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DUMAND - Deep Underwater Muon and Neutrino Detector

TETHERED AND AUTONOMOUS REMOTELY OPERATED VEHICLES FOR OCEANOGRAPHIC RESEARCH AND TECHNOLOGICAL DEEP OCEAN APPLICATIONS

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January 9, 1985

SPECIAL LECTURE ON OCEAN ENGINEERING/OCEANOGRAPHIC RESEARCH

SPEAKER: Dr. Robin Dunbar, Senior Lecturer in Electrical and Electronic Engineering, Heriot-Watt University (Edinburgh, Scotland)

SUBJECT: Tethered and Autonomous Remotely Operated Vehicles for Oceanographic Research and Technological Deep Ocean Applications

TIME AND PLACE: Tuesday, January 15, at 3:00 p.m. in Marine Science Building 100

Dr. Dunbar is visiting UHM until January 24 in order to become familiar with Hawaii's ROV applications, including the DUMAND PROJECT. He is located in Watanabe Hall (Room 226, extension 7391) with the High Energy Physics Group. He is interested in discussing robotics, ROV technology, and related subjects with others in the field. This lecture will provide attendees with an overview of the developmental work being done at Heriot-Watt, some of which has already proved useful in North Sea operations.

The lecture was illustrated by 35 mm color slides and overhead transparencies; these are listed overleaf with some comments.

Prints of the overheads and a copy of a relevant paper are included.

R.M. Dunbar
21st January 1985

	SLIDES	O'HEADS
1.	'EDINBURGH'	(Edinburgh & Scotland) ↓ (covers items 1–13)
2.	volcano	
3.	Tattoo	
4.	pipers	
5.	Castle + mist	
6.	Grassmarket	
7.	Scotch mist	
8.	"Scotch mist"	
9.	Haggis	
10.	hammer	
11.	caber	
12.	L.N. monster 1	
13.	L.N. monster	
14.	'HERIOT-WATT U'	
15.	H.W.U. (old)	
16.	Mountbatten	
17.	New campus	
18.	Angus 002 U/W	ROV designed & built by
19.	003 + bridges	Heriot-Watt University
20.	Seapup	commercial (small)
21.	Amphora	" (")
22.	MMIM	" (large)
23.	AC	" "
24.	PIC	" "

——→ ROV development: O'heads.

U

SLIDES

O'HEADS.

Tethered ROV : 1950 → 1983
bottom vehicle : 50 → 83
total nos. + manipulators.
→ comparison of submersibles.
indicate AROV cf. ROV

25. torpedo — ANGUS project 1969 – 75
26. 001, 2, 3
27. 002
28. 002 U/W
29. 002 surface
30. 003. — 1978 – 82
31. 003 + ROVER — ROV + AROV* shuttle concept
32. 003 + DIVERS. — Man/Machine interaction.
33. RN divers — Wellington bombers on bottom
34. EDU expt. diving unit. — of Loch Ness, in 260'.
35. RN divers
36. 225 — small ROV
37. SCORPI — " "
38. L. Ness
39. Wellington + monster
40. crashed Wimpey
41. Wellington '78
42. " '84
43. " 84
44. 003 + ROVER
45. AROV concept

* AROV = Autonomous Remotely Operated Vehicle

O'HEADS NEXT

SLIDES | O'HEADS

45. AROV Concept

Tetherless ROV's (list)

Tethered ROVs (characteristics)

excl. MNV's (mine neutralisation vehicles)

46. 007 + ROVER mock-up
47. " " "
48. " " "
49. ROVER Dec 84
50. "
51. man + ROBOT .....
52. auto computer control
53. hydrodynamic measurements
54. " "
55. ROV simulation
56. " "
57. " "
58. " "
59. " "

→ HWO Sub. Projects '69–'85.

