 2- Modular design of MODUS: (1) docking cone with latch device for mating operations, (2) protective housing for umbilical termination, (3) open frame (aluminum) with equipment (thrusters, sonar, altimeter, cameras and spotlights, power supply, control system)

Fig. 2 illustrates the modular design of MODUS: To operate the modularized Bottom Station (BS), a docking cone (1) with an opening diameter of 2 m allows the mating with the pyramid shaped top structure of the Station (compare Fig. 1 and Fig. 13). Its inner surface is plated with a detachable, abrasion-proof plastic material to reduce impact forces of the docking pin. The cone is not rigidly connected to the surrounding bumper frame to avoid critical deformations and associated stresses caused by an impact, e.g. collision with the BS or the ship during operations. The latch device is housed in a protecting cage (Fig. 2, (2)). With the aid of a linear actuator it is possible to remotely open a claw mechanism bolting the docking pin. Docking is operating automatically due to a pre-stressed spring, while unlatching needs a double button command from the operator for safety reasons. The aluminum space frame (Fig. 2, (3)) with its peripheral bumpers allows flexible mounting of electronic boxes, thrusters, sonar, altimeter, cameras and spotlights, power supply, etc.

The high degree of modularity with the open frame design guarantees ease of maintenance, rearrangement of equipment, and adaptation to new scientific tasks like surveys with specific payload and work tool packages even without the scientific benthic station. Tab. 1 lists the characteristics of the MODUS prototype as well as two different scientific payload modules used in GEOSTAR and BIODEEP projects.

Flow analysis and hydrodynamic optimization

The identification of critical design aspects concerning potentially serious situations during open water operations is often knowledge based or needs approval by empirical methods. A numerical approach is accompanying this process. The MODUS design is the result of an iterative process, combining 3D CAD (Computer Aided Design) and 3D CFD (Computational Fluid Dynamics) with hydroelastic considerations to arrive at an optimum. The CFD simulations have been validated by full-scale tests in the large circulating water tunnel at the Technical University Berlin [12].

Hydrodynamic assessment

Main advantages of an umbilical tethered remotely operated system like MODUS are the high payload and extended deep sea operation periods due to constant power supply. Nevertheless, it is necessary to optimize power consumption to meet restrictions due to the capacity of the umbilical, limiting the available power on board the ROV. Consequently, drag in transverse flow must be minimized - although it contributes only a small part of the submerged systems drag - to reduce thruster power requirements. For this purpose CFD proves to be a reliable method to predict the drag and to visualize the flow field for a better understanding of relevant phenomena.

Fig. 3- Path lines around MODUS and streamlines from thrusters

Hydrodynamic analysis with CFD assumes a roughly symmetrical MODUS and a symmetrical flow along the vertical mid section. The flow field is discretized by an unstructured tetrahedral grid of up to 900,000 control volumes to achieve a high degree of modeling accuracy even on surfaces with high grade of curvature. Fluent (the software package which has been applied in this optimization process) [13] uses an implicit Finite-Volume Method to solve the Reynolds-Averaged Navier-Stokes Equations.
Fig. 4- Cost effective numerical modeling of design alternatives with CFD: From initial shallow water design to enhanced deepwater design with significant drag reductions. Data for horizontal flow at \( v = 0.4 \, \text{m/s} \). (CFD-Software: Fluent [13])

The flow is considered stationary utilizing the RNG k-\( \varepsilon \) turbulence model, which allows predicting the effects of wall shear stresses, flow separations and secondary flows better than the standard k-\( \varepsilon \) model. The near wall treatment is introduced by standard wall functions.

Simulations of horizontal movements are focusing on the determination of the thrust-drag equilibrium as function of current velocity. Replacing the propellers by a pressure-jump plane of fixed strength simulates the effect of these horizontal thrusters, influencing the flow field. The calculations proof that thruster streamlines are not affected by the MODUS structure due to their favorable position (Fig. 3).

