Remote Manipulation Systems for Research ROVs

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INTRODUCTION

Harbor Branch Oceanographic Institution (HBOI) has for the past 15 years been developing and operating two of the most active and productive (Alldredge and Youngbluth, 1985; Littler et al., 1986) undersea research vehicles, the 805 m operating depth JOHNSON-SEA-LINKs (JSL) I and II. These four-man submersibles were designed with lock-out capabilities enabling two researchers to exit and re-enter the craft at depth. It was originally envisioned that manipulative tasks, and those functions requiring finesse, would be carried out by these lock-out divers. Engineers at HBOI have, however, developed an inventory of tools systems (Tietze and Clark, 1986) which enable the sub's occupants to perform a wide variety of research from within the safety of its hull, and well beyond the depth limits of safe lock-out diving.

Having eliminated the need for the researcher to venture outside the submersible, the next logical evolutionary step, as evidenced by industrial counterparts, is to remove the researcher from the submersible altogether. While the oil industry's replacement of manned submersibles with ROVs is all but complete, the subjective nature of such qualitative research as behavioral studies, in which HBOI is engaged, dictates the continued use of manned submersibles.

There are, however, a number of tasks for which JSL I and II have been employed which could be performed equally well or better with a properly designed and equipped ROV.

Among the more obvious of these tasks are the delivery and retrieval of unattended in situ measurement devices. Beyond these brutish chores, however, lie a number of much more complex research tasks which require the presence and attention of the investigator to perform. The identification and collection of benthic and midwater organisms has been reduced to routine from the manned JSL I and II. The systems described herein afford the investigator sufficient "telepresence" to enable him to perform such work with an ROV.

Demand by the research community for JOHNSON-SEA-LINK I and II has exceeded their availability. To meet this demand, and extend the Institution's 805 m operating depth, HBOI purchased a 1,000 m HYSUB-40 ROV (Figure 1). The vehicle has been fitted with a bolt-on undercarriage (SCIENCE SLED), 30.5 cm high, 104 cm wide and 145 cm deep. Mission-suited tool systems are designed to slide easily into the SCIENCE SLED. This not only facilitates ease of reconfiguring the vehicle for varying tasks within a cruise, but it is further hoped that this concept will be adopted by other research ROV operators, thereby providing the capability for interchanging tool packages among operators, thus facilitating collaborative efforts.

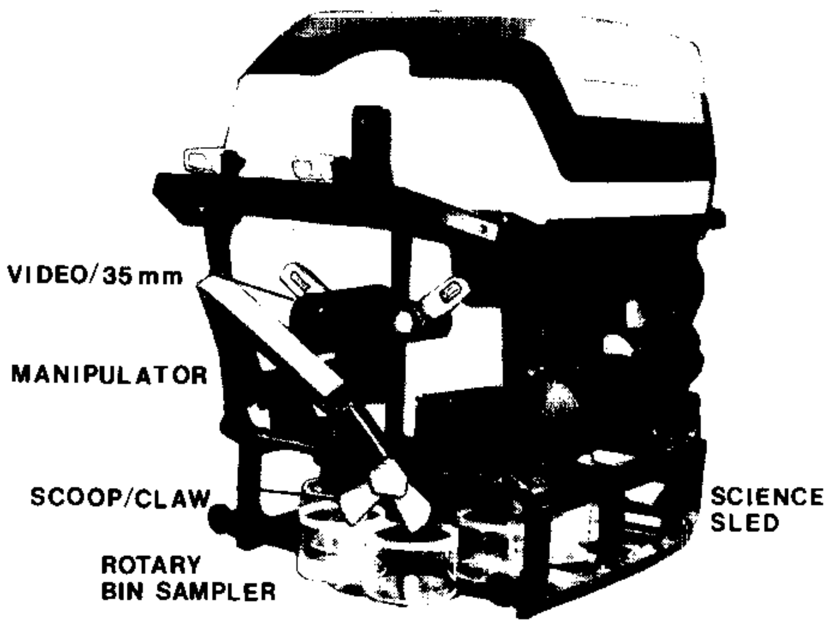


Figure 1. HBOI's HYSUB-40 ROV

SAMPLING SYSTEMS

Manipulator

The portion of the work package which serves to unite the system is the manipulator arm, (Figure 2) designed and manufactured by Schilling Development, Inc. Careful allocation of task responsibility is of key importance in any properly functioning system. The purpose of the manipulator in this scientific work package is to provide the operator with an interactive means of carrying out collection tasks while freeing him of the tedious operations, such as sample storage, which do not necessarily require his attention.

