'commercial' ports are operated as publicly controlled or semi-public entities, which may lease space for terminal facilities to private terminal operators. Bulk cargo or 'industrial' ports for the export or import/processing of raw materials traditionally have been built by and for a specific industry, often with extensive public assistance. The degree of national coordination of port policy and planning varies considerably. The USA has one of the greatest commercial port densities in the world, particularly along its east coast. US commercial ports generally compete among each other as semi-private entities run in the interest of local economic development objectives. The US federal government's primary role in port development is in the improvement and maintenance of navigation channels, since most US ports (apart from some on the west coast) are shallow and subject to extensive siltation.

Future Developments

A gradual shift of the 'centroid' of Asian manufacturing centers westward from Japan and Korea may in the future shift more Asia–America container cargo flows from trans-Pacific to Suez/trans-Atlantic routes. Overall container cargo flows are expected to increase by 4–7% per year. Bulk cargo volumes are expected to increase as well, but at a slower pace.

Container ships will continue to increase in size, reaching perhaps 12 000 TEU capacity in the course of the next decade. Smaller, faster cargo ships may be introduced to compete for high-value cargo on certain routes. One concept calls for a 1400 TEU vessel capable of 36–40 knots (twice the speed of a conventional container ship), making scheduled Atlantic crossings in 4 days.

Port developments will center on improved container terminals to handle larger ships more efficiently, including berths that allow working the ship from both sides, and the further automation and streamlining of moving containers to/from ship and rail/truck terminus.

Conclusions

Today's maritime shipping industry is an essential transportation medium in a world where prosperity is often tied to international trade. Ships and ports handle 90% of the world's cargo and provide a highly efficient and flexible means of transport for a variety of goods. Despite a history of protectionist regulation, the industry as a whole is reasonably efficient and becoming more so. The safety of vessels and their crews, and protection of the marine environment from the results of maritime accidents, continue to receive increasing international attention. Although often conservative and slow to adopt new technologies, the shipping industry is poised to adapt and grow to support the world's transportation needs in the twenty-first century.

See also

International Organizations. Law of the Sea. Marine Policy Overview. Ships.

Further Reading

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SHIPS

R. P. Dinsmore, Woods Hole Oceanographic Institution, Woods Hole, MA, USA

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Introduction

Oceanographic research vessels are shipboard platforms which support the conduct of scientific research at sea. Such research may include mapping and charting, marine biology, fisheries, geology and geophysics, physical processes, marine meteorology, chemical oceanography, marine acoustics, underwater archaeology, ocean engineering, and related fields.

Unlike other types of vessels (i.e., passenger, cargo, tankers, tugs, etc.) oceanographic research vessels (RVs) are a highly varied group owing to the diverse disciplines in which they engage. However, characteristics common to most RVs are relatively small size (usually 25–100 m length overall); heavy outfit of winches, cranes, and frames for overboard work; spacious working decks; multiple laboratories; and state-of-the-art instrumentation for navigation, data acquisition and processing.

Categories of RVs may vary according to the geographic areas of operations as well as the nature and sponsorship of work. Examples are:

1. By Region:

Coastal, usually smaller vessels of limited endurance and capability

Ocean going, larger vessels usually with multipurpose capabilities, ocean-wide or global range

Polar, ice reinforced with high endurance and multipurpose capability

2. By discipline:

Mapping and charting, emphasis on bathymetry

Fisheries, stock surveys, gear research, environmental studies

Geophysics, seismic and magnetic surveys

Support, submersibles, buoys, autonomous vehicles, diving

Multiple purpose, biological, chemical, and physical oceanography; marine geology; acoustics; ocean engineering; student training; may also include support services.

3. By sponsor:

Federal, usually mission oriented and applied research

Military, defense, mapping and charting, acoustics

Academic, basic research, student practicum

Commercial, exploration, petroleum, mining and fisheries

According to information available from the International Research Ship Operators Meeting (ISOM), in 2000 there were approximately 420 RVs (over 25 m length overall) operated by 49 coastal nations.

History

The history of RVs is linked closely to the cruises and expeditions of early record. Most of these were voyages seeking new lands or trade routes. Oceanic studies at best were limited to the extent and boundaries of the seas. Little is known of the ships themselves except it can be assumed that they were typical naval or trading vessels of the era. A known example is an expedition sent by Queen Hatshepsut of Egypt in 1500 BC. Sailing from Suez to the Land of Punt (Somaliland) to seek the source of myrrh, the fleet cruised the west coast of Africa. Pictures of the ships can be seen on reliefs in the temple of Deir-el-Bahri.

These ships represent the high-water mark of the Egyptian shipbuilder and although handsome vessels, they had serious weaknesses and did not play a role in the development of naval architecture.

The earliest known voyage of maritime exploration comes from Greek legend and sailors' tales. It is that of Jason dispatched from Iolcus on the northeast coast of Greece to the Black Sea *c.*1100 BC with the ship *Argo* and a celebrated crew of Argonauts in quest of the Golden Fleece. Although embellished by Greek mythology, this may have a factual basis; by sixth century BC there were Greek settlements along the shores explored by Jason, and the inhabitants traditionally collected gold dust from rams fleeces lain in river beds.

