UNDERWATER VEHICLES IN THE RESEARCH WORK OF SZCZECIN UNIVERSITIES – PROJECTS

Tadeusz Graczyk

Maritime University in Szczecin, Faculty of Navigation, Department of Ocean Engineering and Shipbuilding, Poland

ABSTRACT

The article presents the development and scope of research work in the early period of interest in deep-sea technology in Poland in the 1980s. The research was carried out at the then Szczecin University of Technology and initially concerned studies of the level of world technology, followed by the construction of experimental unmanned underwater vehicles. The work culminated in the development of designs for manned deep-sea vehicles, the construction of which depended on commissions from the countries of the Eastern Bloc. Political and economic changes resulted in the abandonment of the continuation of work.
Key words: underwater technology, underwater vehicles, manned underwater vehicles.

ARTICLE INFO

PolHypRes 2021 Vol. 76 Issue 3 pp. 21 – 34
ISSN: 1734-7009 **eISSN:** 2084-0535
DOI: 10.2478/phr-2021-0014
Pages: 14, figures: 7, tables: 6
page www of the periodical: www.phr.net.pl

Publisher
Polish Hyperbaric Medicine and Technology Society

Review article

Submission date: 15.03.2021 r.
Acceptance for print: 12.04.2021 r.

INTRODUCTION

The 1980s was a period of interest in underwater technology among the scientific and industrial centres of Szczecin, which was associated with the possibilities of extracting natural resources from the seabed (polymetallic nodules at the bottom of the Pacific Ocean) and the involvement of the shipbuilding industry The Adolf Warski Szczecin Shipyard) in the construction of ocean engineering equipment for the Polish Navy and a Soviet shipowner.

Research work including theoretical studies and soon also deep-sea apparatus construction, model, field and application studies was also undertaken at the then Shipbuilding Institute of the Szczecin University of Technology (since 1991 – Faculty of Marine Technology, since 2011 – Faculty of Maritime Technology and Transport of the West Pomeranian University of Technology in Szczecin). This work led to the design and construction of a family of deep-sea vehicles and equipment for underwater operations, Table 1.

In the initial period of intensive development of knowledge in the area of deep-sea apparatus construction (conventionally the years 1979-1990), coinciding with the embargo on providing access to advanced Western European and American submersible technology, the directions of research (carried out also in the scientific centres of the Tricity) included the identification of problems of deep-sea vehicle design and application and the methodology of designing deep-sea systems, [1,2,3,4].

Tab. 1

Deep-sea vehicle system designs at the Faculty of Marine Technology.

No.	System name	Vehicle name	Vehicle characteristics working depth [m] shape/form purpose	dimensions [mm] propellers weight [kg]	Period of development/ research
1*	SPG	*AiTS*	10 PVC frame construction badania kontroli ruchu	1480x830x750 6 propellers 55	1979-1986 experimental vehicle
2*	SPG	*MUNA-400*	400 torpedo shape inspection	2500x1000x1000 8 propellers 500	1985-1990 experimental vehicle
3*	SPG	*MUNA-6000*	6000 torpedo shape inspection	2500x1000x1000 8 propellers	1988-1990 design
4	BZSPG	*NUR*	300 frame construction research equipment underwater works	4500x2500x2700 7 propellers 6200/7700	1986-1990 design subsystems model 1:2
5	SPZ	*PAO-100*	100 cylindrical observation	1200x1200x1900 2 propellers 970	1987 design
6	NPG	*NPG 600*	600 frame construction sphere + cylinder research and working equipment	8800x3000x4400 6 propellers 27600	1989 design model 1:10
7	NPG	*NPG 600/300*	600/300 frame construction sphere + cylinder research and working equipment	7700x3300x3800/4550 6 propellers 25825/26125	1990 design model 1:10
8	MZSPG	*TUM-600*	600 drop shape observation	1000x800x630 4 propellers 82	1990 design

without the participation of the author; other systems with participation of the author as chief designer.

AREA AND SCOPE OF RESEARCH WORK IN THE FIELD OF DEEP-SEA TECHNOLOGY

The research work was initially concerned with unmanned remotely operated deep-sea vehicles (BZSPGs), which were developing rapidly in the world during the 1980s, a period of rapid conquest of the world's ocean by exploiters of oil and gas and other natural resources, as well as for military applications.