Fig. 4 shows the stepwise modeling improvement presenting four design alternatives:

- **Variant A** (md_v0) represents the initial design built for shallow water applications and tested during GEOSTAR 1. Utilizing quadratic profiles for the frame structure and a circular footprint results in a relatively high drag and a high grade of instability during forward motions with significant rotational speeds.

- **Variant B** (md_v1) illustrates the first attempt to reduce structural resistance. Simple plates are integrated to assure forward motion stability.

- **Variant C** (md_v2) shows the design version with a totally encapsulated MODUS. Although the drag is reduced again, the design has been rejected as the time period for maintenance or adaptation of components increases significantly.

- **Variant D** (md_v3) shows the basis of the finally built version of the deepwater MODUS, tested during GEOSTAR 2 scientific missions (see Fig. 13). Drag is significantly reduced as compared to the initial design. Large plastic fins are integrated at the aft of the frame to stabilize forward motions and to increase rotational damping due to a higher added moment of inertia.

Thus, the final design study succeeds in a significant drag reduction of more than 20% for the important horizontal (forward, x-) direction.

Employing MODUS for sensitive scientific tasks like sampling at precisely located horizontal interfaces between normal seawater and brine water (see section: First space shuttle missions-BIODEEP) requires the investigation of the MODUS flow field during descent and ascent operations to detect potential sources of disturbance. These studies are also conducted by CFD, visualizing the wake fields for different motion directions and speeds. Fig. 5 illustrates the large wake fields caused by vertical movements of MODUS.
Hydroelastic analysis

The hydroelastic analysis considers the entire system consisting of:
- ship - A-frame - elastic umbilical - MODUS with or without Bottom Station

in arbitrary sea states at selected target water depths. The weight of MODUS is 7.3 kN, MODUS+(modular equipped dummy-) BS is considered with an exemplary weight of 14 kN, water depth is 3500 m. Of course, any other combination of water depth and weight of payload as well as cable characteristics and ship behavior can be used as input parameters. The core of this evaluation is the determination of MODUS or MODUS+BS oscillations excited by ship motions in irregular seas. The required software package has been developed by Vannahme [5], applications for towed or vertically tethered systems are published in [6] and [7]. The computer program considering non-linear cable characteristics (drag and lift coefficients, cable curvature, etc.) determines stationary conditions at cross flows or currents as well as the dynamic response of the tethered bodies.

As shown in Fig. 6 the dynamic analysis starts with the determination of the wave induced oscillations of the suspension point on the ship (e.g. the A-frame) experienced at the respective sea state. Firstly, the response amplitude operators of the relevant ship motions are calculated. For these investigations the well established 3D-diffraction-radiation panel program WAMIT [14] for wave-structure interaction is applied. Fig. 6 shows the discretization of the vessel and the resulting transfer function (RAO).

To obtain the energy density spectrum of the system response $S_{\text{AF}}(\omega)$ the wave energy density spectrum $S_{\zeta}(\omega)$ is multiplied by the squared RAO.

Note that the respective areas of the wave spectrum and the response spectrum yield the significant wave height and the double amplitude of the significant motion response.

![Fig. 5- Numerical flow field analysis illustrating large wake fields during descent (left) and ascent (right) operations with MODUS](image)

![Fig. 6- Determination of the dynamic behavior of the parent ship applying spectral analysis and short term wave statistics [5]](image)
As the approach is strictly based on linear theory, the relation of the significant response and the significant wave height is a universal parameter which characterizes the motion behavior at the selected spectral zero-upcrossing period $T_0$. The transformation of the system response spectrum from frequency domain into time domain is realized by applying the inverse Fast-Fourier-Transformation.

