# AC 2008-38: MODEL BUILDING AND TESTING AS AN UNDERGRADUATE RESEARCH APPROACH TO ADVANCING AIR-ASSISTED MARINE VEHICLE TECHNOLOGY

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# Model Building and Testing as an Undergraduate Research Approach to Advancing Air-Assisted Marine Vehicle Technology

## Abstract

High-performance air-assisted marine vehicles can benefit many naval and civil applications. However, traditional R&D methods for these craft require enormous resources and sophisticated facilities. An innovative undergraduate research approach has been initiated that aims at advancing the air-supported marine vehicle technology. An emphasis is made on building and testing models of novel air-assisted amphibious transport concepts. One research project and outreach activities are described in this paper.

## Introduction

Advanced air-assisted marine craft, such as Power Augmented Ram Vehicles (PARV), Wing-In-Grounds (WIG), and Air Cavity Ships (ACS), can benefit many naval and civil applications, including landing/patrol/rescue missions, high-speed Sealift, Arctic operations, and shipping and recreational industries. For example, a demand for these craft has been demonstrated by a recent Broad Agency Announcement of the Office of Naval Research.[1] Due to complexity of technologies associated with high-speed motion at the air-sea interface and complex physics of multi-phase flows, traditional rigorous R&D approaches require enormous resources and sophisticated facilities. These problems hold back the advancement of high-performance fast marine transportation.

At the same time, these impressive technologies are very appealing to undergraduate students interested in motor sports on the water, ground, and air. Although most undergraduate students do not have sufficient fundamental knowledge for traditional research on advanced topics, these students are very responsive to the build-and-try method for complex engineering problems. At Washington State University, an alternative and productive research approach in high-performance marine vehicles has been recently initiated.

Small-scale models of air-assisted marine craft with relatively simple structures are designed by a faculty advisor and built and modified by undergraduate students. Propulsion and control system elements for these models are acquired inexpensively from hobby suppliers. The modular model design allows us to test many parameters and to come up with new technical ideas in much shorter time frame and at much lower budgets than it would be possible in traditional R&D. Although our tests do not aim at very precise measurements, the engineering-level accuracy can be achieved with specifically designed low-cost force balance systems, manual pressure multiplexers, and other sensor/data acquisition elements. Outdoor tests with remotely controlled self-propelled models of air-assisted craft in a variety of test conditions add to the understanding and confidence in the novel marine vehicle concepts and serve as great demonstrators for marine industry and for recruiting and retaining students in engineering.

The main steps in this program on advanced marine vehicles are planned as follows:

• Identification of innovative concepts suitable for undergraduate research and review of previous studies in this area.
• Design and construction of models and experimental systems and carrying out tests.
• Development of mathematical models and comparison with test data.
• Publishing technical papers and submitting proposals to funding agencies and companies.

**Technical Concept**

Our research efforts address a variety of high-performance marine vehicle technologies, but the primary focus for undergraduate research in our group is the Power Augmented Ram (PAR) concept, previously used for take-off assistance of Wing-In-Ground craft.[2,3] Figure 1 shows one possible arrangement of PAR craft of a new generation.[4] The payload-carrying platform is placed between two narrow side hulls. The air jet sources (fans, props, jet engines, or nozzles) are placed in front of the platform. The high-momentum air jets decelerate in the under-platform channel generating an increased-pressure dynamic air cushion that supports the vehicle weight. The aft flap regulates the air-cushion pressure and the recovered thrust due to jets escaping above and below the platform. The platform can be made in the wing shape to generate additional aerodynamic lift at high speeds. According to our estimations, ultra-fast and truly amphibious boats of this concept can achieve cruising speeds well above 100 knots at several hundred ton displacement. Full-scale PAR vehicles will be able to operate at lower thrust-to-weight ratio (around 0.2) and higher payload-to-weight ratio (around 0.5) than those of competing air-supported amphibious transports, such as Air Cushion Vehicles and Wing-In-Ground craft.