Designs were also made for other types of deep-sea vehicles and submersible devices, including manned vehicles, which incorporated elements of design tasks specific to the BZSPG system.

THE *AITS* UNDERWATER VEHICLE

The AiTS underwater vehicle was the first experimental remotely operated apparatus built and tested at the then Shipbuilding Institute, Fig. 1, Table 2, [3]. The apparatus had a frame structure, five propellers, a depth stabilisation system, and a battery located in the vehicle. The construction and testing involved the dynamics of frame vehicle motion underwater and the selection of automatic motion controllers.

Realised in the Department of Automation and Systems Theory at the Shipbuilding Institute of the Szczecin University of Technology: a research grant from the Ministry of Science, Higher Education and Technology entitled "The AITS Vehicle," 1979-1986.

Research team: Andrzej Piegat, Mariusz Matejski, Władysław Skórski, Jerzy Sołdek, Piotr Wandrey.

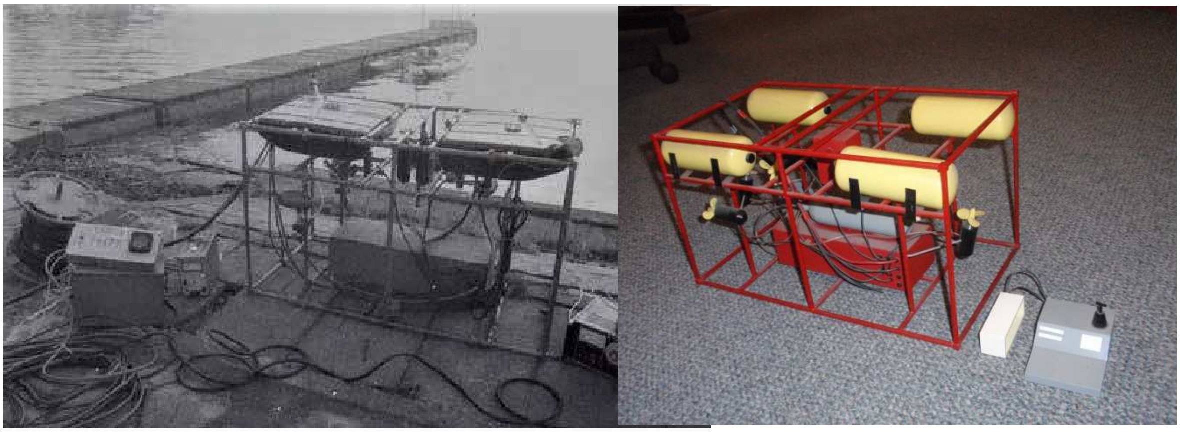


Fig. 1 Experimental underwater vehicle *AITS-1* during trials at Lake Dąbskie (1982) and the model of vehicle *AITS-2*.

Tab. 2

AITS-1 – technical characteristics.

No.	Specification	Description
1	Weight [kg]	55
2	Dimensions [mm]	1700x900x800
3	Working depth [m]	10
4	Propellers – configuration	2 longitudinal, 2 transverse, 2 vertical
5	Speed [m/s]	0.2 – longitudinal, 0.15 – transverse
6	Power supply voltage [V]	12 DC

UNDERWATER VEHICLE *MUNA 400*

The MUNA-400 underwater remotely operated carrier of works devices was designed for inspection of the seabed, oceanographic structures, locating damage to structures, searching for objects and identifying them, Fig. 2, Table 3, [5]. The vehicle allowed remote observation of objects located in the water depth by means of TV cameras and image recording. It was equipped with a system for automatic depth, height above the bottom, heel and trim and progressive speed stabilisation.

Realised in the Department of Automation and Systems Theory at the Shipbuilding Institute: CPBR Research Project 9.5 Objective 26 entitled 'Remotely controlled underwater works devices carrier for operation at depths up to 400 m,' 1985-1990.

Research team: Mariusz Matejski, Władysław Skórski, Andrzej Ruciński.