<table>
<thead>
<tr>
<th>Overall length [m]</th>
<th>61.3</th>
</tr>
</thead>
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<tr>
<td>Length between pp [m]</td>
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</tr>
<tr>
<td>Breadth [m]</td>
<td>11.1</td>
</tr>
<tr>
<td>Depth [m]</td>
<td>5.3</td>
</tr>
<tr>
<td>Draft [m]</td>
<td>3.6</td>
</tr>
<tr>
<td>Displacement [tons]</td>
<td>1115</td>
</tr>
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</table>

Table 2- Main technical characteristics of R/V Urania

<table>
<thead>
<tr>
<th>Operational depth [m]</th>
<th>3500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter [m]</td>
<td>0.0254</td>
</tr>
<tr>
<td>Breaking load [kN]</td>
<td>378</td>
</tr>
<tr>
<td>Working load [kN]</td>
<td>89</td>
</tr>
<tr>
<td>Young modulus [Nm$^{-2}$]</td>
<td>$48.9 \times 10^9$</td>
</tr>
<tr>
<td>Mass per unit length in air [kg/km]</td>
<td>2276</td>
</tr>
<tr>
<td>Weight per unit length in water [kN/km]</td>
<td>18.30</td>
</tr>
<tr>
<td>No. of Optic waveguides</td>
<td>3</td>
</tr>
<tr>
<td>No. of Power conductors (rating 3000 V)</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 3- Main technical characteristics of the umbilical (Rochester 03379)

Results for the hydroelastic behavior of the entire system ship-umbilical-MODUS+BS (input data see Tab. 1, Tab. 2 and Tab. 3) are presented in Fig. 7. The diagrams (a) on top show the vessel heave and pitch RAO in head and beam seas, respectively. Combination of heave and pitch in head seas (case 1), yielding the vertical motion RAO at the A-frame, are presented in diagram (b). The subsequent hydroelastic analysis gives the RAO of MODUS and MODUS+BS, respectively, as related to the vertical motion of the A-frame (diagram (c)). Finally, the squared vertical motion-RAOs of MODUS and MODUS+BS, as related to the exciting wave amplitude, are shown in diagram (d).

As a next step, the motion behavior is evaluated in arbitrary sea states. The associated Pierson-Moskowitz wave spectra -standardized for $H_s=1$ m- are shown in diagram (e). Multiplied by the above squared RAOs (diagram (d)) gives the heave response spectra of MODUS (diagram (f)) and MODUS+BS (diagram (g)), respectively.

From the areas of these response spectra we obtain the significant double amplitudes of the vertical motion of MODUS and MODUS+BS as related to the significant wave height $H_s$. In conclusion, the significant wave height $H_s$ and the associated zero-upcrossing period $T_0$ of the sea state yield the significant motion of MODUS or MODUS+BS, respectively.

Fig. 9 (a) presents the significant vertical motions of A-frame, MODUS and MODUS+BS in case 1: A-frame deployment in head seas.
As an alternative, the ship could also operate in beam seas. In this case the relevant motion RAOS in Fig. 7-diagrams (a) are superimposed, accordingly. The final results are presented in Fig. 9 (b). Although the heave of the ship is much higher as compared to head seas the significantly lower pitch motion RAO yields much smaller A-frame motions. Consequently, the oscillations of the tethered MODUS or MODUS+BS are substantially decreased.

Finally, the motion behavior is evaluated for a parent vessel with a Moon-Pool. In this case, only heave in head seas is responsible for exciting the suspended load. Based on the relevant heave RAO in Fig. 7-diagram (a) we obtain the results in Fig. 9 (c). As a consequence of the significantly smaller excitation we observe very low motion amplitudes of MODUS and MODUS+BS, respectively.

Finally, results of the time simulation for a recovery operation in 3500 m water depth in a sea state of $H_s=0.7$ m and $T_0=5$ s are presented. MODUS and Bottom Station are suspended from the A-frame, and the ship is excited by head seas, i.e. we selected the most critical case 1 at moderate wave conditions. As shown in Fig. 8 the oscillation amplitudes of the suspended load are much higher than the A-frame motion amplitudes. Response motions dominate the dynamic behavior.

