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DRAG REDUCTION STUDIES BY COMPLIANT SURFACES AND SURFACE-ACTIVE SUBSTANCES

Recent experiments are described that deal with drag reduction by compliant surfaces and by surface-active substances.

APL TOW TANK TESTS

In 1982, a small research effort was initiated to investigate the usefulness of compliant (i.e., compressible) surfaces and surfactant injection to produce drag reduction of structures moving through salt water. This effort was initiated as a result of Soviet scientific articles reporting progress in this area,[1,2] as well as suggestions that fish may enhance their speed by injecting fluids into the boundary layer of their flexible skin.

The initial effort was comparative drag testing of identical foam and solid bodies in the APL tow tank.[3] These tests were conducted at tow speeds of 3 and 5 feet per second in salt and fresh water. The strut-mounted models, 4.5 inches in diameter and 3 feet long, are shown in Fig. 1. The solid model (Fig. 1a) was machined from polyvinyl chloride plastic; the foam model was made using a mold of the solid plastic model. The foam had a density of 4 pounds per cubic foot and was about 1.5 inches thick on the model except at the nose and tail.

The model was mounted on a rod that was supported internally on precision bearings and was connected to a strut-attached transducer that directly measured the drag force. The transducer was calibrated with a model in place before and after each test. Each model had a nose cap that could be opened by unscrewing it to allow injection of surfactants. Tests were run to determine the impact of the nose cap position on drag without injection. It was found that as long as the nose cap was not unscrewed more than 1/16 of an inch, there was no significant effect on the model drag.

The results of the initial tests (shown in Fig. 2) show about a 10% drag reduction with the foam-covered model compared to the solid body and an additional 4% reduction when sodium palmitate surfactant was injected into water with a salt concentration equal to seawater. Surfactant drag reduction was not measured for the solid model because of an inadvertent plugging of the injection line.

The initial tests looked promising, but because of the low tow speeds, no conclusion could be drawn regarding the usefulness of the findings.

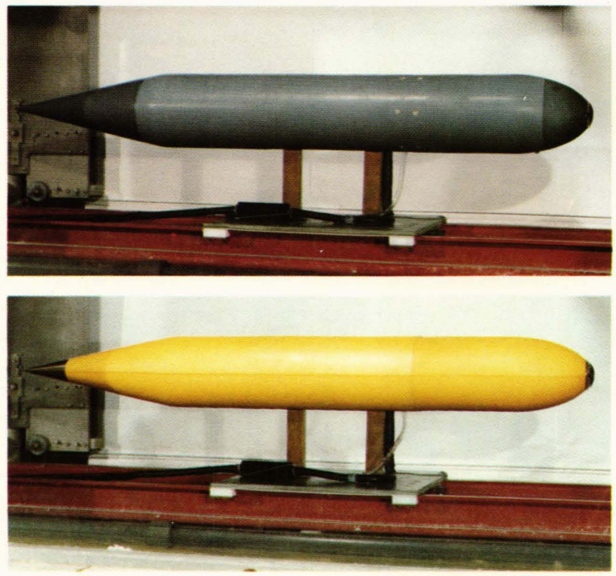

Figure 1 — (top) Strut-mounted solid polyvinyl chloride plastic model. Surfactant liquids can be injected into the boundary layer through an adjustable nose cap. (bottom) Model of identical shape and size covered with flexible polyurethane foam.

U.S. NAVAL ACADEMY TOW TANK TESTS

Higher speed testing was conducted at the Naval Academy tow tank at Annapolis, Md. This testing required modifying the original models from a strut to a sting support, building a tow tank strut to support the model, and assembling a new force-measuring package. The final arrangement is shown in Fig. 3, with the solid model attached for calibration in the APL tow tank. The total system and models were assembled at APL and, after initial checkout, were moved to the Annapolis tow tank.