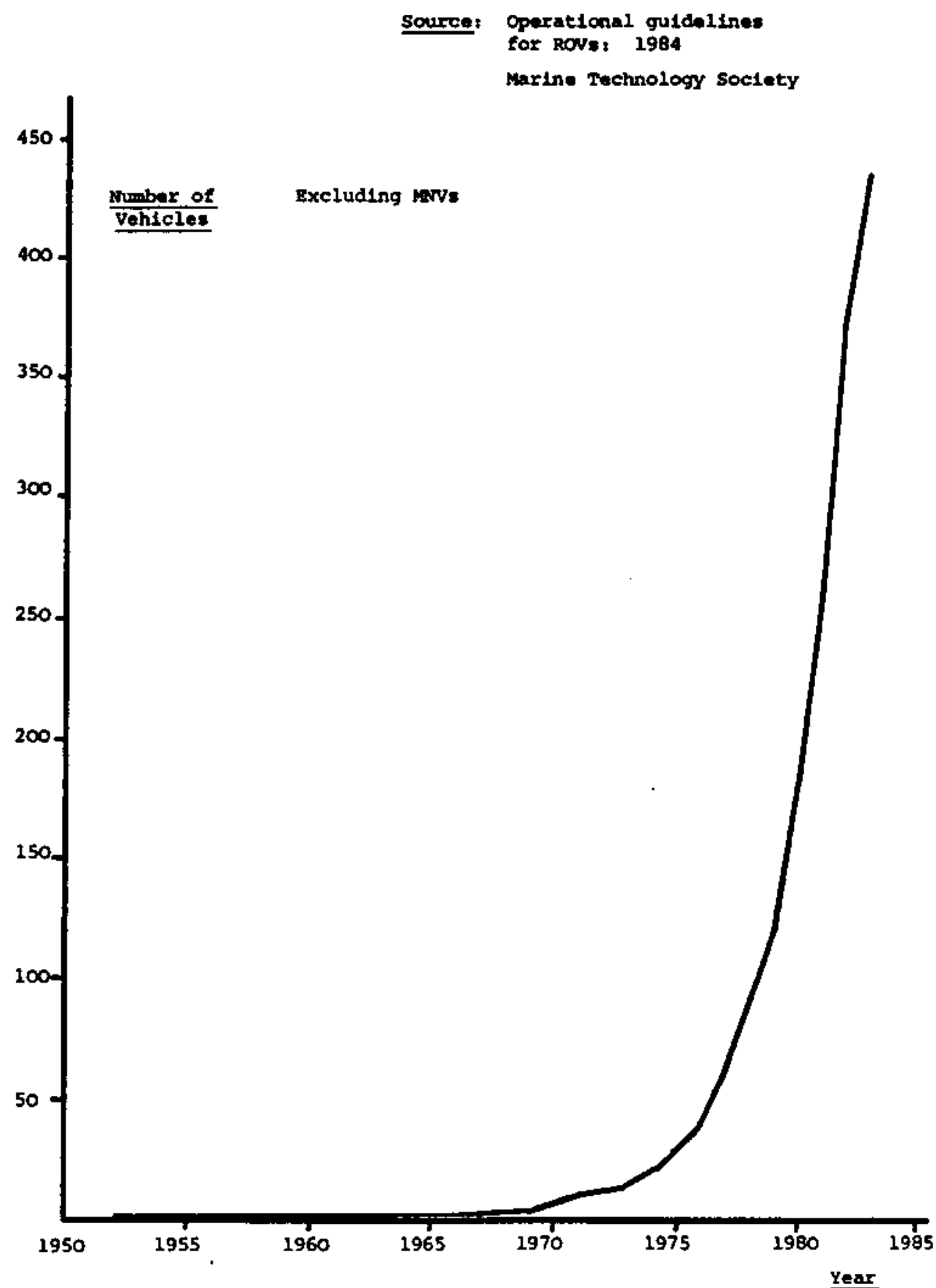
" " " '81–'85

←

60. AROV System (block diagram)
61. GRAPHICS
62. "
63. "
64. SONAR INTRAP /

SLIDES O' HEADS

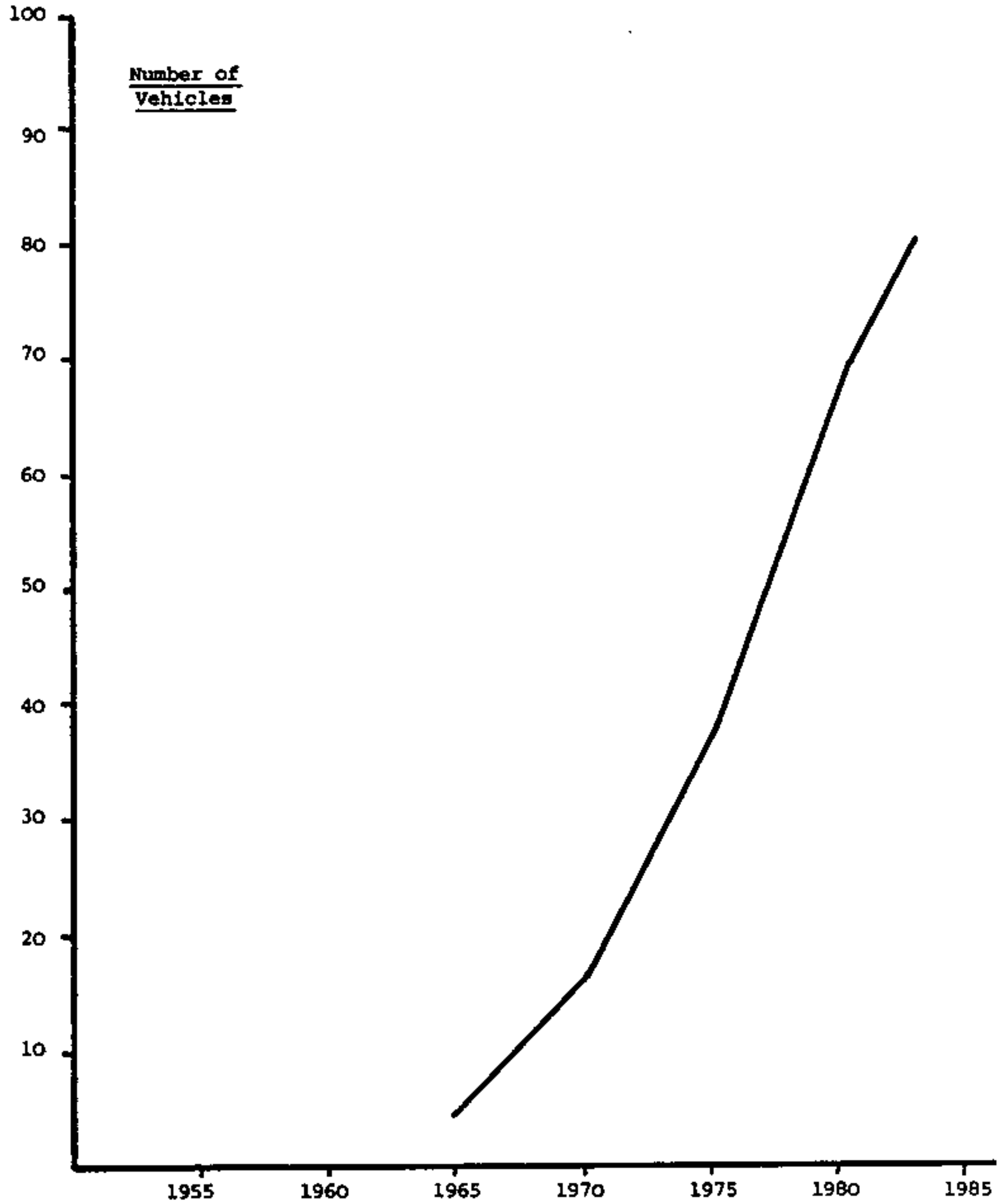
64. SONAR INTERP.N
65 " " (threshold)
66 Sonar Interp. (moving average)
67 "
68 "
69 "
70 Multipath cancellation
71 " (CCD, prog. delay line, adaptive)
72 "
73 Motion Compensation
74 " (for SSTV b-w reduction.)
75 " (acoustic channel v. video rate
76 " mismatch)
77. Cooled CCD T.V. → frame store
78. Optical fibre dispersion
- semi Tetherless ROV
79. BEN NEVIS