Better recorded is an expedition commissioned by Pharaoh Necho II of Egypt in 609 BC. A Phoenician fleet sailed south from Suez and circumnavigated Africa on a four-year voyage. Information from this and other Phoenician voyages over the next 300 years (including Hanno to the west coast of Africa in 500 BC, and Pytheas to the British Isles in 310 BC), although not specifically oceanographic research, contributed to a database from which philosophers and scholars would hypothesize the shape and extent of the world's oceans. In today's terminology these vessels would be characterized as ships of opportunity.

Under the Roman Empire, sea-trade routes were forged throughout the known world from Britain to the Orient. Data on ocean winds and currents were compiled in early sailing directions which added to the growing fund of ocean knowledge. Aristotle, although not a seafarer, directed much of his study to the sea both in physical processes and marine animals. From samples and reports taken from ships he named and described 180 species of fish and invertebrates Pliny the Elder cataloged marine animals into 176 species, and searched available ocean soundings proclaiming an average ocean depth of 15 stadia (2700 m). Ptolemy (AD 90–168), a Greek mathematician and astronomer at Alexandria employed ship reports in compiling world maps which formed the basis of mapping new discoveries through the sixteenth century.

With the fall of the Roman Empire came the dark ages of cartography and marine exploration slowed to a standstill except for Viking voyages to Greenland and Newfoundland, and Arab trade routes in the Indian Ocean and as far as China. Arabian sea tales such as 'Sinbad the Sailor' or the 'Wonders of India' by Ibn Shahryar (905) rival those of Homer and Herodotus. The art of nautical surveying began with the Arabs during medieval times. They had the compass and astrolabe and made charts of the coastlines which they visited.

In the West the city-state of Venice became in the ninth century the most important maritime power in the Mediterranean. It was from Venice that Marco

Polo began his famous journeys. In the fifteenth century, maritime exploration resumed, much of it under the inspiration and patronage of Prince Henry of Portugal (1394–1460), known as the Navigator, who established an academy at Sagres, Portugal, and attracted mathematicians, astronomers, and cartographers. This led to increasingly distant voyages leading up to those of Columbus, Vasco da Gama, and Magellan. With the results of these voyages, the shape of the world ocean was beginning to emerge, but little else was known. From the tracks of ships and their logs, information on prevailing winds and ocean currents were made into sailing directions. Magellan is reported to have made attempts at measuring depths, but with only 360 m of sounding line, he achieved little.

By the late seventeenth and early eighteenth centuries instruments were being devised for deep soundings, water samples, and even subsurface temperatures. However, any ship so engaged either a naval or trading vessel remained on an opportunity basis. In the mid to late eighteenth century the arts of navigation and cartography were amply demonstrated in the surveys and voyages of Captains James Cook and George Vancouver. The latter carried out surveys to especially high standards, and his vessel HMS *Discovery* might well be considered one of the first oceanographic research vessels.

Hydrographic departments were set up by seafaring nations: France in 1720, Britain in 1795, Spain in 1800, the US in 1807. Most were established as a navy activity, and most remain so to this day; exceptions were the French Corps of Hydrographic Engineers, and the US Coast Survey (now the National Ocean Survey). A date significant to this history is 1809 when the British Admiralty assigned a vessel permanently dedicated to survey service. Others followed suit; the first such US ship was the Coast Survey Schooner *Experiment* (1831). By now hydrographic survey vessels were a recognized type of vessel.

In the early to mid-nineteenth century expeditions were setting to sea with missions to include oceanographic investigations. Scientists (often termed ‘naturalists’) were senior members of the ships’ complement. These include the vessels: *Astrolobe*, 1826–29 (Dumont D’Urville); *Beagle*, 1831–36 (Charles Darwin); US Exploring Expedition, 1838–42 (James Wilkes and James Dana); *Erebus & Terror*, 1839–43 (Sir James Ross); *Beacon*, 1841 (Edward Forbes); *Rattlesnake*, 1848–50 (Thomas Huxley). Most of the vessels participating in these expeditions were navy ships, but the nature of the work, their outfitting, and accomplishments mark them as oceanographic vessels of their time.

A new era in marine sciences commenced with the voyage of the HMS *Challenger*, 1872–76, a 69 m British Navy steam corvette. Equipped with a capable depth sounding machine and other instruments for water and bottom sampling, the *Challenger* under the scientific direction of Sir Charles Wyville Thomson obtained data from 362 stations worldwide. More than 4700 new species of marine life were discovered, and a sounding of 8180 m was made in the Marianas Trench. Modern oceanography is said to have begun with the Challenger Expedition. This spurred interest in oceanographic research, and many nations began to field worldwide voyages. These included the German *Gazelle* (1874–76); Russian *Vitiaz* (1886–89); Austrian *Pola*; USS *Blake* (1887–1880); and the Arctic cruise of the Norwegian *Fram* (1893–96).