Furthermore, Fig. 8 signalizes that a strong vertical acceleration of the tethered load leads to a slackening of the cable, indicated by the drop of axial cable forces to zero. In this case the submerged structure and the parent ship are decoupled, and oscillate with different amplitudes and phases.

However, when the cable becomes taut again, erratic motions of the submerged body occur, resulting in large snap loads which may exceed the cable breaking load. The time signal in Fig. 8 shows these large snap loads when the cable becomes taut again although the A-frame amplitude of the subsequent oscillation is rather moderate, indicating the typical “yo-yo” effect due to hydroelastic phenomena.

These results clearly demonstrate that the deployment from the A-frame in head seas can be quite disastrous, even at moderate sea states. In this case heave compensation is strongly recommended.

Since a slackening cable endangers the operation safety, the incipience of slack cable conditions can be introduced as criterion to define maximum permitted sea states and thus, the operational limitations due to weather conditions.

Fig. 10 and Fig. 11 show the differences between the dynamic behavior of the tethered system if the suspended load comprises MODUS (Fig. 10) and MODUS+BS (dummy version) (Fig. 11), respectively.

![Fig. 8- Simulation of dynamic behavior in time domain: A-frame oscillation amplitude, oscillation amplitude of the suspended load, cable force at the A-frame as well as at the suspended load (Hs=0.7 m, T0=5 s)](image)

![Fig. 9- Significant response of vertical motions as related to significant wave height: (a) deployment via A-frame in head seas, (b) deployment via A-frame in beam seas and (c) moon-pool deployment)](image)
Fig. 10- Incipience of slack cable conditions of MODUS: Cable length=3500 m, mass=1090 kg, weight=7.35 kN, current=0.2 m/s, cable weight in water=18.5 N/m, cable elasticity: EA=25*10^6 N

Fig. 11- Incipience of slack cable conditions of MODUS+BS: Cable length=3500 m, mass=3600 kg, weight=14 kN, current=0.2 m/s, cable weight in water=18.5 N/m, cable elasticity: EA=25*10^6 N

The graphs show the incipience of slack-cable conditions, indicating the critical A-frame oscillation amplitude over the relevant frequency range. The region below that curve marks safe operation, whereas the operational conditions above that curve are to be avoided. Fig. 10 reveals that in case of the lighter system (only MODUS) a slackening of the cable occurs already at an A-frame amplitude of 0.5 m with an associated period of T_{Slack}=4 s. In the case of MODUS+BS (Fig. 11) the critical period T_{Slack} is shifted to 5 s with an associated A-frame amplitude of 0.8 m.

First Space Shuttle Deepwater Missions
The finally built prototype of MODUS and its main components passed several dry and wet tests in workshops and water tanks at TUB before the overall system integration with the Bottom Station took place at facilities of the Italian project partner (Tecnomare) near Venice.

To demonstrate qualification, the GEOSTAR project provided several open water tests and two missions in the Mediterranean Sea in shallow water and deepwater, respectively. Diving tests with MODUS stand alone and with a BS dummy structure have been performed in water depths of 370 m, 1000 m and 3500 m. After successfully passing these open water tests, the safe and reliable deployment and recovery of the fully equipped Bottom Station was well prepared.

GEOSTAR
The first phase of GEOSTAR 1 project (1995-1998) succeeded with a shallow water test and an exemplary mission in the Adriatic Sea including
- the deployment of a fully equipped multi-sensor Bottom Station to 40 m water depth,
- an one month scientific mission and finally
- the recovery of the station.

The overall feasibility of the concept led to the positive evaluation of the second project phase GEOSTAR 2 (01/1999-12/2001). Main technological challenges of this phase comprise the static and dynamic behavior of the system at water depths down to 4000 m, leading to the specification of a suitable winch and umbilical, and an improved deep-sea design of MODUS to deploy and recover an upgraded observatory to abyssal depth.