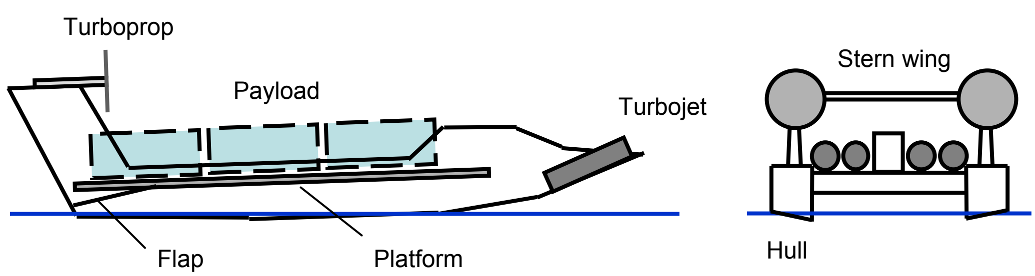


Fig. 1. Side and front views on one PAR craft schematic.

**Project Description**

The model design starts from calculations based on idealized or semi-empirical theories for PAR systems.[5-7] Since these calculation methods involve advanced fluid mechanics, they are carried out by a faculty advisor. In discussions with a faculty advisor, students gain understanding of the basic theoretical results and the expected system behavior in various operational conditions. This helps students in the model construction, selection of materials and propulsion/control elements, and subsequent testing of models.

The second step is for students to prepare drawings applying their knowledge gained in Engineering Graphics classes. They use contemporary CAD tools, such as Rhino, Solid Works, and other programs. Moreover, students can create these drawings as their class projects. Examples of 3D schematics of two PAR models are illustrated in Fig. 2.

Prior to the model construction, the materials for structures and basic arrangement of control and propulsion elements are selected. Since the preceding theoretical calculations are rather approximate and the model performance is quite sensitive to particular configurations, an emphasis in the design is made on the model modularity. Main structural elements are connected together in a way to allow us to interchange them and adjust their positions during experimental optimization. Another requirement in our designs is the low cost of all components due to limited funding. Structural materials are purchased from local hardware stores, and propulsion/control components are acquired from hobby suppliers.

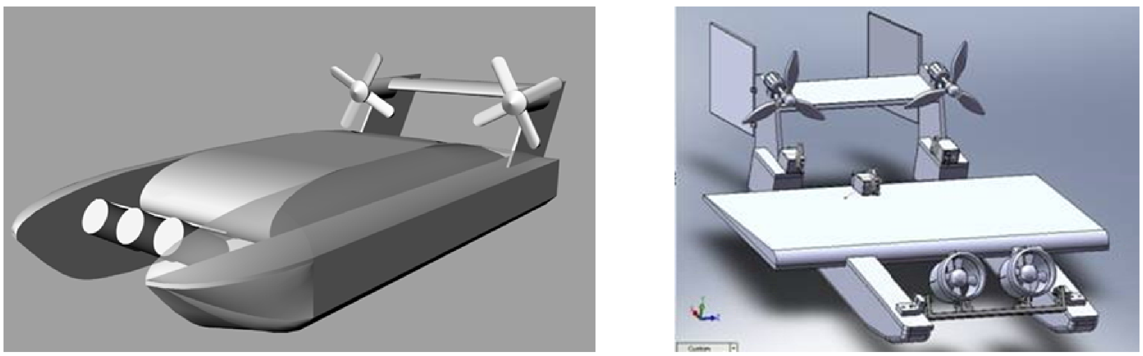

Fig. 2. Drawings of PAR models prepared by students using 3D CAD tools.

The model structural parts are built by students using hand tools available in our lab or machine tools in the university shops. An example of one model is shown in Fig. 3. The side hulls are made of Styrofoam for buoyancy and covered by fiberglass to protect from damages upon minor collisions with solid objects. Wood plates are glued on the hull upper sides. The platform and the tail structure are made of plywood. The stern flap and vertical rudders (visible on the right picture in Fig. 3) are connected with fixed parts by hinges. Aluminum angles are used as adjustable connectors between system elements. For example, the platform height and trim can be easily modified *in-situ*. The front propulsors are carried on the aluminum pylon. Their horizontal and vertical position, as well as inclination, can be adjusted as well.