The late 1800s and early 1900s saw a growing interest in marine sciences and the founding of both government- and university-sponsored oceanographic institutions. These included: Stazione Zoologia, Naples; Marine Biological Laboratory, Woods Hole, USA; Geophysical Institute, Bergen, Norway; Deutsche Seewarte, Hamburg; Scripps Institution of Oceanography, La Jolla, USA; Oceanographic Museum, Monaco; Plymouth Laboratory of Marine Biology, UK. These laboratories acquired and outfitted ships, which although mostly still conversions of naval or commercial vessels, became recognized oceanographic research vessels. The first vessel designed especially for marine research was the US Fish Commission Steamer *Albatross* built in 1882 for the new laboratory at Woods Hole. This was a 72 m iron-hulled, twin-screw steamer. It also was the first vessel equipped with electric generators (for lowering arc lamps to attract fish and organisms at night stations). Based at the Woods Hole Laboratory, the *Albatross* made notable deep sea voyages in both the Atlantic and Pacific Oceans. As with the *Challenger*, the *Albatross* became a legend in its own time and continued working until 1923.

In the early 1900s research voyages were aimed at strategic regions. Nautical charting and resources exploration were concentrated in areas of political significance: the Southern Ocean, South-east Asia, and the Caribbean. Many of the ships were designed and constructed as research vessels, notably the *Discovery* commanded by R. F. Scott on his first Antarctic voyage 1901–04. Another was the nonmagnetic brig *Carnegie* built in 1909 which carried out investigations worldwide. The *Carnegie* was the first research vessel to carry a salinometer, an electrical conductivity instrument for determining the chlorinity of sea water thus avoiding arduous chemical titrations. Research voyages by now were highly systematic on the pattern set by the *Challenger* expedition.

Another era of oceanic investigations began in 1925 with the German Atlantic Expedition voyage of the *Meteor*, a converted 66 m gunboat, that made transects of the South Atlantic Ocean using acoustic echo sounders, modern sampling bottles, bottom corers, current meters, deep-sea anchoring, and meteorological kites and balloons. Unlike the random cruise tracks of most earlier expeditions, the *Meteor* worked on precise grid tracklines. Ocean currents, temperatures, and salinities, and bathymetry of the Mid-Atlantic Ridge were mapped with great accuracy.

After World War II interest in oceanography and the marine sciences increased dramatically. As echo sounding after World War I was a milestone in oceanography, the advent of electronic navigation in the 1950s was another. Loran (LOng RAnge Navigation), a hyperbolic system using two radio stations transmitting simultaneously, provided ships with continuous position fixing. Universities and government agencies both embarked on new marine investigations, the former concentrating on basic science and the latter on applied science. In addition, commercial interests were becoming active in resource exploration. The ships employed were mostly, ex-wartime vessels: tugs, minesweepers, patrol boats, salvage vessels, etc. A 1950 survey of active research vessels showed 155 ships operated by 34 nations.

The first International Geophysical Year, 1957–58, brought together research ships of many nations working on cooperative projects. This decade also saw the formation of international bodies including: the International Oceanographic Congress; Intergovernmental Oceanographic Commission (IOC); the Special Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions, all of which added to the growing pace of oceanic investigations.

The decade of the 1960s is often referred to as the 'golden years of oceanography.' Both public and scientific awareness of the oceans increased at an unprecedented rate. Funding for marine science both by government and private sources was generous, and the numbers of scientists followed suit. New shipboard instrumentation included the Chlorinity–Temperature–Depth sounder which replaced the old method of lowering water bottles and reversing thermometers. Computers were available for shipboard data processing. Advances in instrumentation and the new projects they generated were making the existing research ships obsolete; and the need for new and more capable ships became a pressing issue. As a result, shipbuilding programs were started by most of the larger nations heavily involved in oceanographic research. One of the most ambitious was the construction of fourteen AGOR-3 Class ships by the US Navy. These ships, especially designed for research and surveys, were 70 m in length, 1370 tonnes, and incorporated quiet ship operation, centerwells, multiple echo sounders, and a full array of scientific instrumentation. Of the fourteen in the class, 11 were retained in the US and three were transferred to other nations. During this period, the Soviet Union also embarked on a major building program which resulted by the mid-1970s in probably the world's largest fleet – both by vessel size and numbers. In 1979 there was an estimated total of 720 research vessels being operated by 72 nations, the USSR (194 ships), USA (115), and Japan (94) being the leading three.

By the mid-1980s, the shipbuilding boom which started in the late 1950s had dwindled, but many of those vessels themselves were becoming obsolete. New ships were planned to meet the growing needs of shipboard investigators. This resulted in larger ships with improved maneuverability, seakeeping, and data-acquisition capabilities. The new ships built to meet these requirements plus improvements to selected older vessels constitute today's oceanographic research vessels. The worldwide fleet is now smaller in terms of numbers than 25 years ago, but the overall tonnage is greater and the capability vastly superior.

The Nature of Research Vessels

The term 'oceanographic research vessel' is relatively new; earlier ships with limited roles were 'hydrographic survey vessels' or 'fisheries vessels.' As marine science evolved to include biological, chemical, geological, and physical processes of the ocean and its floor and the air–sea interface above, the term 'oceanography' and 'oceanographic research vessel' has come to include all of these disciplines.

When research vessels became larger and more numerous it was inevitable that regulations governing their construction and operation would come into force. Traditionally, ships were either commercial, warships, or yachts. Research ships with scientific personnel fit into none of these, and it became necessary to recognize the uniqueness of such ships in order to preclude burdensome and inapplicable laws. Most nations have now established a definition of an oceanographic research vessel. The United Nations International Maritime Organization (IMO) has established a category of 'Special Purpose Ship' which includes 'ships engaged in research, expeditions, and survey'. Scientific personnel are defined as '… all persons who are not passengers or members of the crew … who are carried on board in connection with the special purpose …'

United States law is more specific; it states

> The term oceanographic research vessel means a vessel that the Secretary finds is being employed only in instruction in oceanography or limnology, or both, or only in oceanographic or limnological research, including those studies about the sea such as seismic, gravity meter, and magnetic exploration and other marine geophysical or geological surveys, atmospheric research, and biological research.