Tethered Free Swimming ROV Growth Rate - Cumulative Over 1950 to 1983

Source: Operational guidelines for ROVs: 1984

Marine Technology Society

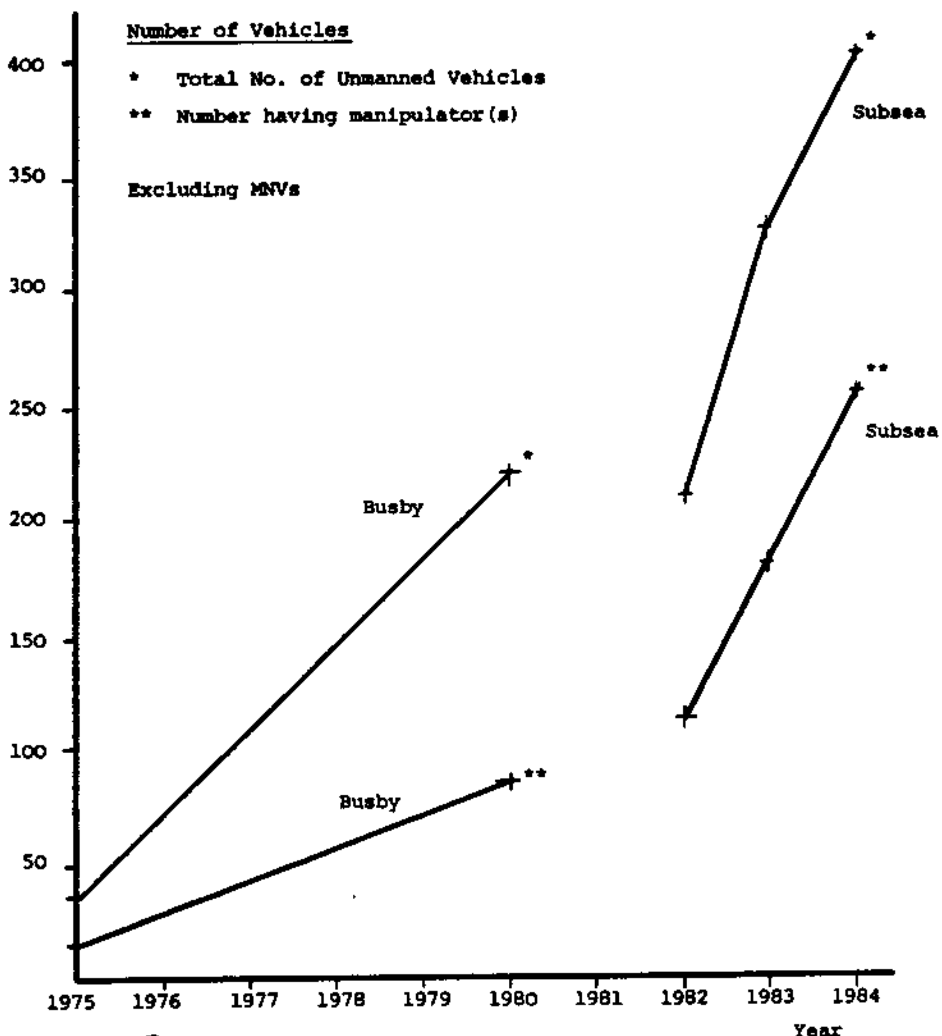


Bottom Reliant and Towed Vehicle
Growth Rate - 1965 to 1983

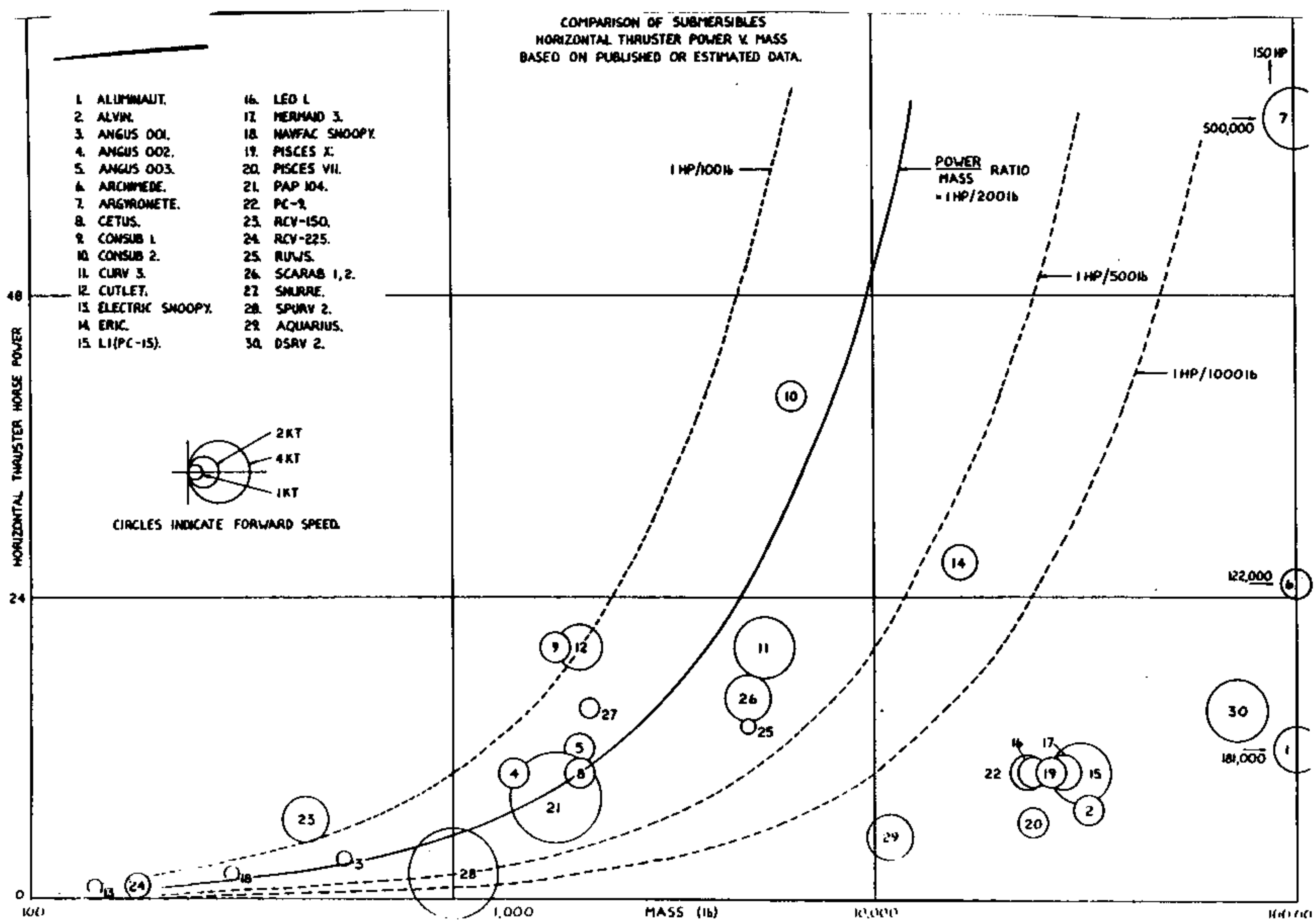
Sources:

Busby Review of Submersibles, 1976
Busby Undersea Vehicle Directory, 1981
Subsea 1982, 1983, 1984

Note: The Busby lists appear to be more comprehensive than others.