These requirements established certain design criteria for the manipulator. The machine must be subject to a tight control loop for the performance of interactive as well as pre-programmed operations. In addition, in the interactive mode of operation, the slave arm must perform at a velocity high enough to allow the operator's own human control system to play an active roll; the operator should never have to wait for the slave arm. The ability of the arm to maximize performance is determined by its mechanical, as well as its electrical design. While the dynamic performance of the system can, to a great extent, be shaped in software, proper hydraulic design was not

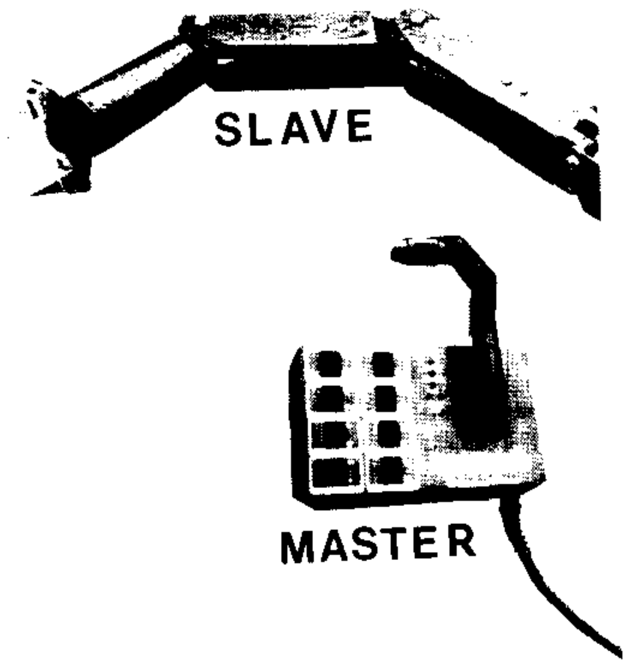


FIGURE 2. Schilling Manipulator and Controller

overlooked. The manipulator system yields this high performance through careful attention to mechanical design and the integration of a powerful microprocessor control system, in addition to a hand held terminal assembly to provide maximum flexibility. An important aspect of the manipulator portion of this system, is the design of its master control assembly. Its miniature design affords the operator with a comfortable means of controlling the five-degree of freedom arm. Unlike conventional master control arms, this design does not require the operator to hold his or her arm outstretched at any position in the operating envelope. From the front panel of the master control assembly, the operator can select various modes of arm operation. The overall control dynamics can be altered by the operator to facilitate the arm's operation in air or submerged. Additionally, the wrist rotate function can be operated in a slaved mode or a velocity mode to provide for tasks requiring continuous wrist rotation. Likewise, the jaw function has two modes of operation; it can be used in the toggle mode, which requires two actuations to open and then close the jaw, or in the open mode, where the jaw remains open unless the button at the tip of the master arm is held depressed. The slave arm can also be electronically frozen in any position from the front panel of the master control assembly.

A variety of detachable appendages which affix to the arm have been designed to perform various types of collecting, grasping or manipulation. Figure 1 depicts a multi-purpose scoop/claw designed especially for grasping and dislodging sponges and similar organisms. The multiplexed control system (described below) for the manipulator also provides proportional control for the suite of collection and data acquisition devices.

Control System

Beyond the mechanical design of the arm lies its control system (Figures 3 and 4). The control system for this manipulator was designed with several criteria in mind: power, reliability, flexibility and expandability.

For the package to possess power, it must have sufficient processor band width. Hence, the system was based around an Intel 8088 microprocessor. While this is not a brute-force chip, it provides more than adequate power.

The reliability of the package is assured by maximizing the use of digital components throughout the system, along with the fact that all control system parameters are defined in software. This provides for a system that requires no hardware adjustments.

System flexibility is obtained through the software-defined control parameters. This allows the user to actually alter the control algorithm through the hand held terminal.