The same law defines scientific personnel as those persons who are aboard an oceanographic research vessel solely for the purpose of engaging in scientific research, or instructing or receiving instruction in oceanography, and shall not be considered seamen.

The specific purposes of research vessels include: hydrographic survey (mapping and charting); geophysical or seismic survey; fisheries; general purpose (multidiscipline); and support vessels. Despite their differences, there are commonalities that distinguish a research vessel from other ships. These are defined in the science mission requirements which set forth the operational capabilities, working environment, science accommodations and outfit to meet the science role for which the ship type is intended. The science mission requirements are the dominant factors governing the planning for a new vessel or the conversion of an existing one. The requirements can vary according to the size, area of operations, and type of service, but the composition of the requirements is a product of long usage.

A typical set of scientific mission requirements for a large high-endurance general purpose oceanographic research ship is as follows.

1. General: the ship is to serve as a large general purpose multidiscipline oceanographic research vessel. The primary requirement is for a high endurance ship capable of worldwide cruising (except in close pack ice) and able to provide both overside and laboratory work to proceed in high sea states. Other general requirements are flexibility, vibration and noise free, cleanliness, and economy of operation and construction.

2. Size: size is ultimately determined by requirements which probably will result in a vessel larger than existing ships. However, the length-over-all (LOA) should not exceed 100 m.

3. Endurance: sixty days; providing the ability to transit to remote areas and work 3–4 weeks on station; 15 000 mile range at cruising speed.

4. Accommodations: 30–35 scientific personnel in two-person staterooms; expandable to 40 through the use of vans. These should be a science-library lounge with conference capability and a science office.

5. Speed: 15 knots cruising; sustainable through sea state 4 (1.25–2.5 m); speed control ± 0.1 knot in the 0–6 knot range, and ± 0.2 knot in the range of 6–15 knots.[1]

6. Seakeeping: the ship should be able to maintain science operations in the following speeds and sea states:

> 15 knots cruising through sea state 4 (1.25–2.5 m);
> 13 knots cruising through sea state 5 (2.5–4 m);
> 8 knots cruising through sea state 6 (4–6 m);
> 6 knots cruising through sea state 7 (6–9 m).

7. Station keeping: the ship should be able to maintain science operations and work in sea states through 5, with limited work in sea state 7. There should be dynamic positioning, both relative and absolute, at best heading in 35-knot wind, sea state 5, and 3-knot current in depths to 6000 m, using satellite and/or bottom transponders; $\pm 5^\circ$ heading and 50 m maximum excursion. It should be able to maintain a precision trackline (including towing) at speeds as low as 2 knots with a 45° maximum heading deviation from the trackline under controlled conditions (satellite or acoustic navigation) in depths to 6000 m, in 35 knot wind; and 3-knot current. Speed control along track should be within 0.1 knot with 50 m of maximum excursion from the trackline.

8. Ice strengthening: ice classification sufficient to transit loose pack ice. It is not intended for icebreaking or close pack work.

9. Deck working area: spacious stern quarter area – 300 m^2 minimum with contiguous work area along one side 4×15 m minimum. There should be deck loading up to 7000 kg m^{-2} and there should be overside holddowns on 0.5 m centers. The area should be highly flexible to accommodate large, heavy, and portable equipment, with a dry working deck but not more than 2–3 m above the waterline. There should be a usable clear foredeck area to accommodate specialized towers and booms extending beyond the bow wave. All working decks should be accessible for power, water, air, and data and voice communication ports.

10. Cranes: a suite of modern cranes:

(a) to reach all working deck areas and offload vans and heavy equipment up to 9000 kg;

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[1] 1 (Nautical) mile = 1.853 km, 1 knot = 1.853 km h^{-1} = 0.515 ms^{-1}.

(b) articulated to work close to deck and water surface;

(c) to handle overside loads up to 2500 kg, 10 m from side and up to 4500 kg closer to side;

(d) overside cranes to have servo controls and motion compensation;

(e) usable as overside cable fairleads at sea.

The ship should be capable of carrying portable cranes for specialized purposes such as deploying and towing scanning sonars, photo and video devices, remotely operated vehicles (ROVs), and paravaned seismic air gun arrays.

11. Winches: oceanographic winch systems with fine control ($0.5\,\mathrm{m\,min^{-1}}$; constant tensioning and constant parameter; wire monitoring systems with inputs to laboratory panels and shipboard data systems; local and remote controls including laboratory auto control.

Permanently installed general purpose winches should include:

- two winches capable of handling 10 000 m of wire rope or electromechanical conducting cables having diameters from 0.6 mm to 1.0 cm.
- a winch complex capable of handling 12 000 m of 1.5 cm trawling or coring wire, and 10 000 m of 1.75 cm electromechanical conducting cable (up to 10 kVA power transmission and fiberoptics); this can be two separate winches or one winch with two storage drums.