Total Numbers of Unmanned Submersibles over 1975 to 1984; Number having Manipulator Capacity


COMPARISON OF SUBMERSIBLES
HORIZONTAL THRUSTER POWER V. MASS
BASED ON PUBLISHED OR ESTIMATED DATA.
1. ALUMINAUT.
2. ALVIN.
3. ANGUS 001.
4. ANGUS 002.
5. ANGUS 003.
6. ARCHIMEDE.
7. ARGYRONETE.
8. CETUS.
9. CONSUB 1.
10. CONSUB 2.
11. CURV 3.
12. CUTLET.
13. ELECTRIC SNOOPY.
14. ERIC.
15. L1(PC-15).
16. LEO 1.
17. MERMAID 3.
18. NAVFAC SNOOPY.
19. PISCES X.
20. PISCES VII.
21. PAP 104.
22. PC-9.
23. RCV-150.
24. RCV-225.
25. RUWS.
26. SCARAB 1, 2.
27. SNURRE.
28. SPURV 2.
29. AQUARIUS.
30. DSRV 2.
2KT
4KT
1KT
CIRCLES INDICATE FORWARD SPEED.
1 HP/100lb
POWER/MASS RATIO = 1 HP/200lb
1 HP/500lb
1 HP/1000lb
150 HP
500,000
122,000
181,000
HORIZONTAL THRUSTER HORSE POWER
48
24
0
100
1,000
MASS (lb)
10,000

List of Tetherless Unmanned Submersibles

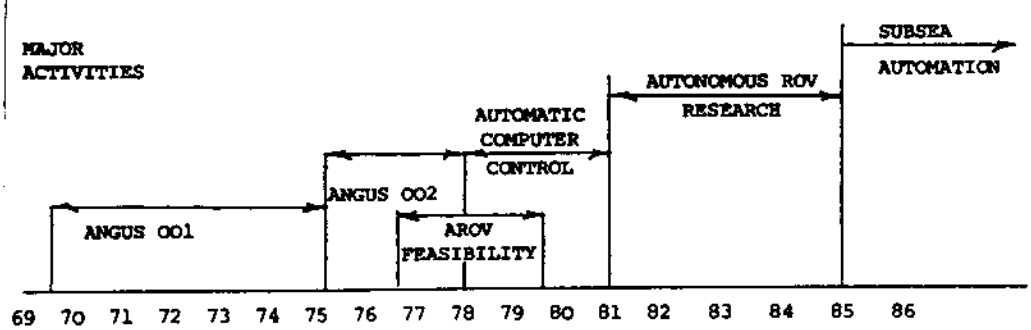
Vehicle	Built By	Application
ARCS	ISE, B.C., Canada	Under ice, mapping
AUSS	NOSC, San Diego, USA	Search, identification
B-1	NUSC, Rhode Is., USA	Laminar flow studies
CMU ROVER	Carnegie-Mellon, Univ. Pittsburgh, USA	Feasibility studies
DMT	EMI, UK	Submarine target simulation
DOLPHIN	ISE, B.C., Canada	Experimental hydrographic surveying: diesel engine
EAVE-EAST	Univ. New Hampshire, Durham, USA	Structure, pipeline inspection: feasibility
EAVE-WEST	NOSC, San Diego, USA	Structure, pipeline inspection: feasibility
ELIT	CNEXO/COMEX, France	Observation & measurement
EPAULARD	CNEXO, France	Seabed photography & topography
OSR-V	MITSUI, Tokyo, Japan	Oceanographic research
ROBOT II	MIT, Cambridge, Mass., U.S.A.	Experimental vehicle
ROVER	H.W. Univ, UK	Research vehicle
SKAT	Inst. Oceanology, Moscow, USSR	Ocean research
SPURV I	APL, Seattle, USA	Oceanographic measurement
SPURV II	APL, Seattle, USA	Mid-water research
UARS	APL, Seattle, USA	Under-ice survey
UFSS	NRL, Washington DC, USA	Long range search
VERA	CEA & France, Dunkerque Shipyard, France	Deep ocean module collection

Characteristics of Tetherless ROV's

Vehicle	Length m	Beam m	Height m	Mass kg	Payload kg	Max. Depth m	Power Storage	Propulsion H.P.	Speed (Kn.) Duration (hrs.)
ARCS	4.8	0.54	0.54	1.5 t	N/A	300	10/20 kWh	N/A	5/10
AUSS	N/A	N/A	N/A	N/A	N/A	6100	N/A	N/A	N/A
B-1	N/A	N/A	N/A	N/A	N/A	90	N/A	N/A	N/A
CMU-ROVER	N/A	N/A	N/A	N/A	N/A	Surface	N/A	N/A	N/A
DMT	3.28	0.32	0.324	236	N/A	366	35 Ah	30	2.1/1.6
DOLPHIN	6.5	1.0	1.0	2.4 t	N/A	3/30	Diesel	100	12/20
EAVE-EAST	1.52	1.52	1.04	369	45	50	7.5 kWh	0.5	0.4/N/A
EAVE-WEST	2.74	0.53	0.53	182	~20	600	12 V/ 630 Ah	~0.5	1.2/1.0
ELIT	N/A	N/A	N/A	N/A	N/A	1000	N/A	N/A	N/A
EPAULARD	4.0	1.1	2.0	2900	40	6000	48 V/ 15 kWh	N/A	0.5/6.0
OSR-V	4.8	2.15	1.75	2976	0	250	100 V/ 256 Ah	10	1/N/A
ROBOT-II	2.31	0.37	0.37	110	11.4	61	12 V/ ~30 Ah	~0.25	0.6/6.1
ROVER	2.0	0.7	0.5	100	10	300	40 Ah	2 x ¼	3/4
SKAT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SPURV II	3.05	0.61	0.61	454	45	1829	72 V/ 130 Ah	2	1/6
UARS	3.05	0.48	0.48	408	23	457	24 V/ 260 Ah	0.25	0.8/12
UFSS	6.1	1.22	1.22	N/A	N/A	457	N/A	0.33	1.3/25
VERA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

YEAR	APPROXIMATE FUNDING £K	ACTIVITY	EXTERNAL INFLUENCES: INTO PROJECT	EXTERNAL INFLUENCES: FROM PROJECT
69	1	Technical Survey	ideas	
70	1	Student Projects	Integrated Electronics	Seminars
71	2	ANGUS Project	Acoustics	
72	10	ANGUS 001	Umbilicals U-W T.V.	Personnel to Industry
73	2	Trials	Overseas Liaison	
74	15	Underwater Navigation Sea Trials for	Oil & Gas	ROV demos, Trials for Government
75	30	MAFF, ARL	Manned & ROV operations	Consultancy to Oil, ROV, Industry, Govt.
76	50	ANGUS 002		
77	100	Trials AROV Feasibility	Fibre Optics	P. Grad. Projects leading to
78	100	Computer controlled ROV Research Hydrodynamic Meas.	Microprocessors	
79	75	S.S. baseline Navigation Computer Control	LSI	Digital Techniques Laboratory
80	75	Trials 3-D Navigation	Robotics	Image Processing
81	100	AROV Research		British Telecom Research
82	100	Communications	A.I.	Govt. Research Planning
83	90	Control	VLSI	MOD Projects
84	90	AROV Test Vehicle	IKBS	Alvey Projects
		Initial Trials of AROV		
85	100	Robotics		