The issue of expandability was addressed in the design by providing additional analog interface circuitry beyond that which the arm itself requires. The manipulator control consists of two

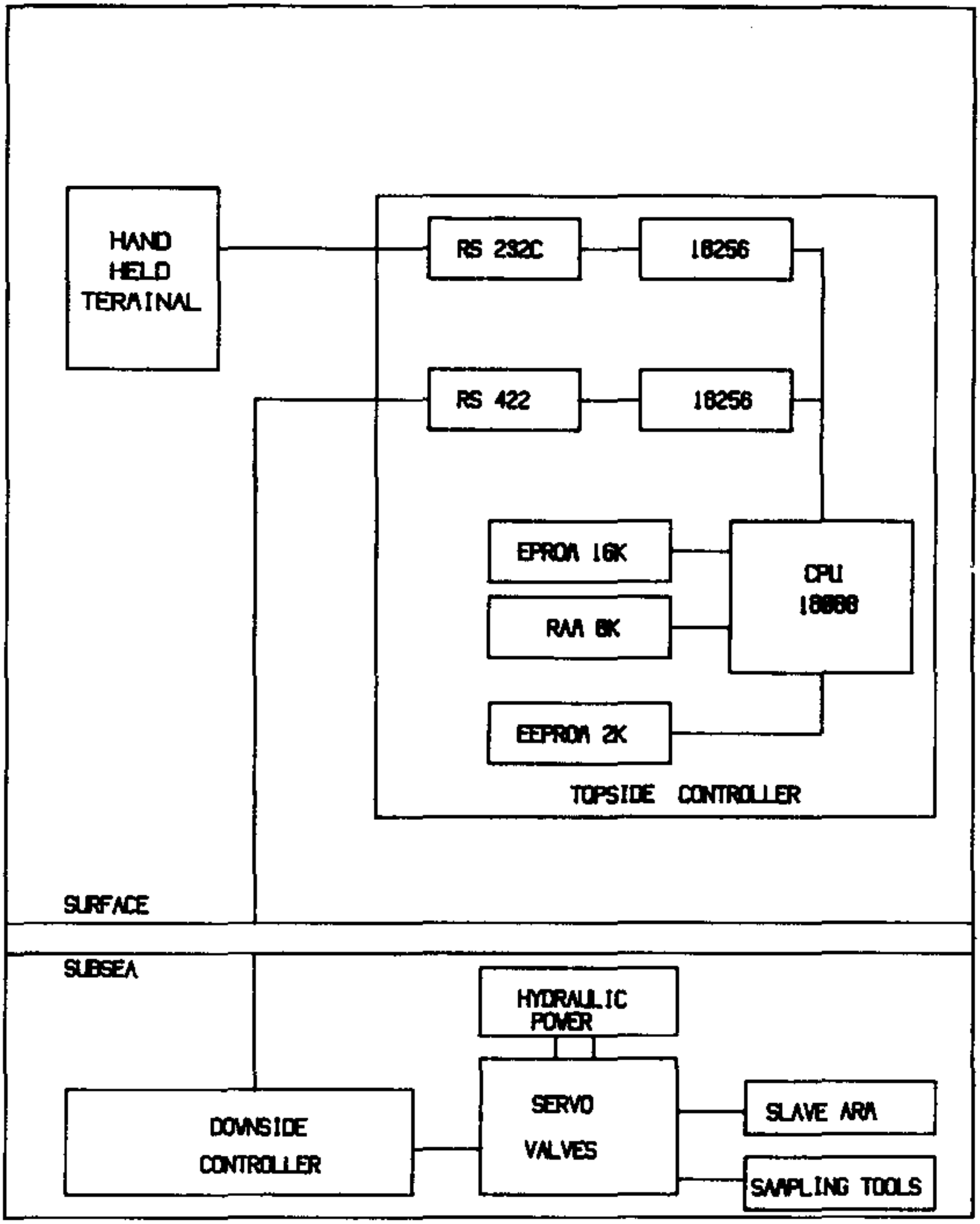


Figure 3. Control System Schematic

identical computer packages, one top-side and the other housed within the subsea valve package (Figure 5). These assemblies communicate over a twisted wire pair by an RS 422 standard. They utilize a data packet transmission scheme to provide maximum fault tolerance.