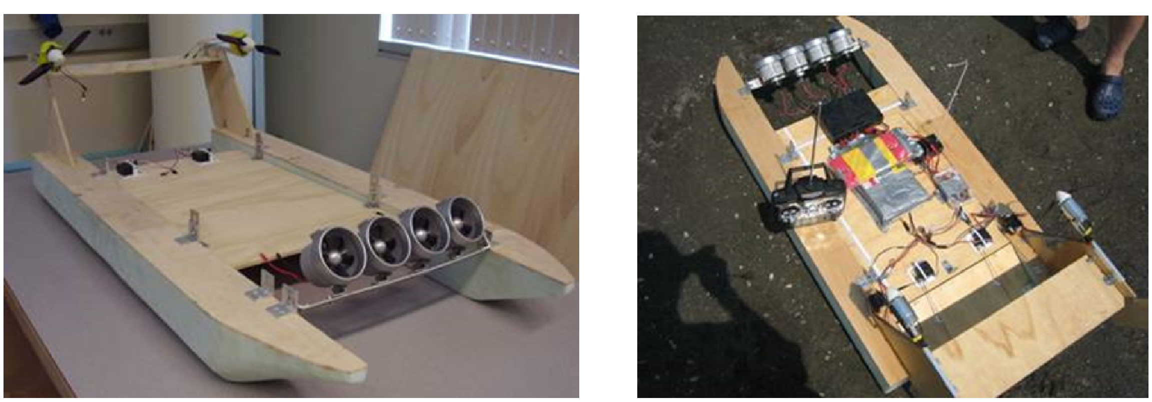

Fig. 3. PAR model under assembly and instrumented for initial testing. Length and beam of the model are approximately 115 and 60 cm.

A variety of propulsion and control elements and energy sources for them can be obtained from airplane hobby suppliers. We decided to use fully electric arrangements to eliminate pollution and reduce noise. An important requirement for application of electric motors in our systems is their ability to operate in high-power regimes at low or zero speeds, when cooling due to fast forward motion in the air is not available. Auxiliary static tests with propulsion units are conducted to find suitable motors that can produce high thrust (measured by a force gauge) at zero speed without overheating. The system modularity allows us to substitute electric components for optimizing the model performance or replacing a damaged element. The electric power can come from stationary power supplies in laboratory tests and batteries in outdoor tests. In the latter case, the radio control mode is implemented using a four-channel hobby radio.

Laboratory tests are conducted with models in the zero-speed regime. These experiments provide useful information for amphibious capabilities of models and their potential for acceleration to high-speed regimes. The primary parameters of interest are the jet-induced lift and the recovered thrust (propulsor thrust minus jet-induced platform drag). The input parameters include the system geometry, loading conditions, propulsor thrust, and surface types. An example of the model tested in an inflatable pool is given in Fig. 4a. The static thrust is measured by a force gauge Omega DFG-6011, which is located behind the model. The model is connected to the gauge via a fishing line. Besides the recovered thrust, we also record the underside platform pressure and model's heave and trim. The electric power is provided to the motors by a stationary regulated power supply.

The setup shown in Fig. 4b is constructed to determine the pressure distribution under the platform over a solid ground. Pressure taps on the platform are connected to Dwyer Magnehelic pressure gauges via plastic hoses and multi-way valves. The incident jets are provided by air blowers, such as Jabsco Model 35440-Series and Peerless D8C model. The velocity field in the jets is measured by United Sensor Pitot-static probes.