In the first tests in August 1982, the foam surface separated from its metal support, and the body drag could not be determined accurately at increased speeds. Also, the transducer was not sized properly to measure the drag accurately at low speeds. Two new foam models were fabricated and a new trans-

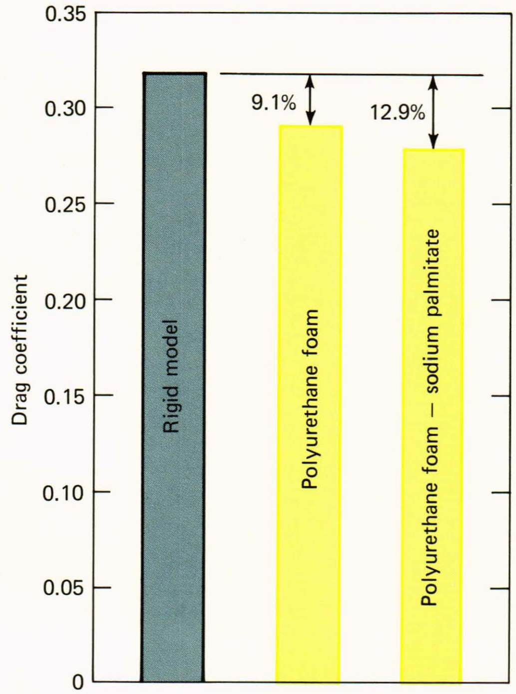

Figure 2 — Changes in drag coefficient brought about by a flexible foam and surfactant injection. (Water velocity, 5 feet per second; Reynolds number, 1.6×10^5; water temperature, 61°F; foam density, 4 pounds per cubic foot.)

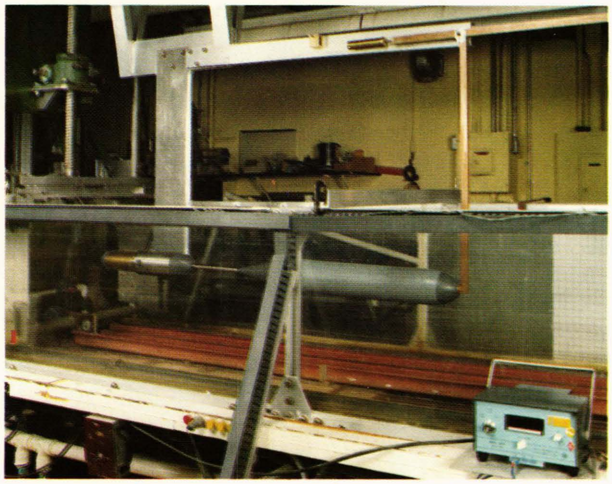

Figure 3 — Sting-mounted model undergoing calibration tests in the APL tow tank.

ducer was purchased. A new set of tow tests was conducted in February 1983 with the model approximately 2 feet below the water surface. Results are shown in Fig. 4. In the middle of the test speed range, they are contaminated by wave drag produced by the flow interacting with the free surface of water in the tank. In Fig. 4a we see that, when the speed drops to approximately 5 feet per second, the drag on the foam model is less than the drag on the solid model, which is in agreement with our earlier results. It is noteworthy that the compliant model responds differently than the solid model to wave drag. The data were taken during a number of different runs with the models interchanged. Calibrations were conducted before and after each test sequence, and the results were reproducible within 1%. Since salt water could not be used in the tank, no attempt to test surfactants was made because salt is needed to give good drag reduction performance.