The function of the down-side control package is the closure of the control loop, while the top-side assembly contains the "personality" of the system. The top-side software generates the data used to update the tables in the down-side control loop. This data is generated by either reading joint angle values from the master arm, or

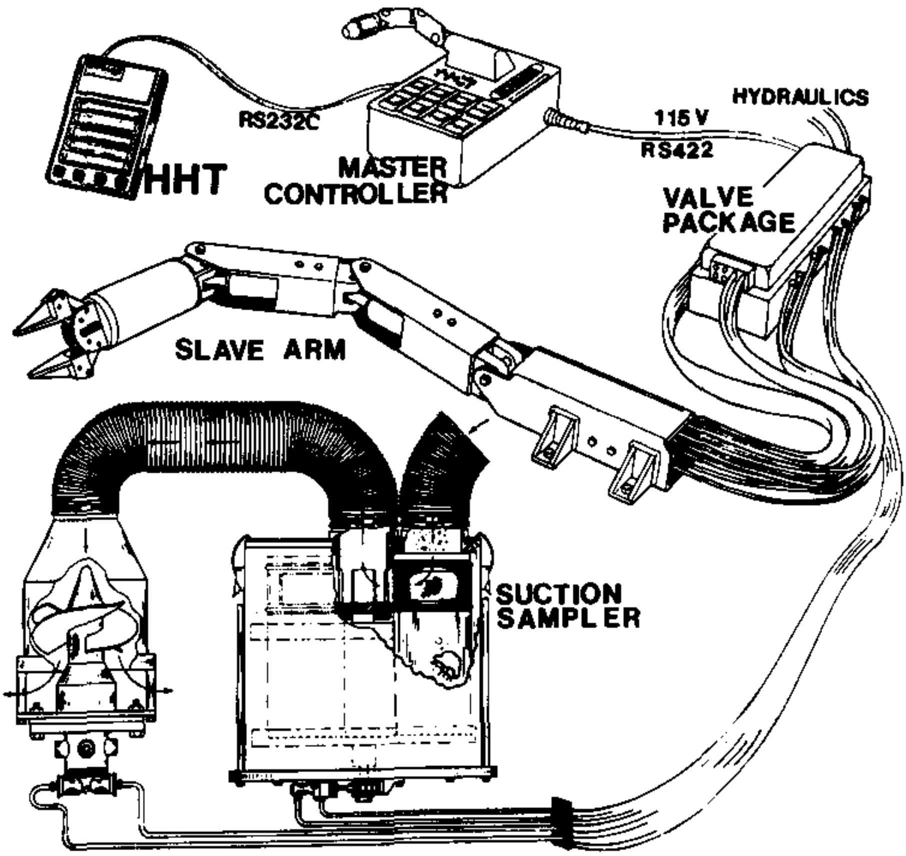
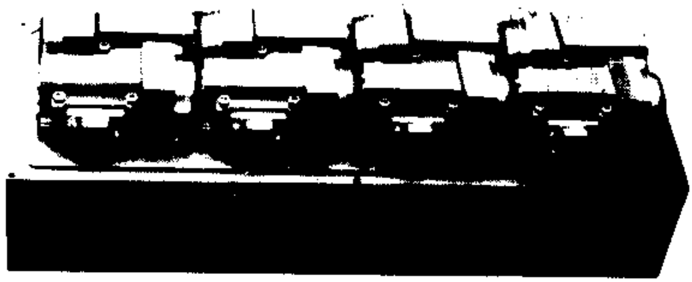