Additional special purpose winches may be installed temporarily at various locations along working decks. Winch sizes may range up to 40 mtons and have power demands up to 250 kW. (See also multichannel seismics.) Winch control station(s) should be located for optimum operator visibility with communications to laboratories and ship control stations.

12. Overside handling: various frames and other handling gear able to accommodate wire, cable, and free-launched arrays; matched to work with winch and crane locations but able to be relocated as necessary. The stern A-frame must have 6 m minimum horizontal and 10 m vertical clearances, 5 m inboard and outboard reaches, and safe static working load up to 60 mtons. It must be able to handle, deploy and retrieve very long, large-diameter piston cores up to 50 m length, 15 mtons weight and 60 mtons pullout tension. There should be provision to carry additional overside handling rigs along working decks from bow to stern. (See also multichannel seismics).

13. Towing: capable of towing large scientific packages up to 4500 kg tension at 6 knots, and 10 000 kg at 2.5 knots in sea state 5; 35 knots of wind and 3 knot current.

14. Laboratories: approximately $400\,\mathrm{m^2}$ of laboratory space including: main lab ($200\,\mathrm{m^2}$) flexible for subdivision providing smaller specialized labs; hydro lab ($30\,\mathrm{m^2}$) and wet lab ($40\,\mathrm{m^2}$) both located contiguous to sampling areas; bio-chem analytical lab ($30\,\mathrm{m^2}$); electronics/computer lab and associated users space ($60\,\mathrm{m^2}$); darkroom ($10\,\mathrm{m^2}$); climate-controlled chamber ($15\,\mathrm{m^2}$); and freezer(s) ($15\,\mathrm{m^2}$).

Labs should be arranged so that none serve as general passageways. Access between labs should be convenient. Labs, offices, and storage should be served by a man-rated lift having clear inside dimensions not less than 3 × 4 m.

Labs should be fabricated of uncontaminated and 'clean' materials. Furnishings, doors, hatches, ventilation, cable runs, and fittings should be planned for maximum lab cleanliness. Fume hoods should be installed permanently in wet and analytical labs. Main lab should have provision for temporary installation of fume hoods.

Cabinetry should be of high-grade laboratory quality with flexibility for arrangements through the use of bulkhead, deck and overhead holddown fittings.

Heating, ventilation, and air conditioning (HVAC) should be appropriate to labs, vans and other science spaces being served. Laboratories should be able to maintain a temperature of 20–23°C, 50% relative humidity, and 9–11 air changes per hour. Filtered air should be provided to the analytical lab. Each lab should have a separate electric circuit on a clean bus and continuous delivery capability of at least $250\,\mathrm{VA\,m^{-2}}$ of lab area. Total estimated laboratory power demand is 100 kVA. There should be an uncontaminated seawater supply to most laboratories, vans, and several key deck areas.

15. Vans: carry four standardized 2.5 × 6 m portable vans which may have laboratory, berthing, storage, or other specialized use. With hook-up provision for power, HVAC, fresh water, uncontaminated sea water, compressed air, drains, communications, data and shipboard monitoring systems. There should be direct van access to ship interior at key locations. There should be provision to carry up to four additional vans on working and upper decks with supporting connections at several locations. The ship should be capable of loading and off-loading vans with its own cranes.

16. Workboats: at least one and preferably two inflatable boats located for ease of launching and recovery. There should be a scientific workboat 8–10 m LOA fitted out for supplemental operation at sea including collecting, instrumentation and wide-angle signal measurement. It should have 12 h

endurance, with both manned and automated operation, be of 'clean' construction and carried in place of one of the four van options above.

17. Science storage: total of 600 m^3 of scientific storage accessible to labs by lift and weatherdeck hatch(es). Half should have suitable shelving, racks and tiedowns, and the remainder open hold. A significant portion of storage should be in close proximity to science spaces (preferably on the same deck).

18. Acoustical systems: ship to be as acoustically quiet as practicable in the choice of all shipboard systems and their installation. The design target is operationally quiet noise levels at 12 knots cruising in sea state 5 at the following frequency ranges:

- 4 Hz–500 Hz seismic bottom profiling
- 3 kHz–500 kHz echo sounding and acoustic navigation
- 75 kHz–300 kHz Doppler current profiling

The ship should have 12 kHz precision and 3.5 kHz sub-bottom echo sounding systems, and provision for additional systems. There should be a phased array, wide multibeam precision echo sounding system; transducer wells (0.5 m diam) one located forward and two midships; pressurized sea chest (1.5 × 3 m) located at the optimum acoustic location for afloat installation and servicing of transducers and transponders.

19. Multichannel seismics: all vessels shall have the capability to carry out multichannel seismic profiling (MCS) surveys using large source arrays and long streamers. Selected vessels should carry an MCS system equivalent to current exploration industry standards.

20. Navigation/positioning: There shall be a Global Positioning System (GPS) with appropriate interfaces to data systems and ship control processors; a short baseline acoustic navigation system; a dynamic positioning system with both absolute and relative positioning parameters.

21. Internal communications: system to provide high quality voice communications throughout all science spaces and working areas. Data transmission, monitoring and recording systems should be available throughout science spaces including vans and key working areas. There should be closed circuit television monitoring and recording of all working areas including subsurface performance of equipment and its handling. Monitors for all ship control, environmental parameters, science and overside equipment performance should be available in most science spaces.