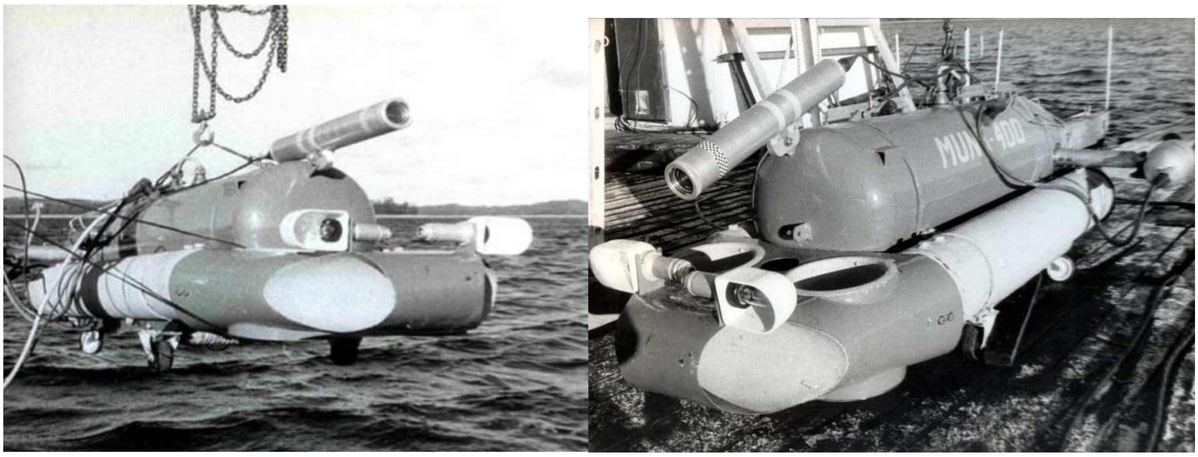


Fig. 2 *MUNA-400* underwater carrier during surveys on Lake Ińsko.

Tab. 3

MUNA 400 – technical characteristics.

No.	Specification	Description
1	Weight [kg]	500
2	Dimensions [mm]	2500x1000x1000
3	Working depth [m]	400
4	Propellers – configuration	2 longitudinal, 2 transverse, 4 vertical
6	Speed [m/s]	3 – longitudinal, 1 – transverse and vertical
7	Power requirements [kW]	5

UNDERWATER WORKS DEVICES CARRIER *MUNA 6000*

In connection with the planned exploitation of polymetallic nodule deposits from the bottom of the Pacific Ocean by the Interoceanmaetal Consortium, a decision was taken in 1988 to adapt the MUNA-400 underwater carrier, which was undergoing functional testing, to operate at depths of up to 6000 m.

The system was equipped with a garage that served as a ballast for the heavy umbilical cable, an intermediate station for power and signal transmission systems, and a container for the underwater carrier during its lowering, raising and towing in the depths. The vehicle was connected to the garage by a light umbilical cable. It was equipped with a trim system, an emergency lifting system, a manual and automatic motion control system, a depth, roll and trim stabilisation system. The television observation system featured three monochrome cameras, allowing observation from a distance of 4-6m, and eight floodlights. Two observation systems were located in the *MUNA-6000* carrier and one on the garage.

Implemented in the Department of Automation and Systems Theory at the Shipbuilding Institute, 1988-1990. Project terminated after partner changes in the Interoceanmetal Consortium.

Research team: Władysław Skórski, Lech Tołkacz.

WORK EQUIPMENT CARRIER - *NUR*

The *NUR* work equipment carrier was designed to support underwater work carried out by divers and for tasks without their participation, including inspection, search, transport of components, simple underwater work, [6]. In autonomous tasks, the vehicle could be used as a versatile inspection tool for water space, bottom and underwater structures. As an underwater workshop for the diver, the vehicle was equipped with a set of hydraulic tools, [7], which included a winch, spreader, puller, spanner, grinder, drill, rope and cable cutters and a platform-seat for the diver on a hydraulic extension arm, as well as an optional welding module, ultrasonic defectoscope and ground flushing ejector, Fig. 3, Table 4.

The research resulted in the technical design of the vehicle and the working design of most of the equipment, as well as the construction of a significant part of the vehicle's subsystems, Fig. 4, i.e.: the steel load-bearing structural frame, subsequently tested in the Laboratory of the Ship Construction and Mechanics Department of the Szczecin University of Technology, a set of electric motors for the electrohydraulic propulsion system, floodlights, lighting, a monochrome TV camera, a transport lift, a set of hydraulic tools (prototypes of most of the tools and 4 usable sets for a shipowner from the USSR).