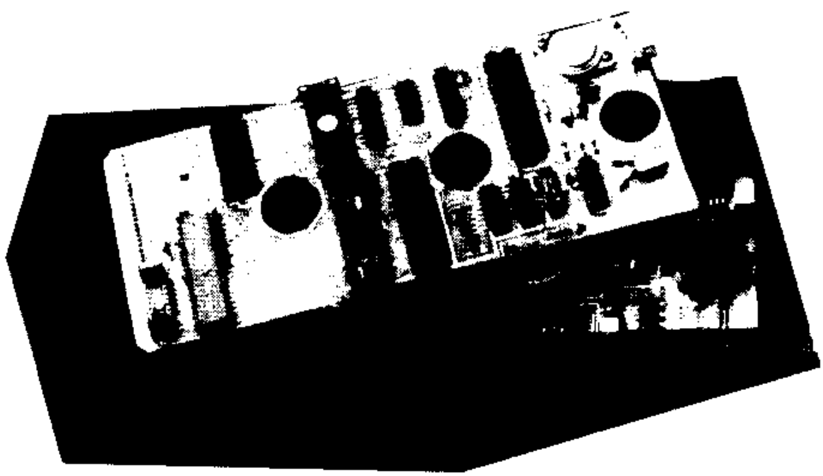
Figure 4. Remote Manipulation System

drawing this information from memory in the case of pre-programmed operation. Also contained in the top-side unit are the values which represent the limits of the operational envelope. These limits can be defined to prevent the manipulator from making unintended contact with other vehicle systems.

As a result of close attention to design of the mechanical portion of the machine, the actual control scheme implemented is very classical, yet still provides the performance objectives established at the onset. Further performance gains are expected to be yielded through the implementation of more creative techniques. These gains are envisioned to provide optimum performance in the pre-programmed modes of operation.



HYDRAULICS (TOP VIEW)



ELECTRONICS (BOTTOM INSET)

Figure 5. Subsea Valve Package

Hand Held Terminal (HHT)

The practicality of pre-programmed operation is provided through the use of the Hand Held Terminal (HHT). This menu-driven terminal unit allows the operator to input a program sequence to the control computer in two ways. The operator can select a point-to-point mode for simple program paths, or a streaming mode with pre-selected record increments for more involved paths. In both modes, the operator moves the arm in a normal master/slave manner. He can then store these paths, and execute them on command. The HHT is composed of five LCD screens, each with fifteen touch sensitive areas (Figure 6). To operate the device, the operator need only touch the desired command prompt. The unit also affords the capability to read auxiliary sensory data: hydraulic pressure, temperature, water intrusion, etc., as well as the capability to control auxiliary functions. These functions may include the operation of the ROTATING BIN SAMPLER, suction pumps, still cameras or other data acquisition systems. An additional benefit of the HHT is its ability to perform diagnostic functions on the manipulator system. The ultimate power of the control system and HHT lies in their flexibility. The low probability of the designer predicting fully the needs of the operator in the field has been established through experience. Therefore, the ability of the operator to change the rules "on the fly" is very important.

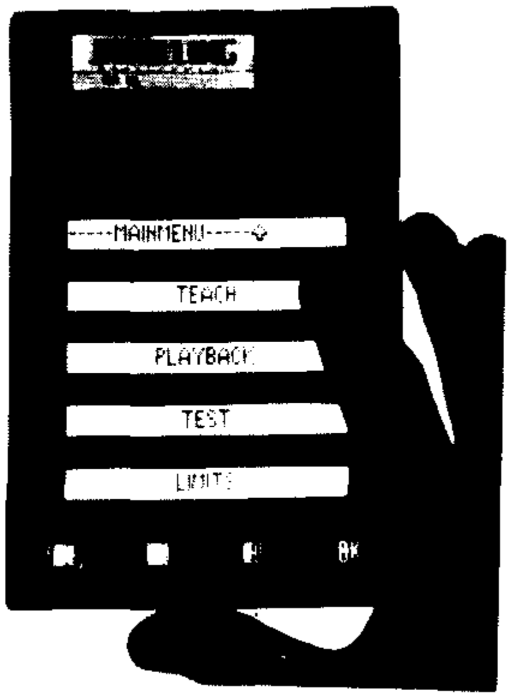


Figure 6. Hand Held Terminal (HHT)

Rotating Bin Sampler

The ROTATING BIN SAMPLER slides into the tracks of the SCIENCE SLED. Basically, the device indexes and stores discrete samples in sets of up to 18 (17.8 cm diameter x 17.8 cm) bins or 12 (25.4 cm diameter x 17.8 cm) bins. The bins are acrylic cylinders which are conveyed to the sampling location by way of a titanium chain. When collecting large, solid specimens, as with the manipulator's scoop appendage, a numbered bin is indexed beneath a funnel into which the manipulator drops the specimen. The operator can effect this through either the supervisory or pre-programmed mode. The system can also be used to collect and index macro- or microscopic, and liquid samples. A suction plenum is mounted at the top of the tray, adjacent to the funnel. Samples are drawn in by means of a hydraulically driven "slurp" pump through a flexible hose fixed to the manipulator. The specimen is deposited in the bin positioned beneath the suction plenum. The titanium chain is driven and indexed by a reversible, low speed-high torque hydraulic motor.