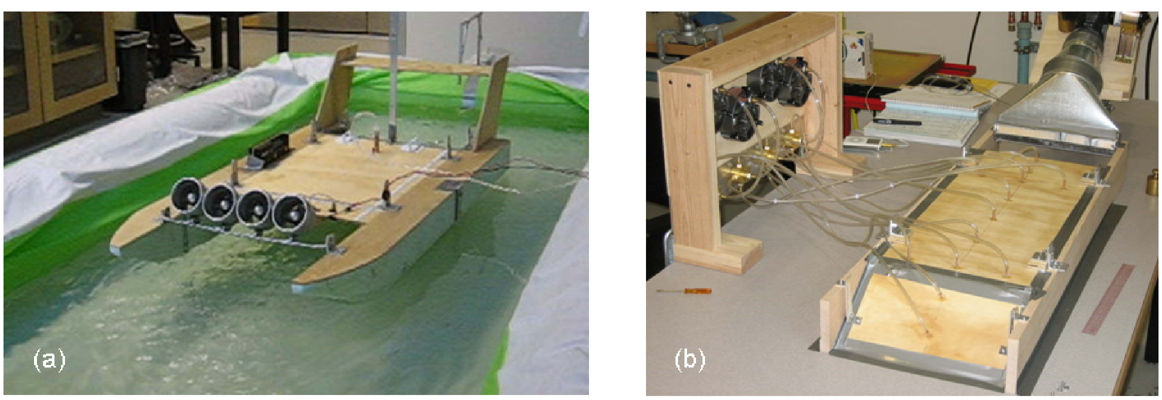


Fig. 4. (a) Static thrust model test in a pool. (b) Test rig for measuring pressure distribution under the platform.

Examples of results obtained in these tests are shown in Fig. 5. The recovered static thrust of the model in the pool (Fig. 5a) increases with increasing propulsor thrust and the stern flap gap. Theoretical results based on the potential-flow theory with an empirical correction for turbulent mass entrainment in the incident jets and accounting for the water surface depression agree well with test data. In contrast with the recovered thrust, the pressure under the platform decreases with increasing the flap gap (Fig. 5b). Therefore, an optimal flap deflection exists at a given propulsor thrust and model mass that provides the maximum recovered thrust at the condition of the air-cushion lift being equal to the model weight.

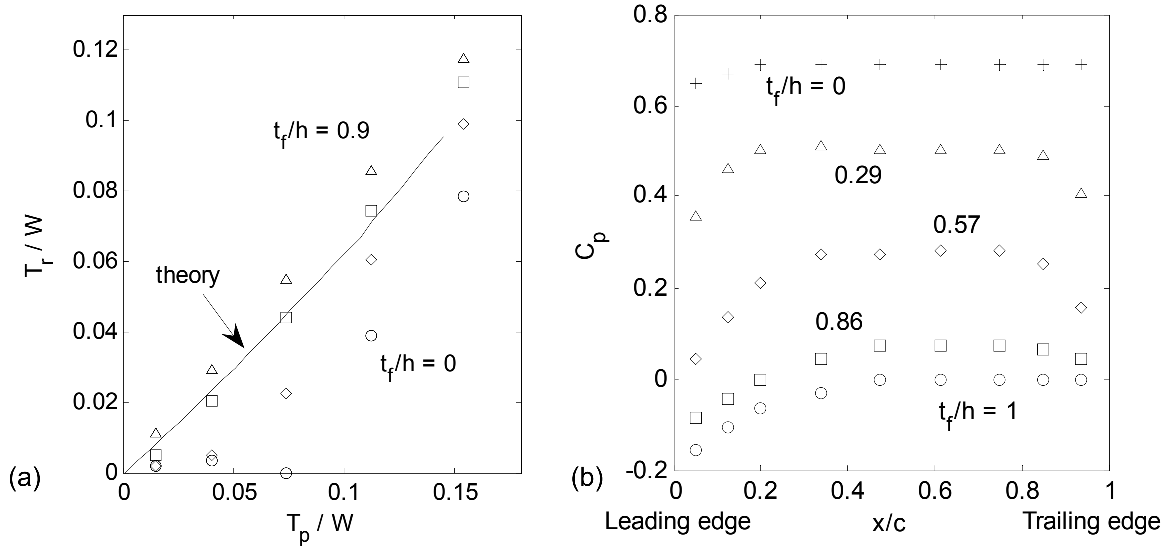


Fig. 5. (a) Recovered thrust $T_r$ versus propulsor thrust $T_p$ for various back flap gaps $t_f$. W is the model weight; h is the platform height. Theoretical results correspond to t/h = 0.6, symbol □ in test data. (b) Pressure coefficient $C_p$ under a flat plate for various flap gaps versus relative horizontal coordinate x/c along the platform.