Tab. 4

Technical characteristics of the *NUR* work equipment carrier.

No.	Specification	Description
1	Weight [kg]	6200
2	Dimensions [mm]	4500x2500x2700
3	Metacentric height [mm]	500
3	Working depth [m]	300
4	Speed – direction [m/sec]	1,5 – longitudinal, 1,0 – transverse and vertical
5	Load-bearing structure	rectangular steel frame
6	Propellers, configuration	7 hydraulic propellers, each with a power of 15 kW 4 inclined in the horizontal plane, 3 vertical
7	Power supply	3*380 V, 50 Hz
8	Equipment	TV camera, floodlights, sonar grab – opening 400÷1400 mm lift – lifting capacity 300 N 6-function manipulator – lifting capacity 600 N, reach 2 m, diving platform – reach 5 m welding module hydraulic tool kit ultrasonic defectoscope ground ejector

A 1:2 scale model of the vehicle was also built, Photo 3, which was tested at the Ship Hydromechanics Centre at the Ship Design and Research Centre in Gdańsk to determine the vehicle's resistance and stability characteristics.

Implemented at the Ship Technology Department of the Shipbuilding Institute of the Szczecin University of Technology: CPBR Research Project 9.5 Objective 23 entitled "Carrier (David type) of technological tools/equipment for underwater works," 1986-1990.

Research team: Tadeusz Graczyk, Leszek Bednarski, Jan Dutkiewicz, Tadeusz Jastrzębski, Andrzej Kaczmarek, Stefan Kępski, Mirosław Małecki, Krzysztof Piotrowski, Eugenius Skrzymowski, Henryk Szymański, Włodzimierz Wnuk.

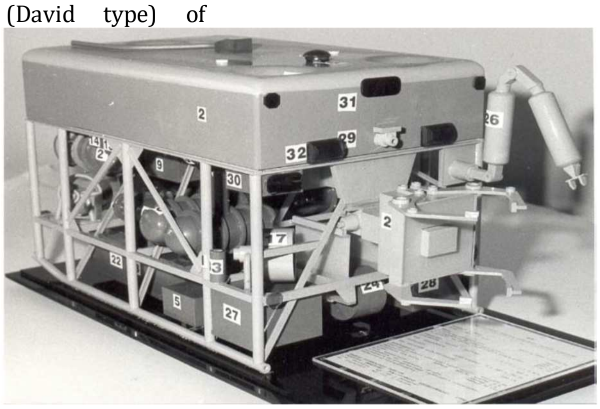


Fig. 3 The *NUR* work equipment carrier – 1:2 scale model for resistance testing and 1:10 scale vehicle model showing equipment layout.

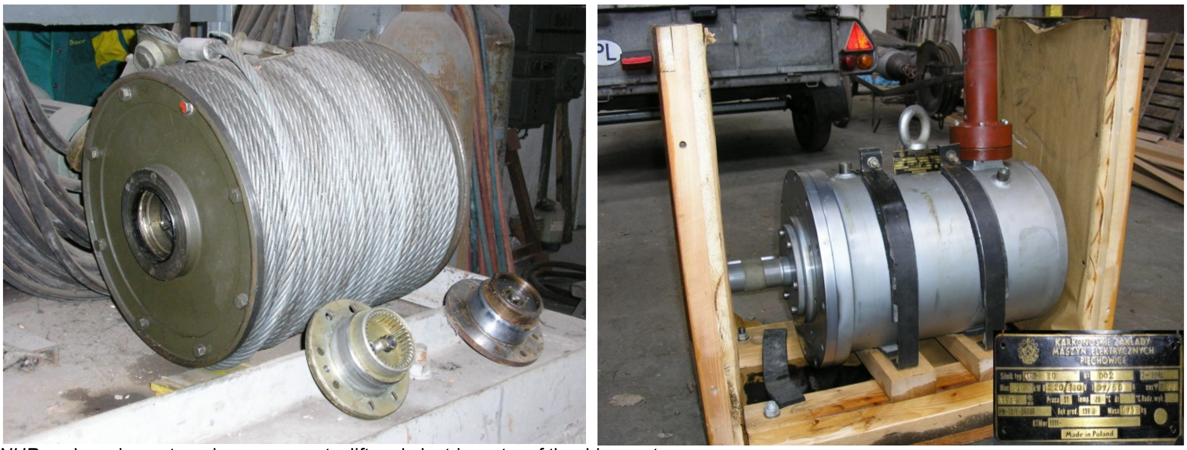


Fig. 4 The *NUR* work equipment carrier components: lift and electric motor of the drive system.