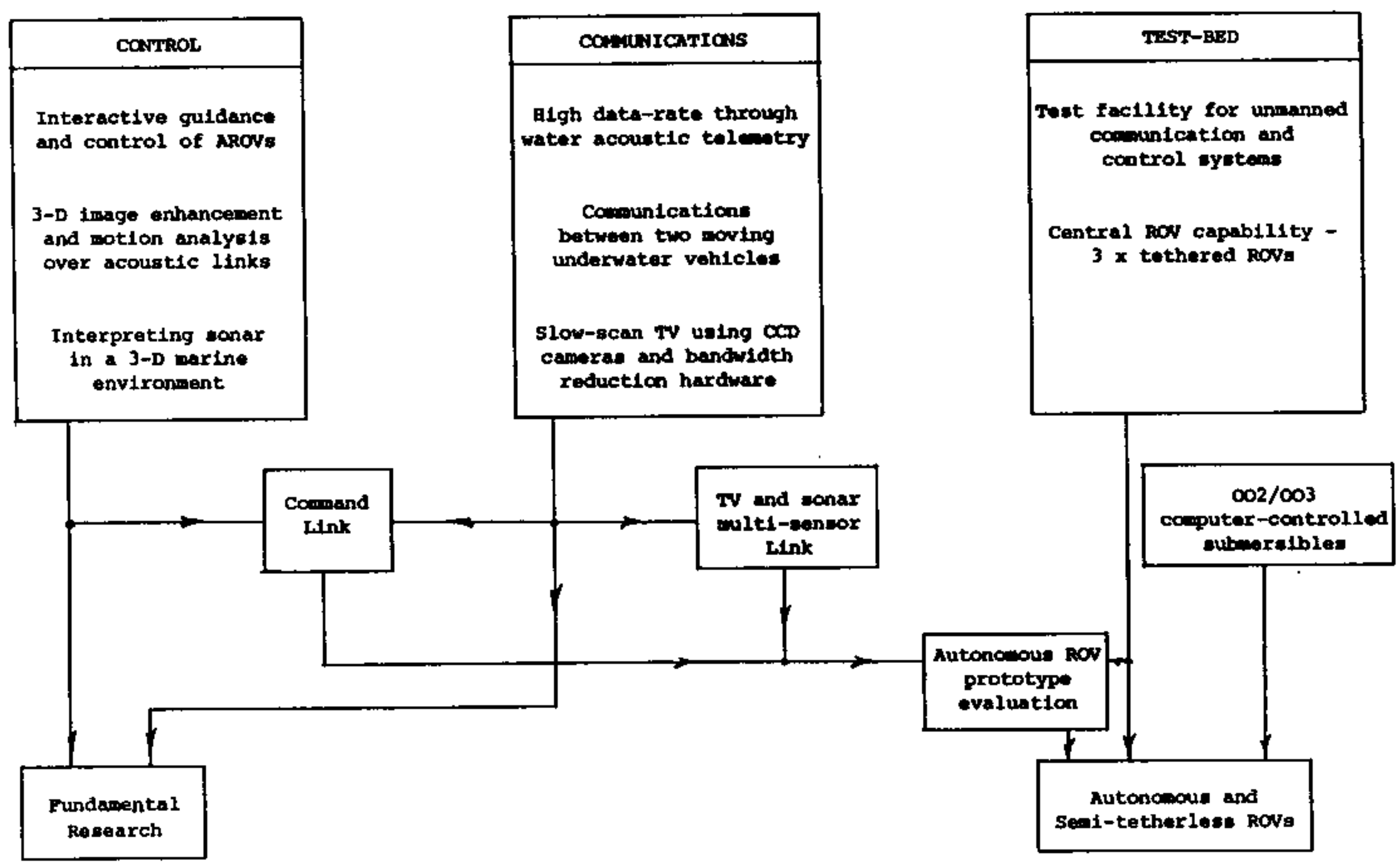
MAJOR ACTIVITIES



Heriot-Watt University Submersibles Project

HERIOT-WATT UNIVERSITY **SUBMERSIBLES PROJECT**

1981 - 1985



The Role of Tetherless ROVs in Inspection — A Practical Assessment for the Future

By ROBIN M. DUNBAR, Heriot-Watt University, Scotland

In this paper by Robin M. Dunbar of the Department of Electrical and Electronic Engineering, Heriot-Watt University, Scotland, a review of the characteristics of tetherless ROVs is presented including comparisons with tethered systems and an indication of applications. Fundamental problems are examined including techniques of through-water communications, bandwidth-reduction for TV image transmission, control requirements, and power storage systems.*

The problems to be faced in developing tetherless submersibles with performances similar to or exceeding those of typical cable-controlled vehicles are formidable and must not be underestimated.

A simplistic view of the pros and cons of tetherless vehicles is as follows:

For: no umbilical cable, therefore greatly reduced hydrodynamic drag forces to be overcome, and no risk of cable entanglement.

Against: no umbilical cable, therefore control and sensor data must be transmitted through the water, and a self-contained power supply must be carried on board.

These rather bland statements hide the extensive technical difficulties to be overcome in developing guidance, navigation, multiplexed sensor, and through-water T.V. transmission systems for example, and it will be several years before tetherless vehicles are capable of being used with the same ease as many tethered vehicles are at present.

Several tetherless submersibles do exist however, some for very advanced applications, and research is increasing to find practical solutions to the problems of control and communications.

Applications and typical vehicles will now be discussed, followed by a more detailed examination of technical problems.

Inspection Applications for RCVs

Most tetherless submersibles to date have been designed for open-water applications, some being equipped with oceanographic sensors and acoustic monitoring equipment. These will be referred to in Section 3. However, most interest in "IRM", Inspection, Repair and Maintenance, centres on requirements for offshore structure inspection, and this duty creates even more difficulties for the tetherless ROV. A list of typical survey requirements puts the problem in perspective.

General Surveys: visual inspection and testing for:
— broken or bent structural members
— corrosion
— cracking and pitting
— debris accumulation
— marine fouling
— effectiveness of anti-corrosion system
— scouring at base of platform.