22. Exterior communications: reliable voice channels for continuous communications to shore stations (including home laboratories), other ships, boats and aircraft. This includes satellite, VHF and UHF. There should be: facsimile communications to transmit high-speed graphics and hard copy on regular schedules; high-speed data communications links to shore labs and other ships on a continuous basis.

23. Satellite monitoring: transponding and receiving equipment including antennae to interrogate and receive satellite readouts of environmental remote sensing.

24. Ship control: the chief requirement is maximum visibility of deck work areas during science operations and especially during deployment and retrieval of equipment. This would envision a bridge-pilot house very nearly amidships with unobstructed stem visibility. The functions, communications, and layout of the ship control station should be designed to enhance the interaction of ship and science operations; ship course, speed, attitude, and positioning will often be integrated with science work requiring control to be exercised from a laboratory area.

These science mission requirements are typical of a large general-purpose research vessel. Requirements for smaller vessels and specialized research ships can be expected to differ according to the intended capability and service.

Design Characteristics of Oceanographic Vessels

In general the design of an oceanographic ship is driven by the science mission requirements described above. In any statement of requirements an ordering of priorities is important for the guidance of the design and construction of the ship. In the case of research vessels the following factors have been ranked by groups of practicing investigators from all disciplines.

1. Seakeeping: station keeping
2. Work environment: lab spaces and arrangements; deck working area; overside handling (winches and wire); flexibility
3. Endurance: range; days at sea
4. Science complement
5. Operating economy
6. Acoustical characteristics
7. Speed: ship control
8. Pay load: science storage; weight handling

These priorities are not necessarily rank ordered although there is general agreement among oceanographers that seakeeping, particularly on station, and work environment are the two top priorities. The remaining are ranked so closely together that they are of equal importance. The science mission requirements set for each of these areas become threshold levels, and any characteristic which falls below the threshold becomes a dominant priority.

General Purpose Vessels

Ships of this type (also termed multidiscipline) constitute the classic oceanographic research vessels and are the dominant class in terms of numbers today. They have outfitting and laboratories to support any of the physical, chemical, biological, and geological ocean science studies plus ocean engineering. The science mission requirements given above describe a large general purpose ship. Smaller vessels can be expected to have commensurately reduced requirements.

Current and future multidiscipline oceanographic ships are characterized as requiring significant open deck area and laboratory space. Accommodations for scientific personnel are greater than for single purpose vessels due to the larger science parties carried. Flexibility is an essential feature in a general purpose research vessel. A biological cruise may be followed by geology investigations which can require the reconfiguration of laboratory and deck equipment within a short space of time.

In addition to larger scientific complements, the complexity and size of instrumentation now being deployed at sea has increased dramatically over the past half century. As a result, the size of general purpose vessels has increased significantly. A research vessel of 60 m in length was considered to be large in 1950; the same consideration today has grown to 100 m and new vessels are being built to that standard. Even existing vessels have been lengthened to meet the growing needs.

The majority of oceanographic research vessels, however, are smaller vessels, 25–50 m in length, and limited to coastal service.

Mapping and Charting Vessels

Mapping and charting ships were probably the earliest oceanographic vessels, usually in conjunction with an exploration voyage. Incident to the establishment of marine trade routes, nautical charting of coastal regions became routine and the vessels so engaged were usually termed hydrographic survey ships. Surveys were (and still are) carried out using wire sounding, drags, and launches. Survey vessels are characterized by the number of boats and launches carried and less deck working space than general purpose vessels. Modern survey vessels, however, are often expected to carry out other scientific disciplines, and winches, cranes and frames can be observed on these ships.

Recent developments have affected the role (and therefore design) of this class of vessel. As a result of the International Law of the Sea Conferences, coastal states began to exercise control over their continental shelves and economic zones 200 miles (321.8 km) from shore. This brought about interest in the resources (fishery, bottom and sub-bottom) of these newly acquired areas, and research vessels were tasked to explore and map these resources. The usual nautical charting procedures are not applicable in the open ocean regions, and modern electronic echo-sounding instruments have supplanted the older wire measurements. This involves large hull-mounted arrays of acoustic projectors and hydrophones which can map a swath of ocean floor with great precision up to five miles in width, and at cruising speeds. The design of vessels to carry this equipment requires a hull form to optimize acoustic transmission and reception, and to minimize hull noise from propulsion and auxiliary machinery. Further, such new ships also may be outfitted to perform other oceanographic tasks incident to surveys. Their appearance, therefore, may come closer to a general purpose vessel.

Fisheries Research Vessels

Fisheries research generally includes three fields of study: (1) environmental investigations, (2) stock assessment, and (3) gear testing and development. The first of these are surveys and analyses of sea surface and water column parameters; both synoptic and serial. These are biological, physical, and chemical investigations (as well as geological if bottom fisheries are considered); and can be accomplished from a general purpose oceanographic research vessel.

Ships engaged in fish stock assessment and exploratory fishing, or development work in fishing methods and gear, fish handling, processing, and preservation of fish quality on board, are specialized types of vessels closely related to actual fishing vessels. Design characteristics include a stern ramp and long fish deck for bringing nets aboard, trawling winches, and wet labs for analyses of fish sampling. Newer designs also include instrumentation and laboratories for environmental investigations, and extensive electronic instrumentation for acoustic fish finding, biomass evaluation, and fish identification and population count.