Figure 4b shows interesting results obtained for the drag when small trips were placed on the nose of each model to make the flow turbulent over the body. For this situation, the foam body has significantly less drag than the solid body until wave drag takes over. This is surprising, but it may be an indication that compliant surfaces perform better in "noisy" environments. Perhaps this is why Kramer, when testing his models, found drag reduction in the ocean and not in a tow tank.[4] If further testing bears out the findings, a compliant surface may be a useful drag reduction technique for applications that usually

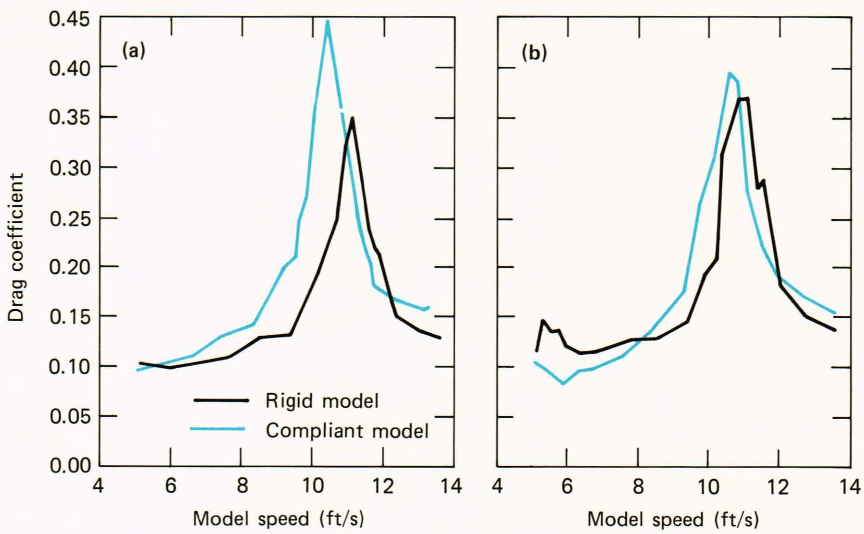

Figure 4 — (a) Drag coefficients as a function of towing speed without boundary layer trip (Naval Academy tow tank tests: data reproducibility 1%). (b) Drag coefficient as a function of towing speed in the presence of a boundary layer trip.

operate in noisy environments and have rough surfaces.

When the foam model became soaked with water, there was no noticeable effect on the drag. This implies that for some short-duration applications a body could be saturated with a surfactant that bleeds into the flow and thereby reduces drag.

The Naval Academy tow tank tests were partially successful because they confirmed the previous results of drag reduction at low speed but were inconclusive at higher speeds because wave drag dominated the data. They revealed the significant result that a compliant surface body with roughness can yield much less drag than a solid body with roughness. The speed range for this observation was again limited by wave drag, however, and further tests in a facility that avoids wave drag are required.[5]

FUTURE WORK

Two tests should be conducted to make clear the usefulness of compliant surfaces and surfactants for drag reduction. The first is to conduct drag measurements at various speeds in a water tunnel or covered tow tank so that wave drag is eliminated. It appears that the best location to make these tests would be at Pennsylvania State University because their water tunnel can accept the 4.5-inch-diameter model without significant blockage of the flow. This test should be made on smooth bodies and on bodies with roughness elements. Because this water tunnel will not accept salt water for surfactant tests, a second test should be conducted in salt water with surfactant injection. At present, the only way this test can be made at modest cost is to cover the APL tow tank, which has salt water capability, and increase its tow speed from 5 to 15 feet per second. The existing models could then be employed to test surfactants at speeds higher than 5 feet per second.

REFERENCES and NOTE

[1] L. F. Koslov and V. V. Babenko, *Experimental Boundary Layer Studies*, Kiev (1978).

[2] P. V. Aslanov et al., *Mekh. Zhid. Guzu* **1**, 36-43 (Jan 1980).

[3] A. Brandt and D. A. Hurdis, *Johns Hopkins APL Tech. Dig.* **3**, 42-47 (1982).

[4] M. O. Kramer, *Naval Engr. J.*, 41-45 (Oct 1977).

[5] During the preparation of this note, a paper by Koslov, Korobov, and Babenko appeared in the *Proc. Ukr. Acad. Sci.* **A**, 45-47 (1983) that confirms an average drag reduction of 20 to 30% by flat plate foam surfaces in a turbulent flow for Reynolds numbers up to 2×10^7. Water-saturated foams were also shown to yield good drag reduction.

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