Cleaning: prior to detailed inspection:
— brushing, chipping, scraping
— water jetting

N.D.T. Techniques
— magnetic particle
— magnetographic
— iron depth meter
— ultrasonic; thickness and crack
— acoustic holography
— radiography
— corrosion potential

Increasing numbers of tethered ROVs are being designed or modified to carry one or more NDT sensor, and large, sophisticated vehicles[1] like MMIM and DAVID are appearing, custom built for platform inspection and maintenance. When one considers the various dimensions, masses, and power requirements of different types of NDT equipment, the problems of cleaning prior to detailed inspection, and the difficulties of holding station to the precision required by some of the methods, one soon realises that it would probably be unwise to attempt to design a tetherless submersible "capable of doing everything". Consequently it is to be expected that when tetherless ROVs do start to appear on the IRM scene they will be designed to suit specific tasks, with a resultant variety in shapes, sizes, performance and cost, ranging from "eyeballs" like the RCV 225 to sophisticated monsters like MMIM, and beyond.

Examples of Tetherless RCVs

There are relatively few tetherless submersibles in existence, compared to the proliferation of tethered unmanned vehicles and manned submersibles. Ten vehicles which can be studied from open, unclassified literature are compared in Tables 1 and 2.

Tetherless Vehicles compared with Tethered Unmanned and Manned Free Swimming Vehicles

The position of two tetherless vehicles on an overall league table of submersibles is illustrated in figure 1.

Continued on page 10

**This paper was first presented at the IRM '82 Conference in Edinburgh, 2-4 November 1982, and is reproduced here by kind permission of the organisers, Offshore Conferences & Exhibitions Ltd. This, and other papers are available from the company's managing director, John Daniels, at 30A Sackville Street, London W1X 1DB. Tel: 01-734-4343.*

Table 1 — List of Tetherless Unmanned Submersibles

NAME	BUILT BY	APPLICATION
DEEP MOBILE TARGET (DMT)	E.M.I. Limited, U.K.	Submarine simulation for ASW & training.
EAVE-EAST	University of New Hampshire, Durham, U.S.A.	Pipeline instrumentation platform.
EAVE-WEST	Naval Ocean Systems Center, San Diego, U.S.A.	Experimental free-swimming vehicle
EPAULARD	C.N.E.X.O., France	Oceanographic research.
OCEAN SPACE ROBOT (OSR-V)	Mitsui Shipbuilding and Engineering Co. Ltd., Tokyo, Japan	Oceanographic research submersible.
PAP 104	Societe ECA, Meudon, France	A wire guided submersible for sea-bed exploration and the identification of underwater objects.
ROBOT II	M.I.T., Department fo Ocean Engineering, Cambridge, Mass., U.S.A.	Experimental robot submersible.
SELF-PROPELLED UNDERWATER RESEARCH VEHICLE (SPURV)	Applied Physics Lab, Seattle, Washington, U.S.A.	Oceanographic parameter measurement, recording and telemetering.
UNMANNED ARCTIC RESEARCH SUBMERSIBLE (UARS)	Applied Physics Lab., Seattle, Washington, U.S.A.	Exploration of near-surface, under-ice region; sub-ice-surface profiling
UFSS	Naval Research Laboratory, Washington D.C., U.S.A.	Long range, low noise, autonomous vehicle.

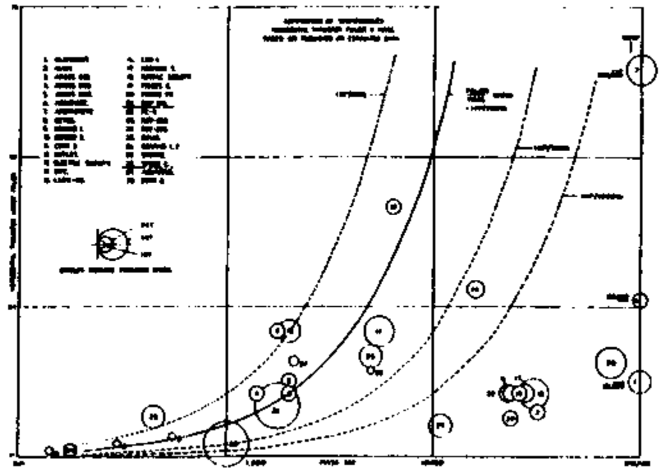


Fig. 1.

Here the performance of SPURV-2 and PAP 104 clearly stand out from the rest in that they are capable of considerably higher forward speeds for a small power input, not being constrained by cable drag, or by the large mass of some manned vehicles. It should be noted that PAP 104 is not stricly "tetherless" since it pays out a fine communications cable as it travels through the water. However, the drag on the vehicle is very small and it is hence virtually tetherless.

FUNDAMENTAL PROBLEMS

An Outline Design Specification

In view of the comments made in Section 3 regarding the need for application — constrained design, an outline design for a vehicle will be postulated so that fundamental problems can be discussed with more realism.

Table 2 — Comparison of Vehicle Characteristics

VEHICLE	Length m	Beam m	Height m	Mass kg	Pay-load kg	Max Depth m	Power Storage	Propul-sion H.P.	Speed Duration m/s/hour	Special Equipment (see code)
D.M.T.	3.28	0.32	0.324	236	?	366	? 35Ah	30	4.1/1.6	P,S
EAVE-EAST	1.52	1.52	1.04	369	45	50	7.5kWh	0.5	0.8/?	S
EAVE-WEST	2.74	0.53	0.53	182	~20	600	12V 630Ah	~½	2.4/1	C,L,P
EPAULARD	4.0	1.1	2.0	2900	40	6000	48V 15kWh	?	1.0/6.0	C,D,L,O,P,R,S
OSR-V	4.8	2.15	1.75	2976	0	250	100V 256Ah	10	2 max/?	C,L,O,P,R,S
PAP-104	2.69	1.22	1.30	800	136	150	32V 145Ah	?	2.8 max	D,L.P,T
ROBOT-II	2.31	0.37	0.37	110	11.4	61	12V ~30Ah	~½	1.14/6.1	O,P,S
SPURV 11	3.05	0.61	0.61	454	45	1829	72v 130Ah	2	2.0/6.0	O,P
UARS	3.05	0.48	0.48	408	23	457	24V 260Ah	¼	1.5/12	O,P,R,S
UFSS	6.1	1.22	1.22	?	?	457	?	⅓	2.5 max/ 25h	V

Special Equipment Code:

C — still camera(s)
D — droppable mass
L — light(s)
M — cine camera(s)
O — oceanographic transducer(s)
P — pinger(s), homing device(s)
R — profiler(s), echo sounder(s)
S — sonar(s)
T — television camera(s)
V — VLF radio navigation

Continued on page 12

The relatively simple (apparently) requirement of a visual inspection device for operation near the seabed in say 300 m water depth will be chosen, for applications such as pipeline inspection. The payload in this case will be taken as a low-light T.V. camera, requiring only modest electrical power for itself and lighting. When one considers the design of such a vehicle one will probably be led to a low-drag, streamlined shape, of adequate dimensions to house a battery supply capable of powering the vehicle at a design speed for a specified duration. That oversimplifies the problem but it is a fair step to take here since design techniques are available for its solution. More severe problems appear when one considers requirements for automatic heading, height and position control, and communication between submersible and support vessel, for control purposes and transmission of data, visual or otherwise from the vehicle.