As with mapping and charting ships, most fishery research vessels are operated by government agencies.

Geophysical Research Vessels

The purpose of marine geophysical research vessels is to investigate the sea floor and sub-bottom, oceanic crust, margins, and lithosphere. The demanding design aspect for these ships is the requirement for a MCS system used to profile the deep geologic structure beneath the seafloor. The missions range from basic research of the Earth's crust (plate tectonics) to resources exploration.

The primary components of an MCS system are the large air compressors needed to 'fire' multiple towed airgun sound source arrays and a long towed hydrophone streamer which may reach up to 10 km in length. The supporting outfit for the handling and deployment of the system includes large reels and winches for the streamer, and paravanes to spread the sound source arrays athwart the ship's track. This latter results in the need for a large stern working deck close to the water with tracked guide rails and swingout booms. Electronic and mechanical workshops are located close to the working deck. The design incorporates a large electronics room for processing the reflected signals from the hydrophones and integrating the imagery with magnetics, gravity and navigation data.

The highly specialized design requirements for a full-scale marine geophysics ship usually precludes work in other oceanographic disciplines. On the other hand, large general purpose research ships often carry compressors and portable streamer reels sufficient for limited seismic profiling.

Polar Research Vessels

Whereas most oceanographic research vessels are classed by the discipline in which they engage, polar research vessels are defined by their area of operations. Earlier terminology distinguished between polar research vessels and icebreakers with the former having limited icebreaking capability, and the latter with limited or no research capability. The more current trend is to combine full research capability into new icebreaker construction.

Arctic and Antarctic research ships in the nineteenth and early twentieth centuries were primarily ice reinforced sealing vessels with little or no icebreaking capability. World War II and subsequent Arctic logistics, and the International Antarctic Treaty (1959) brought about increased interest in polar regions which was furthered by petroleum exploration in the Arctic in the late twentieth century. Icebreakers with limited research capability early in this period became full-fledged research vessels by the end of the century.

The special requirements defining a polar research vessel include increased endurance, usually set at 90 days, helicopter support, special provisions for cold weather work, such as enclosed winch rooms and heated decks, and icebreaking capability. Other science mission requirements continue the same as for a large general purpose RVs. Of special concern is seakeeping in open seas. Past icebreaker hull shapes necessarily resulted in notoriously poor seakindliness. Newer designs employing ice reamers into the hull form also offer improved seakeeping.

Ice capability is usually defined as the ability to break a given thickness of level ice at 3 knots continuous speed, and transit ice ridges by ramming. Current requirements for polar research vessels have varied from 0.75 m to 1.25 m ice thickness in the continuous mode, and 2.0 to 3.0 m ridge heights in the ramming mode. These correspond to Polar Class 10 of Det Norske Veritas or Ice Class A3-A4 of the American Bureau of Shipping.

Support Vessels

Ships that carry, house, maintain, launch and retrieve other platforms and vehicles have evolved into a class worthy of note. These include vessels that support submersibles, ROVs, buoys, underwater habitats, and scientific diving. Earlier ships of this class were mostly converted merchant or fishing vessels whose only function was to launch and retrieve and supply hotel services. Recent vessels, especially those dedicated to major programs such as submersible support, are large ships and fully outfitted for general purpose work.

Other Classes of Oceanographic Research Vessels

In addition to the above types, there are research ships which serve other purposes. These include ocean drilling and geotechnical ships, weather ships, underwater archaeology, and training and education vessels. The total number of these ships is relatively small, and many of them merge in and out of the category and serve for a limited stretch of time.

Often ships will take on identification as a research vessel for commercial expediency or other fashion not truly related to oceanographic research. Such roles may include treasure hunting, salvage, whale watching, recreational diving, ecology tours, etc. These vessels may increase the popular awareness of oceanography but are not bona fide oceanographic research vessels.

Research Vessel Operations

Oceanographic cruises are usually the culmination of several years of scientific and logistics planning. Coastal vessels, typically 25–50 m length, will usually remain in a home, or adjacent regions on cruises of 1–3 weeks' duration. Ocean-going vessels, 50–100 m length, may undertake voyages of 1–2 years away from the home port, with cruise segments of 25–35 days working out of ports of opportunity. New scientific parties may join the ship at a port call and the nature of the following cruise leg can change from, for instance biological to physical oceanography. This involves complex logistics and careful planning and coordination, within a typical 4–5 day turnaround.

From the time of the *Meteor* expedition of 1925, cruise plans are usually highly systematic with work concentrating along preset track lines and grids, or confined to a small area of intense investigation. Work can take place continuously while underway using hull-mounted and/or towed instrumentation, or the ship will stop at a station and lower instruments for water column or bottom sampling. Typical stations are at 15–60-mile intervals and can last 1–4 h. Measurements or observations that are commonly made are shown in **Table 1**. In addition, work may include towed vehicles along a precise trackline at very slow controlled speeds making many of the observations, chiefly acoustic, photographic, and video.

Cooperative projects among research vessels including different nations have become commonplace. These share a common scientific goal, and cruise tracks, times, methodology, data reduction, and archiving are assigned by joint planning groups.