As a result of a lack of further funding, the design and construction work was discontinued in 1990, however, the components and equipment built were used in later research work and also in service underwater diving works. The project implementation contributed to the identification of problems in the design, construction and application of deep-sea vehicles. This knowledge enabled the research team to undertake further tasks in the design of unmanned and manned deep-sea vehicles.

UNDERWATER OBSERVATION DEVICE *PAO-100*

The design of the *PAO-100* underwater observation vehicle, Fig. 5, assumed a stay at a depth of 100 m, [8]. Although it is a manned object, the theoretical issues of buoyancy, stability, structural strength, motion control are characteristic of deep-sea vehicles in general, including the BZSPG, which made it possible to use the experience gained in the design of the NUR vehicle system in this project. At the same time, research into the life support system of the apparatus allowed more advanced designs of deep-sea diving NPG vehicles to be undertaken as the next task.

Realised at the Ship Technology Department of the Ship Institute of the Szczecin University of Technology, 1987.

Research team: Leszek Bednarski, Tadeusz Graczyk, Marian Kukliński, Krzysztof Piotrowski.

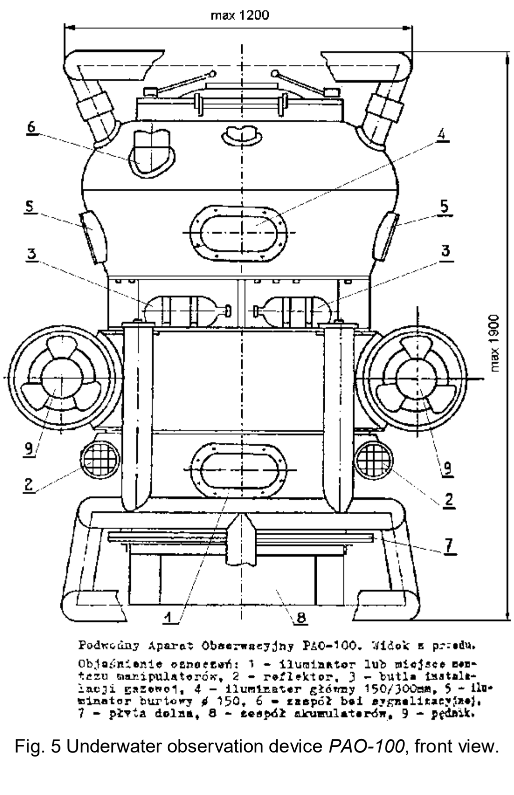


Fig. 5 Underwater observation device *PAO-100*, front view.

DIVING UNDERWATER VEHICLES *NPG-600* AND *NPG-600/300*

As a result of cooperation with the Szczecin Shipyard and experience in the construction of hyperbaric chambers, two designs were developed for a deep-sea diving vehicle intended for the transport of divers, their work and their supervision in the water depths, [9]. The vehicles were crewed by two pilot-operators in the command compartment and three divers in the working compartment. Observation tasks carried out by the pilots from the navigation cabin, without the divers, were also possible. For observation and penetration of hard-to-access and dangerous spaces, the *NPG* vehicle was equipped with a miniature *TUM* observation vehicle, the design of which is discussed below.

The design of the NPG-600 was executed in the conceptual and quotation scope. It included four versions of a vehicle consisting of two hyperbaric compartments in the shape of a sphere or sphere and cylinder, made of high-strength steel.

The NPG-600/300 design was executed at a quotation level. It presented a vehicle containing two compartments – a spherical compartment for pilots and a cylindrical compartment for divers–- made optionally of high-strength steel or titanium.