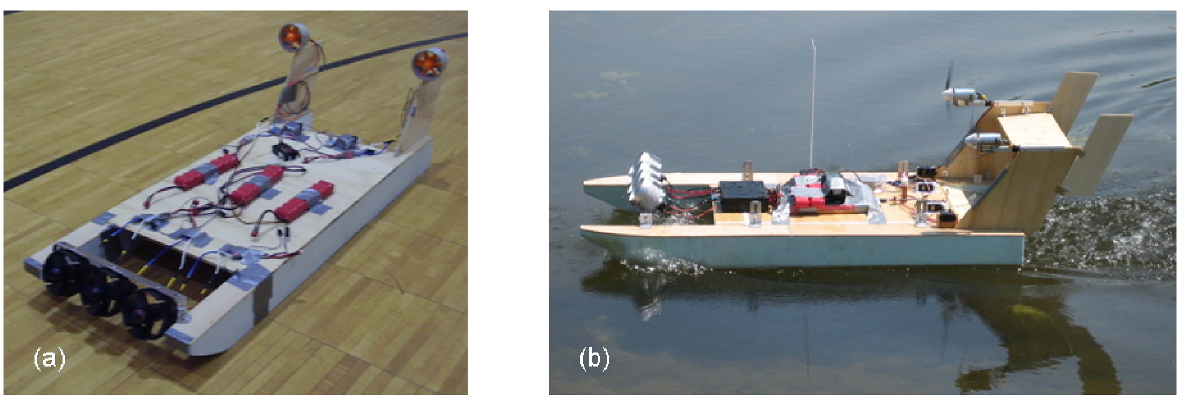


Fig. 6. (a) Model tested in the university gym. (b) Model tested in a pond.

Radio-controlled PAR models are also tested in forward motion for their speed characteristics (using GPS units or measuring travel time at given path length), maneuvering, and ability to overcome obstacles and transit between different surfaces. Tests on the gym floor correspond to nearly ideal conditions with minimum ground friction (Fig. 6a). Outdoor tests are conducted on a variety of ground surfaces, including grass, sand, mud, ice, and snow. The PAR models are tested in the open-water reservoirs, including windy and wave conditions. A photo of a PAR model sailing in calm water is shown in Fig. 6b. Outdoor testing experience improves our understanding of the PAR system dynamics and capabilities and suggests further directions for the vehicle improvement.

## Some Aspects of Student Involvement

This undergraduate research program was initiated in Fall 2006. Three undergraduate students, two juniors and one sophomore, have been involved in research for 1-2 semesters or during a summer session. The student work is extracurricular, not connected to any courses or student club activities. The students are paid either through the faculty advisor funding or external undergraduate stipends. Students work several hours per week during regular semesters and half-time in summer. So far all undergraduate projects were individual.

The participating students are recruited from the entire Mechanical Engineering pool at Washington State University, which amounts to several hundred students. Junior-level students, including those with excellent GPA and/or special skills, demonstrate the highest interest in this opportunity. About 15 students were interviewed for each position. Our top priorities in choosing research assistants are their strong motivation, a degree of potential dedication to the project, and hardware skills, especially marine-oriented. For example, two of our students have previously built their own hydroplanes, which is a sub-category of air-assisted class of marine craft. The student performance in this program was found to be insensitive to the student GPA.

The research activities of students greatly benefit from knowledge they obtain in the core undergraduate engineering courses, such as laboratory classes. Throughout a project, the faculty advisor meets with a student once a week during regular semesters and at least three times a week during summer research program. To ensure a success of undergraduate student research work, it is vital to carefully define the scope of student activities that must be within the student capabilities and competence. The faculty advisor outlines a project and directs students in building experimental systems. The first experimental measurements (and sometimes an entire test series) are carried out by students together with the faculty advisor. Students are encouraged but not required to widen their understanding of this technology by reading technical literature and information available on the Internet. The learning objectives and assessments of achievements of these objectives are summarized in Table 1.

| Learning objectives | Assessment methods |
|---|---|
| 1. To understand basic principles of innovative air-assisted marine transports. | 1. Discussions with students. Student suggestions on organizing tests. |
| 2. To design, set up, and carry out laboratory experiments. | 2. Scope and quality of obtained research data. |
| 3. To build and test robust self-propelled, radio-controlled models. | 3. Achieved model performance: speed, payload, maneuvering, and amphibious capabilities under various conditions. |
| 4. To interpret test results and compare them with theories. To advance air-assisted marine technologies. | 4. Comparison with mathematical models. Establishing empirical correction factors. Technical improvements in model design. |

Table 1. Learning objectives and assessment methods.