A significant factor affecting oceanographic research cruises today is the permission required by a research vessel to operate in another nation's 200-mile economic zone. As a result of the United Nations Law of the Sea Conventions and the treaties resulting therefrom (1958–1982), coastal nations were given jurisdiction over the conduct of marine scientific research extending 200 nautical miles out from their coast (including island possessions). This area is termed exclusive economic zone (EEZ). As of 2000 there were approximately 151 coastal states (this number varies according to the world political makeup), and 36% of the world ocean falls within their economic zones. Most coastal nations have prescribed laws governing research in their zones. The rules include requests for permission, observers, port calls, sharing data, and penalties. This often poses a burden on the operator of a research vessel when permission requirements are arbitrary and untimely. It is not, however, an unworkable burden if done in an orderly manner, and does have desirable features for international cooperation. Problems arise when requests are not submitted within the time specified, or resulting data are not forthcoming. These are complicated by unrealistic requirements on the part of the coastal state, delay in acknowledging or acting on a request, or ignoring it totally. These can have a profound effect on scientific research and need to be addressed in future Law of the Sea Conventions.

Table 1 Common measurements and observations made from RVs

Underway	*On station*
Single channel echo sounding	Echo sounding
Multichannel echo sounding	Sub-bottom profiling
Sub-bottom profiling (3.5 kHz)	Acoustic Doppler profiling
Acoustic Doppler profiling	Surface to any depth
Sea surface:	Temperature
Temperature	Salinity
Salinity	Sound velocity
Fluorometry	Dissolved oxygen
Dissolved oxygen	Water sample
Towed magnetometer	Bottom sampling
Gravimeter	Bottom coring
Meteorological	Bottom photography and video
Wind speed and direction	Bottom dredging
Barometric pressure	Geothermal bottom probe
Humidity	Biological net tows and trawls
Solar radiation	Biological net tows
Towed plankton recorder	

World Oceanographic Fleet

The precise number of oceanographic research vessels worldwide is difficult to ascertain. Few nations maintain lists specific to research vessels, and numbers are available chiefly by declarations on the part of the operator. Some ships move in and out of a research status from another classification, e.g., fishing, passenger, yacht, etc. Also, some operators keep hydrographic survey, seismic exploration, and even fisheries research ships as categories separate from oceanographic research; here they are included within the general heading of oceanographic research vessels.

Based on the best available information, 48 nations or international agencies operated 420 oceanographic research vessels of size greater than 25 m LOA in 2000. Of these, 310 ships were from nine nations operating 10 or more ships each (**Table 2**).

A significant step in international cooperation affecting oceanographic research vessels and the

Table 2 Countries operating 10 or more oceanographic research ships

Russia	86
United States	84
Japan	66
China	17
Ukraine	14
Korea	11
Germany	11
United Kingdom	10
Canada	10
All others (39)	111
Total	420

marine sciences they support has been the International Ship Operators Meeting, an intergovernmental association, founded in 1986, comprising representatives from various ship operating agencies that meets periodically to exchange information on ship operations and schedules, and work on common problems affecting research vessels. In 1999, 21 ship-operating nations were represented and extended membership by other states is ongoing.

Future Oceanographic Ships

The interest in, and growth of, marine science over the past half century shows little or no indication of diminishing. The trend in oceanographic investigations has been to carry larger and more complex instrumentation to sea. The size and capability of research vessels in support of developing projects has also increased.

Future oceanographic research ships can be expected to become somewhat larger than their counterparts today. This will result from demands for more sizeable scientific complements and laboratory spaces. Workdeck and shops will be needed for larger equipment systems such as buoy arrays, bottom stations, towed and autonomous vehicles. Larger overside handling systems incorporating motion compensation will make demands for more deck space.

There will be fewer differences between basic science, fisheries, and hydrographic surveying vessels so that one vessel can serve several purposes. This may result in fewer vessels, but overall tonnage and capacity can be expected to increase.

New types of craft may take a place alongside conventional ships. These include submarines, ‘flip’-type vessels which transit horizontally and flip vertically on station, and small waterplane-area twin hull ships (SWATH). SWATH, or semisubmerged ships, are a relatively recent development in ship design. Although patents employing this concept show up in 1905, 1932, and 1946, it was not until 1972 that the US Navy built a 28 m, 220 ton prototype model. The principle of a SWATH ship is that submerged hulls do not follow surface wave motion, and thin struts supporting an above water platform which have a small cross-section (waterplane) are nearly transparent to surface waves, and have longer natural periods and reduced buoyancy force changes than a conventional hull. The result is that SWATH ships, both in theory and performance, demonstrate a remarkably stable environment and platform configuration which is highly attractive for science and engineering operations at sea.

See also

Coastal Zone Management. Fishing Methods and Fishing Fleets. International Organizations. Law of the Sea. Maritime Archaeology. Shipping and Ports.

SILICA

See **MARINE SILICA CYCLE**

SINGLE COMPOUND RADIOCARBON MEASUREMENTS

T. I. Eglinton and A. Pearson, Woods Hole Oceanographic Institution, Woods Hole, MA, USA

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Introduction

Many areas of scientific research use radiocarbon (carbon-14, ^{14}C) measurements to determine the age of carbon-containing materials. Radiocarbon's $\sim$5700-year half-life means that this naturally