Guidance and Control

For many reasons, including the fact that communication through the water may be interrupted, interfered with or simply lost in an acoustic shadow zone, it is virtually essential that the vehicle has its own on-board decision-making computer. This is a complex branch of high technology but it is achievable. In 1981 full automatic computer control of vehicle heading, height and position was demonstrated using the ANGUS 002 tethered submersible as a test vehicle, and the research is continuing with a view to producing an autopilot for a free swimming vehicle. Details of this research are reported in reference 2. A further development of this work is the graphical presentation of vehicle position and attitude to pilot and observer. Work is progressing[3] on developing a 3-dimensional presentation of position and seabed topography, using all available sensor information including short-baseline navigation and sonar. This is necessary since it is impossible (with forseeable technology) to get a real-time high resolution image of the seabed over a through-water path from a moving vehicle. The problem is even more complex when both vehicle and observer are moving.

Through-Water Communication

Electromagnetic Wave Communication

While there is little doubt that long-range (100 m to 10 km) through-water communications are best achieved at present by acoustics, E-M wave techniques should not be discarded out of hand for short range work. The high electrical conductivity of sea-water, about 4 s/m leads to high attenuation of E-M waves propagating in the sea[4], particularly at higher frequencies, but with carrier frequencis below 10 kHz ranges of up to about 100 m become achievable. Experimental "Magnetic Field"[5] and "Conduction Field"[6] signalling systems have been described in the literature. Long range radio communication with deeply submerged submarines is a very different story, requiring enormous powers and antenna systems[7] beyond the reach of the average civil user.

Semi-Tetherless Submersibles

If a fine insulated wire or optical fibre is fed out from a dispenser reel on-board a moving vehicle the resulting hydrodynamic drag force can be negligible, leading to a virtually tetherless mode of operation. A miniature twin-wire transmission line can permit signalling at tens of kilohertz over very long lengths while an optical fibre can transmit signals with bandwidths of tens of Megahertz over many kilometers. Studies[8,9] show this to be an excellent engineering solution for many applications.

Acoustic Communications

The "outline design" arrived at in Section 4.1 is close to the design specification aimed at in research currently carried out by the author and his colleagues. The basic problem to be faced is that an unprocessed T.V. signal is inherently wide-band (around 6 MHz) whereas an acoustic channel is inherently narrow-band (a 10 kHz data rate is considered to be very good). Consequently there is a bandwidth mismatch ratio of around 1000:1. Research under the "Communications" heading is progressing in two main directions, one to increase the acoustic data rate to a maximum reliable value, and the other to reduce the information (T.V.) bandwidth to a minimum value, using slow-scan and coding techniques.

The communication system is required to provide initially, from submersible to surface, a binary digital data link of reasonable accuracy (probability of error = 10^{-3}) at a rate of at least 10 k bits/sec and preferably much higher. Eventually for a true free-swimming submersible an additional two-way computer data link is required, at slower data rate, but at much higher accuracy. The first major decision for an acoustic link is that of carrier frequency. Increasing attenuation with frequency limits the maximum frequency for the operational conditions described to about 600 kHz. A typical path loss for 100 m at 600 kHz is 55 dB, still allowing adequate Signal-to-[thermal] Noise ratio (SNR) at the receiver for only a few watts of transmitter power.

The most significant source of interference will be from other sonar systems, particularly high resolution side-scan sonars which use high frequencies at very large peak powers. A secondary source will be mechanical and cavitation or turbulance noise, although this is more of a problem at lower frequencies.

Multipath Problems

In many acoustic links through the water, the biggest problem is multipath interference. A ray path study shows that an unwanted reflection differs from the wanted direct signal in three ways, (i) angle of incidence at transducer, (ii) propagation time delay, and (iii) relative attenuation. Difference (iii) tends to be small and insignificant. In any practical system the range of these parameters will be large, but an important correlation exists between them in that if angular difference is small at both transducers of the link then time delay tends to be short, and relative attenuation is small. However, when using high data rates, even these delays are long enough such that the unwanted reflection is delayed by 10's of data bits.

Conditions are particularly difficult in shallow water where the signal may arrive by many paths, some very uncertain because of insufficient information on the acoustic properties of the prevailing seabed. Mathematical models have been devised to aid the sonar system designer but multipath propagation under such conditions remains an area requiring further research.

Bandwidth Reduction

The aim of this part of the current research programme is to examine various methods of reducing the bandwidth of T.V. images, so as to permit their transmission across a through-water acoustic communication link. In order to achieve this, a PDP 11/23 computer based image processing system and associated software package have been developed to allow the digitization, display and processing of T.V. images. The result of some initial studies are briefly presented here. An adaptive coding strategy is also described, as one possible solution to the problem of the restricted bandwidth channel.

Proposed System for F.S.V.

The spatial and temporal resolutions of a T.V. system for a free swimming vehicle are to a large extent dictated by the missions such a vehicle would be asked to undertake. In an effort to establish suitable resolution parameters for a system, two possible modes of vehicle operation have been postulated:

(i) *Piloting Mode:* In this mode the received T.V. images are used to pilot the vehicle in and around objects of interest. As the maximum velocity of the vehicle is envisaged at 1 m/s and in view of the fact that the range of viewing in turbid waters may only be a matter of a few metres, a frame rate update time of 4 frames/sec is thought desirable. The spatial resolution, however, need only be sufficient to allow the identification of an object and an image of 128 × 128 picture elements (pixels) is thought sufficient. Adaptive resolution is also feasible, related to vehicle speed, and visibility.

(ii) *Inspection Mode:* In this mode the received images are used to inspect objects of interest in order, for example, to assess defects and damage in underwater structures. This mode then requires higher definition images, but since the objects are in the main stationary, a further reduction in the frame rate is normally acceptable. For this mode an update time of 1 frame every four seconds or more can be tolerated, while a spatial resolution of 512 × 512 pixels/frame is desirable.