Students involved in this program participate in preparing technical publications for both conferences and archival journals.[8-10] Students also present technical posters in intramural events. These activities provide useful technical writing/presenting experiences for undergraduate students and increase their exposure to potential employers. The only student from this program who already graduated from WSU currently works for a naval shipyard. One of the present students has accepted a job offer from the same shipyard.

**Outreach Activities**

Besides carrying out research work, our group is spreading activities elsewhere, for example, cooperating with student clubs and organizing summer schools for high-school students. One of student clubs in our university is the Solar Splash. Students in this club build solar-powered/electric boats, such as shown in Fig. 7a, and participate in the international competition. The faculty of our research group serves as a faculty advisor for this club. The body of the Solar Splash club represents an excellent pool of undergraduate students that can be recruited for research on advanced marine technologies. The knowledge and equipment can be shared between the research group and the student club.

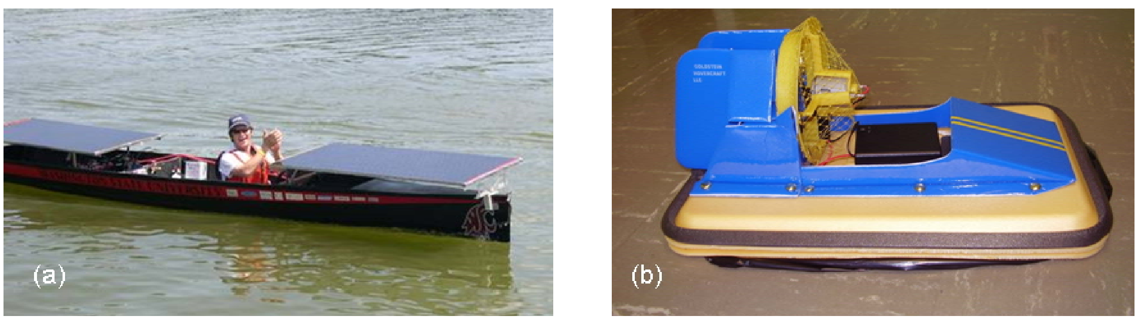


Fig. 7. (a) Solar-powered manned boat. (b) Air-cushion kit model.

Another example of outreach activities of our group is organization of two 4-days workshops on Ground Effect Machines for high-school students within the university program *Cougar Quest* in summer 2008. Several multi-media lectures will be given to the students to introduce them into the fascinating world of air-assisted marine vehicles. The students will assemble Goldstein Hovercraft kits (Fig. 7b), carry out simple tests (e.g., static thrust, hover height, maximum speed), and compete with each other in several fun races. The students will also be given an opportunity to operate our research-grade air-assisted models. This summer school has a great potential for recruiting students in engineering in general and into the field of advanced marine vehicles in particularly.

**Concluding Remarks**

Results of our initial research and development efforts can benefit high-performance marine vehicle technologies and suggest important problems for fundamental sciences. Equally valuable outcomes of our program are recruiting and retaining engineering students, as well as graduating students with skills and enthusiasm necessary for developing advanced marine craft of new generations. This program also demonstrates that undergraduate students are capable of carrying out high-quality research on advanced marine technologies, as suggested by our technical publications in engineering literature.

We aim at developing our capabilities towards more complex research and increasing research productivity. The current and near-future activities include (1) installation of remote data acquisition systems for gathering time-resolved data on models in high-speed motion, (2) testing models with multi-component force balance systems, (3) utilization of hydrodynamic flumes for water-based laboratory experiments, and (4) interrelation of experimental work with Computational Fluid Dynamics studies conducted by graduate students in our group.[11] More distant plans involve using fuel cells as power sources for our models and building manned vehicle prototypes.

The successful development of this recently started undergraduate research program requires the growth of our group to a certain critical mass (several students employed simultaneously) with students specializing in different aspects of marine vehicle technology and interacting as a team. An involvement of faculty from other disciplines (e.g., electrical and structural/materials engineering) is also highly desirable for our research, since their expertise in related engineering areas is critically important for constructing high-performance marine craft.

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