The suction force is infinitely variable through the multiplexed control system, and flow is monitored topside by the output of an in-line flowmeter. Thus, the device can be adjusted to low flow, for capturing extremely delicate organisms, or to high flow for dredging sediment.

Photographic/Video

Much of the data collected by researchers using HBOI submersibles is visual documentation. As such, high quality video and still photography are paramount in making this ROV a viable research tool. Sharp focus of 35 mm still photographs is insured by a system in which both a color video imaging tube and a 35 mm film cartridge share the same lens (Figure 7). Thus, images brought into focus on the topside monitor by the operator can be recorded on 35 mm film by a single trigger which activates both the shutter and strobe. The microprocessor-controlled system also provides the researcher alphanumeric write-on capability for specimen documentation.

In order to maintain the highest possible resolution, video signals are transmitted up the lift umbilical via 50/120 μm graded index silicon optical fibers. Analog fiber optic transmitters and receivers are nested within both the subsea and the surface slip rings, thereby eliminating the need for an optical swivel joint.

The vehicle is equipped with an auxiliary transformer which provides 1500 W at 24V, 28V, 32V DC and 110V AC to facilitate various other 35 mm or large format camera systems and their strobes. Compact dual laser systems have been developed to serve as range-finding and absolute measurement scales.

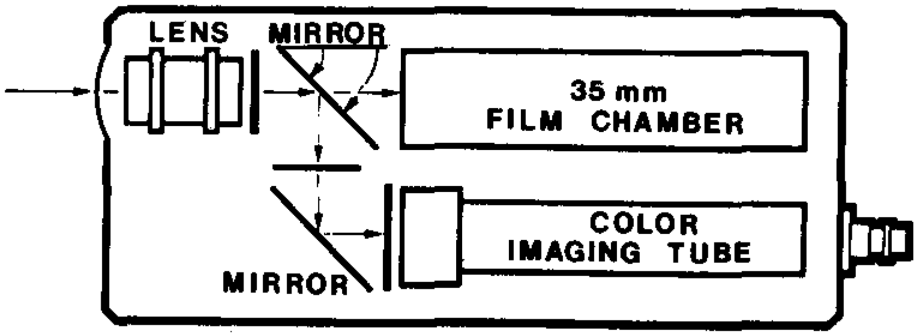


Figure 7. Video/35 mm System (Courtesy of Osprey Electronics)

FUTURE ENHANCEMENTS

Further optimization of the manipulator portion of this work system is anticipated in the area of interchangable end effectors. Man often takes for granted the fact that the human hand functions as dozens of tools while the jaw portion of a manipulator has very limited capabilities. Therefore, the ability to change out remotely and automatically specialized end tooling is of utmost importance. A system to provide for the interchange of hydraulic tools which may be either open or closed loop type is in the initial stages of design.

A number of different schemes are being evaluated for providing pseudo 3D viewing by means of color stereo video systems. Such a system, coupled with the easily mastered and highly dextrous Schilling manipulator, will provide the researcher with further telepresence. Thus, the co-pilot's seat at the operator console is readily occupied by investigators with little or no ROV experience, yet with the ability to identify, collect, index and record a vast array of specimens at depths to 1,000 m.

Data acquisition systems, standard to the JSL manned submersibles, which enable monitoring and recording such parameters as conductivity, temperature, and transmisivity are being adapted for use on this vehicle. Perhaps the single most significant enhancement anticipated is an upgrade of the ROV's operating depth. Through modifications to the vehicle's telemetry system and replacement of the 38 mm diameter lift umbilical with an umbilical more reliant on optical fibers and subsequently, of significantly decreased diameter, it is intended to ultimately increase the vehicle's operating depth to 2,000 m. The vehicle's manufacturer, International Submarine Engineering, Ltd. (ISE) has built two other vehicles to-date which meet or exceed this design depth, and are currently building a 5,000 m system. As such, it is not anticipated that this upgrade will present insurmountable technological problems.

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