The projects were carried out in the team of employees of the Ship Technology Department and A. Warski Shipyard, Fig. 6, Table 5. The author acted as the chief designer with respect to co-ordination of works, development of the vehicle configuration, general design calculations, as well as detailed calculations concerning vehicle balancing, resistance and manoeuvrability properties, propulsion characteristics prediction of the vehicle propellers. He also developed a programme of model tests of the vehicle at the Ship Hydromechanics Centre at the Ship Design and Research Centre in Gdańsk for the vehicle model, Fig. 7.

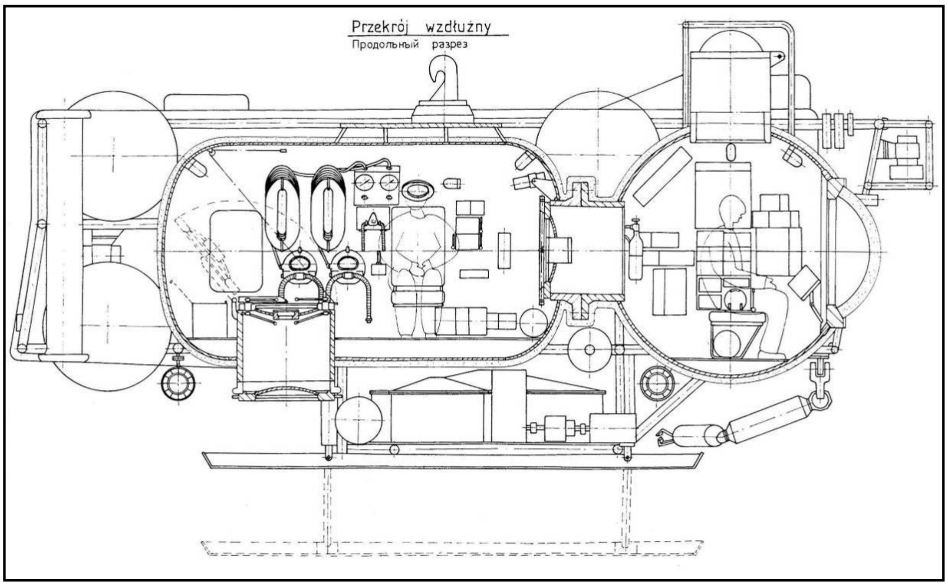


Fig. 6 *NPG-600/300* deep-sea diving vehicle – cross-section in the plane of symmetry through the diving and command compartments.

Tab. 5

Technical characteristics of *NPG-300* and *NPG-600/300* vehicles.

No.	**Specification**		***NPG-600***	***NPG-600/300***
1	Weight	[kg]	27600	25825 or 26125
2	Dimensions	[mm]	8800x3000x4400	7700x3300x3800/4550
3	Metacentric height	[mm]	400	300
4	Working depth	[m]	600	600/300
5	Cruise speed [m/sec]		1.4 – ascent, 1.2 – descent	
6	Load-bearing structure		rectangular steel frame	
7	Crew compartments		sphere + drum steel	sphere + drum titanium or steel
8	Propellers, configuration		6 screw propellers in the nozzle electric DC motors, each 15 kW, two longitudinal, transverse and vertical	
9	Power supply		electro-hydraulic drive system 110 V, 16 MPa 2 DC electric motors 9.5 kW each	
10	Equipment		2 TV cameras, 2 photo cameras, floodlights, 6-function manipulator – lifting capacity 500 N, reach 1150 mm, manipulator-grab 10 kN, 1600 mm, hydraulic tool kit, measuring and control apparatus, miniature camera – TV camera carrier	
9	Reach	[m]	5200	7000
Z	Autonomy	[h]	10	10

Carried out at the Ship Technology Department of the Shipbuilding Institute of the Szczecin University of Technology: Research Project CPBR 9.2 Task 27.09.01 entitled “Autonomous submersible vehicle with divers’ exit,” 1989-1990.

Research team: Tadeusz Graczyk, Leszek Bednarski, Jerzy Grześkowiak, Marian Kukliński, Jerzy Minkowski, Eugenius Skrzymowski.

Fig. 7 Model of deep-sea diving vehicle *NPG 600/300* in 1:10 scale.