Practical Results with Slow-Scan T.V. Transmitted over an Acoustic Link

As part of the research programme T.V. images were transmitted over a through-water acoustic link to assess the effects of fading, multipath interference, and coding techniques on received picture quality. The T.V. signals were coded and decoded before and after transmission using a frequency shift keying (FSK) coding strategy.

The results demonstrated that:

(a) In the absence of multipath effects, i.e. the reception of a signal and time delayed portions of the same signal, an error free image is received.

(b) When multipath effects were introduced (by moving one transducer at right angles to the signal direction thus decreasing the direct path signal strength while maintaining the same strength of signal from the effected paths) errors occurred. If the multipath effects produced single errors the D.P.C.M.* coding strategy employed by the S.S.T.V. resulted in an erroneus column which could be effectively removed using the error concealment facility. However, if a burst of errors occurred several columns became erroneus and employing the error concealment facility in this instance did little to improve the image.

The above results, which were recorded on video tape, indicate that some form of error detection and correction is required to combat the effects of multipath. Further, inter-pixel D.P.C.M. as a coding strategy produces catastrophic results for a single error within a column while only giving a 2:1 improvement in the bandwidth required.

Resolution Experiments

In an attempt to simulate the effects of piloting a free swimming tetherless submersible using a T.V. system with a greatly reduced frame rate, the S.S.T.V. Receiver and Transmitter systems were connected back to back. Employing the cable controlled test bed vehicle ANGUS 002, an experienced pilot was then asked to manually control the submersible while sitting at a monitor driven from the S.S.T.V. system.

Spatial Resolution

The results indicated that:

(a) The spatial resolution of 208 × 290 pixels per frame provided by the S.S.T.V. was found to be more than adequate for piloting the vehicle, however it is felt that for inspection purposes, a higher resolution is desirable.

(b) The grey scale resolution provided, that of 256 levels, was again found to be more than adequate for all modes of operation, however the second grey scale resolution available, that of 16 levels (PCM mode), is insufficient for even piloting mode.

Temporal Resolution

Several frame rates were examined from 1 frame every 5 seconds to 1.5 frames every second (the highest frame rate currently available on the slow scan T.V. system). The results indicated that:

(a) Even with a frame rate of 1.5 frames/second piloting a remote controlled vehicle was found to be difficult and it is felt 3 or 4 frames/second will be needed for piloting, while a lower spatial resolution might be accepted.

(b) The method of frame update employed by the S.S.T.V. system was found to be unsatisfactory. The current method of updating is from left to right, column at a time, which was found to be most distracting by the pilot.

(c) Familiar objects such as ropes, pipelines, etc. make the task of piloting considerably easier.

(d) Due to the drastically reduced frame rate, in the event of image break-up, the pilot loses all sense of position.

Comments on Results

When designing a low bandwidth T.V. system suitable for a free swimming tetherless submersible the designer must give consideration to the tasks such a vehicle will eventually undertake. In this way the best compomrise can be reached between the conflicting requirements of high resolution/rapidly updated images and a low bandwidth signal, and the experiments described support the piloting and inspection modes postulated earlier.

Continued on page 15

*DPCM = *differential pulse code modulation.*

Power Storage for Tetherless RCVs

A variety of battery systems exist and the submersible designer must make his choice on the basis of energy density, cell life, safety and cost. A comparison of some secondary battery systems is given in Table 3.

Table 3 — Properties of Secondary Battery Systems

System	Cell Volt	W-h/kg	kW-h/litre	Remarks[10]
Ni-Cd	1.2	35	0.11	Rugged; expensive
H_2-Ni	1.2	40	0.05	Needs gaseous H_2 (1976); space applications
Fe-Ni	1.2	44	0.11	Edison cell; cheap
Fe-Ag	1.3	88	0.14	Prototype; good recharge very expensive
Ni-Zn	1.6	59	0.12	High current rate with good shelf life
AgO-Zn	1.8	176	0.42	Recharge with care; very expensive
Pb-acid	2.0	44	0.07	Rugged; cheap; abuse-tolerant

Prospects for the Future

Although the problems described are formidable there is no doubt that the attraction of a submersible without a cable, capable of out-performing a tethered RCV, especially for applications in deep-water, will remain a driving force for engineers involved in this branch of research.

Solutions are being found to many of the control and guidance problems, via tethered vehicle research, knowlege grows on means of combatting multipath interference, and solid-state technology is expected to produce a hardware realisation of large bandwidth-reduction factors.

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FRONT COVER

"Check Mate" the Norwegian submersible being launched into the sea outside the NUTEC base. At the front of the vehicle can be seen a torpedo recovery system (white) to be tested out at the test centre.

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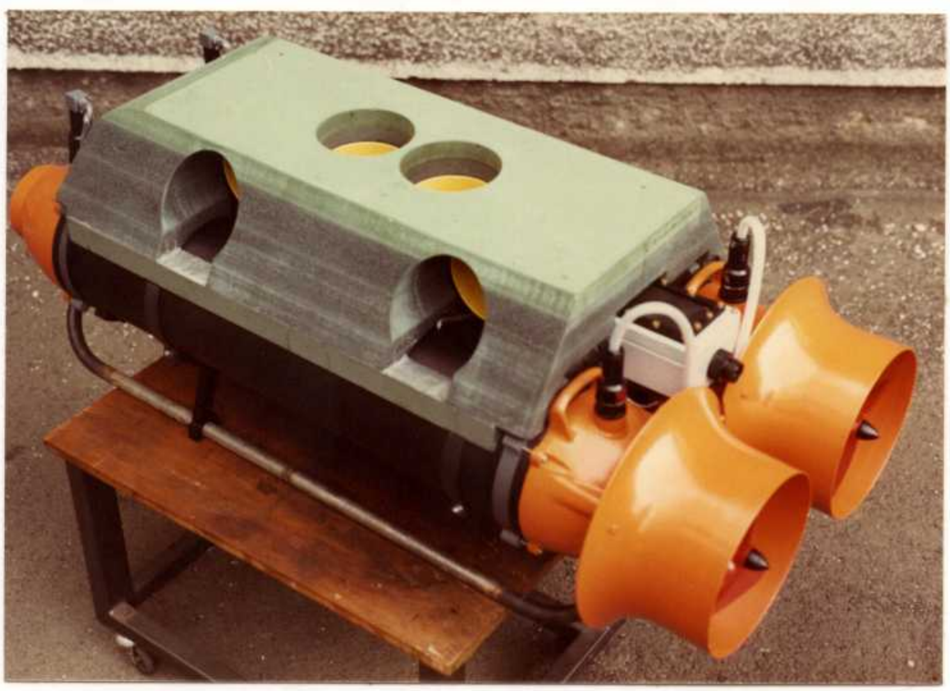

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