Fig. 12 illustrates the approach of MODUS to the Bottom Station in 2000 m water depth. Left: The image of the sonar system guides the MODUS operator and the captain of the R/V to the target. Fig. 12 (right) shows an exciting moment during recovery of the Bottom Station after seven months of autonomous operation, when MODUS rediscovers and mates the Station at the ocean floor.

Finally, GEOSTAR 2 succeeded in a deepwater (2000 m) scientific mission in the Tyrrhenian Sea including
- the deployment of a fully equipped multi-sensor Bottom Station; the installation of an acoustic communication line
- a seven month autonomous scientific mission and finally
- the recovery of the station (Fig. 13) with subsequent data recovery and analysis
Fig. 13- GEOSTAR 2 (04/2001): MODUS coupled with the Bottom Station after successful recovery on board Italian R/V Urania. BS has been autonomous working for 7 months in 2000 m depth.

BIODEEP

The EU-project BIODEEP (BIOtechnology from the DEEP) aims at the development and use of new instruments and new techniques exploring and exploiting the geochemical and microbial resources of deep, hypersaline, anoxic environments (DHABs). For this purpose MODUS has been equipped with a supporting frame structure (SCISKID) guiding and observing an innovative scientific package (SCIPACK) which is connected to MODUS by a short (secondary) umbilical (depending on configuration 10-200 m long) (Fig. 14). This package allows the surface operators to carry out accurate and controlled sampling missions in and outside the harmful brine environments, discovered in Mediterranean deep-sea basins within the last 30 years [15].

Fig. 14- BIODEEP (08/2001): MODUS mounted on top of SCISKID with scientific package (SCIPACK – right hand side).

Tab. 4 shows the sequence of 17 dives to certain water depths with different system configurations during the first BIODEEP cruise (11 days) in Aug./Sep. 2001: Blue columns (A) represent sampling missions, green (B) represent survey missions (no SCIPACK, only MODUS) and orange (C) represent interrupted dives due to technical problems. The duration of each dive is also represented by smaller columns. A maximum duration of up to 465 minutes during that cruise indicates the ability for extended, fully controlled surveying and sampling in full depth. Due to the tight schedule of the cruise it was necessary to change the configuration directly after a dive, up to three times a day. This also marks a significant step forward in the overall system performance.

Table 4- MODUS dive missions during the first BIODEEP scientific expedition, August/September 2001.

Conclusions

The high availability and reliability of deep-sea shuttles for handling and operating arbitrary intervention tools in deepwater environment is a basic requirement for application in industry and science. The latest success of the MODUS carrier system during extensive field operations like the deployment/recovery of a large and heavy station, video field survey, remote operation of sampling tools etc. down to 3700 m demonstrates its availability with reliable performance.

Case studies prove that operational decisions like favorable orientation of the parent vessel to wave propagation or the integration of a moon pool in the ship center may significantly reduce downtime. Heave compensation is strongly recommended to reduce the risk of slack cable situations as illustrated in Fig. 15. Hydrodynamic optimization helps to limit energy consumption increasing the scope of applications and the duration of deep sea operations.

MODUS proves to be a versatile and economic tool to operate, handle and maintain a spacious network of heavy-duty seafloor observatories. Thus, MODUS provides all features necessary to meet requirements of adaptable structures for marine science and offshore technology [16].
Fig. 15- One camera view up: Slack cable situation during hoisting of stand alone MODUS

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- TFH Berlin, University of Applied Sciences D
- Technical University Berlin D
- Ifremer F
- Orca Instrumentation F
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- Institut de Physique du Globe de Paris F

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- TFH Berlin, University of Applied Sciences D
- Technical University Berlin D
- Technical University Braunschweig D
- Institute of Marine Biology of Crete GR
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References