TUM-600 MONITORING EQUIPMENT TRANSPORTER

The cooperation between the Ship Technology Department and the SUBMAR Design and Service Company in Gdynia, bringing together, among others, specialists from the Naval Academy, resulted in the design of a miniature observation vehicle, called the *TUM-600* monitoring equipment transporter, Fig. 8, Table 6. The vehicle was intended as an observation tool for divers and NPG deep-sea vehicle pilots to remotely penetrate wrecks and other inaccessible or dangerous objects.

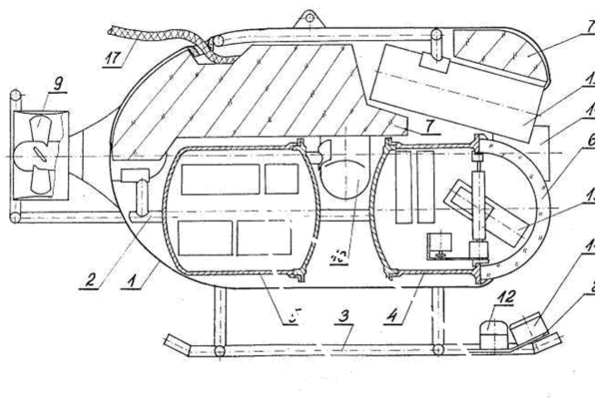
Realised at the Ship Technology Department of the Ship Institute of the Szczecin University of Technology, year 1990.

Research team: Tadeusz Graczyk, Leszek Bednarski, Bartłomiej Jakus, Eugeniusz Skrzymowski, Antoni Wiliński, Ryszard Wróbel.

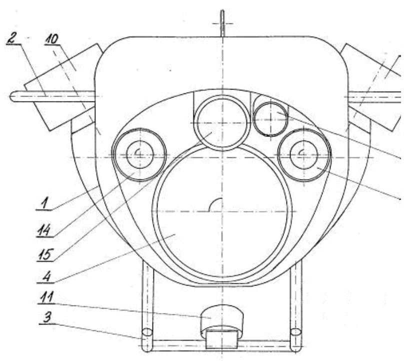
Tab. 6

Technical characteristics of *TUM-600* vehicle.

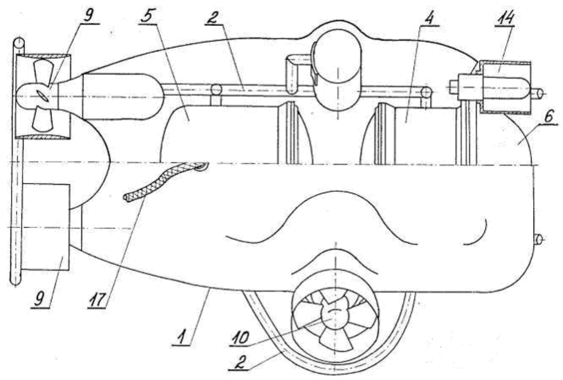
No.	Specification		Description
1	Weight	[kg]	82
2	Dimensions	[mm]	1000x800x630 mm
3	Working depth	[m]	600
3	Metacentric height	[mm]	40
4	Speed	[m/sec]	1,5
5	Hull shape, construction		drop shape, framework - aluminium tubes, pressure vessels – steel, floats – syntactic foam
6	Propellers, configuration		2 longitudinal, 2 inclined in transverse plane
7	Power supply		220 V/50Hz
8	Equipment		monochrome TV camera with vertical tilt mechanism, 2 floodlights, camera and flash, compass, depth gauge



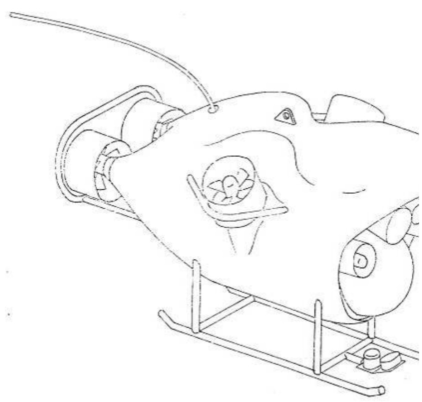
Cross-section in the plane of symmetry



Front view



Top view



General view

1 - hull cover	7 - buoyancy element	13 - tv camera
2 - suport frame	8 - bracket	14 - floodlight
3 - skid	9 - longitudinal propeller	15 - photo camera
4 - tv camera container	10 - inclined shaft propeller	16 - flash
5 - power pack container	11 - depth gauge	17 - umbilical cable
6 - acrylic window	12 - compass	

Fig. 8. *TUM-600* monitoring equipment transporter.

CONCLUSION

The first period of research work in the field of deep-sea technology allowed for the identification of theoretical and technical problems concerning deep-sea vehicles.

An experimental *AiTS* underwater apparatus was built and the problems of remote control were discerned. Furthermore, the *MUNA* vehicle was designed and built, solving technical problems related to ensuring the integrity of the apparatus under high pressure, problems of power supply, communication and control. The *NUR* vehicle was designed to cooperate with a diver, and prototypes of the vehicle's essential equipment were developed and built.

Design work was also undertaken on *PAO* and *NPG* manned vehicles that could be included in the range offered by the Szczecin Shipyard, which was already developing other high-pressure facilities, i.e. hyperbaric chambers for divers [10]. The vehicle life support system constituted a more important part of the system. In this field, close cooperation was established between the University and the Shipyard.

Although the work on manned vehicles did not progress beyond the design stage, the knowledge and experience gained during the design process was used in the construction of other deep-sea systems and their operation, including those involving divers.

Further research work on deep-sea vehicles, including the design, construction and application of unmanned vehicle systems, will be the subject of a separate paper entitled “Remotely operated underwater vehicles in the research work of Szczecin universities – systems and applications”.

References

1. Graczyk T.: *Optimisation of power distribution in the operating system of an unmanned remotely operated vehicle,* doctoral thesis, supervisor Anoni Wiliński, Ph.D., Naval Academy, Gdynia, 1992, p. 267.
2. Jastrzębski T.: *Selected problems of design theory of offshore floating structures*, Wydawnictwo Uczelniane Politechniki Szczecińskiej, Szczecin, 1994.
3. Piegat A.: *Bewegungsverhalten und automatische Kursteuerung von unbemannten Unterwasserfahrzeugen mit offener Rahmenkonstruktion*, Wilhelm-Pieck Universität, Rostock, 1988.
4. Skrzymowski E.: *Ocean engineering and its development in West Pomerania*, Budownictwo Okrętowe, no. 5/1989, pp. 4-5.
5. Orłowska A., Skórski W., Matejski M.: *Remotely controlled equipment carrier for operation at depths up to 400 m.* 5th Conference "Design and Construction of Ocean Engineering Objects", Komisja Oceanotechniki Sekcji Okrętowców ZG SIMP, Instytut Okrętowy Politechniki Szczecińskiej, Szczecin, 12-13.10.1989, pp. 212-218.
6. Graczyk T.: *Remotely operated vehicle NUR as a sophisticated equipment for ships supporting offshore industry*, proc. of the International Ship Technique Symposium, Wilhelm Pieck University of Rostock, 3-6 October 1989, vol. 4, pp. 381-387.
7. Piotrowski K.: *Research into methods of implementation of selected technological operations associated with the use of mechanised hand tools in the operation of offshore equipment,* doctoral thesis, supervisor Prof. Leszek Pacholski, Poznań University of Technology, 1991.
8. Bednarski L.: Characteristics of the underwater observation apparatus PAO-100, Conference "Ergonomics in the maritime economy", Scientific Session "Ergonomic Problems of Underwater Works Technology", Shipbuilding Institute of the Szczecin University of Technology, SIMP, PTE, MOSZ, ODOK, Szczecin, 21-22.04.1988, pp. 67-85.
9. Bednarski L., Graczyk T.: Diver lock-out submersible of *NPG-600* type destined for deep ocean penetration, proc. of the 5th International Congress on Marine Technology Athens '90, The Hellenic Institute of Marine Technology, Athens, 28-31 May 1990, pp. 196-198.
10. Skrzymowski E.: *A.Warski Szczecin Shipyard - manufacturer and supplier of ocean engineering devices and equipment,* Comecon countries conference, Suzdal, USSR, 27.11-2.12.1988.

Tadeusz Graczyk, PhD, Eng., Associate Professor
Maritime University in Szczecin
Faculty of Navigation
Department of Ocean Engineering and Shipbuilding
t.graczyk@am.szczecin.pl

ORCID 0000-0001-7136-0773