SOME EXPLORATORY TESTS ON CIRCULAR AND SIDEWALL ACIB CONCEPTS

(ESSAIS PRÉLIMINAIRES SUR DEUX BRISE-GLACE À COUSSIN D'AIR : L'UN CIRCULAIRE, L'AUTRE À PAROIS LATÉRALES)

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ABSTRACT

Non-dimensional parameters are proposed for the resistance and speed of air cushion ice-breaking bows (ACIBs). Data obtained from tests on circular and sidewall ACIBs indicate that resistance is independent of ice thickness and related to the air cushion pressure. Models required higher pressure ratios (cushion pressure, expressed in terms of height of a water column, over the ice thickness) to break the model ice than the ratio that was effective with full-scale ACIBs, probably due to higher relative toughness of the model ice, allowing a higher deflection prior to rupture than the real ice.

RÉSUMÉ

Des paramètres sans dimensions sont proposés pour normaliser la résistance et la vitesse de brise-glace à coussin d'air. Des essais sur deux maquettes, circulaire et à parois latérales, indiquent que la résistance à l'avancement serait indépendante de l'épaisseur de la glace et plutôt reliée à la pression du coussin d'air. Les maquettes exigeaient des rapports de pression plus élevés que ceux observés sur les essais en vraie grandeur (le rapport de pression concerne celle du coussin d'air, exprimée en hauteur manométrique, sur l'épaisseur de la glace). Cela proviendrait du fait que la glace modèle est très épaisse, permettant une plus grande déflection avant la rupture que la glace réelle.

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by

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BACKGROUND

The ability of air cushion vehicles or hovercraft to break floating ice sheets was discovered by accident. During the early seventies, the towed air cushion platform known as the ACT-100 was observed to break sheets about 1m thick during field trials near Yellowknife in the NWT [1]. Typically, the water surface directly beneath the craft was depressed below the lower edge of the sheet, and an air cavity was formed which propagated away from the craft under the sheet. The sheet failed mainly due to bending stresses set up by the weight of an unsupported or overhanging section of the sheet inside the cushion [1]. The ACT-100 was later mated with the bow of an icebreaker ship, which pushed it onto the floating sheets. On an energy consumption basis, this combination was found to be much better than the icebreaker acting alone [1]. Its resistance to forward motion was much lower, and it broke ice at a faster rate. More recent operations have shown

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ACIB: Air Cushion Icebreaker Bow
IMD: Institute for Marine Dynamics, Newfoundland
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that a tugboat is just as effective as a conventional icebreaker in this role. Unlike conventional icebreakers, the hovercraft/ship combination does little damage to port facilities, mainly because it exerts insignificant forces in the plane of a sheet. However, operations to date have shown that hovercraft cannot break ridged pack ice of the type and size that occurs in the Arctic.

CIRCULAR/SIDEWALL CONCEPTS

In 1984, two new craft were proposed. The rationale for these can be found in [2]. One was a circular or round planform craft designed for operation in inland waters with an ability to break uniform ice sheets about 1 m thick at full scale; the other was a sidewall craft designed for mid-Arctic operation in regions where ice sheets, with moderate ridging, are typically about 2 m thick. Both craft used a simple kneeless segment skirt, to simplify maintenance. Both used drag sheets to keep the skirt free from ice blockage, and both used a spray apron to minimize spray-ice build-up on the super-structure. The craft are shown schematically in Fig. 1.

EXPLORATORY WORK AT IMD

Models of the new craft were constructed at MUN at a geometric scale of 1:20 and tested in the Ice Tank at IMD [3]. For this, the sidewall craft was first scaled down to the size of the round craft. Pictures of the models are shown in Fig. 2. Each had a support structure constructed from plywood approximately 18 mm thick and aluminum plate approximately 3 mm thick. Each used a kneeless segment skirt made from a light nylon fabric approximately 0.25 mm thick, supplied by UNITED SAILWORKS (Newfoundland). Neither model used drag sheets or a spray apron. It was felt that these were unnecessary complications at model scale. It was also felt that a skirt at the rear of the sidewall craft was unnecessary: an inclined flat plate was used instead in the model. The sidewall craft used a total of fourteen segments while the round craft used sixty. The size of the segments was the same for each craft. For the exploratory work, all model motions, except for surge, were suppressed. It was hoped that this would simplify data interpretation. Each model was towed over a number of sheets, each with thickness approximately uniform throughout, at a number of constant speeds, and its resistance to forward motion in each case was measured with a load cell. Cushion pressure and flow were also measured, and video cameras were used to record the icebreaking action. A vortex blower was used to supply cushion air. Standard procedures were used to grow ice sheets with scaled mechanical properties [3].

Some preliminary tests with the circular model on intact and pre-broken sheets showed that the breaking component of resistance is insignificant, at least at low speed. This suggests that ice properties such as strength have at best only a minor influence, which implies that scaling laws can ignore ice properties. Resistance to forward motion F can be nondimensionalized in a number of ways. In hydrodynamics, it is customary to nondimensionalize it by a force equal to a pressure times an area. This is the approach taken here. The dynamic head due to craft motion gives a pressure. However, for ACIB work, the cushion pressure P is probably more appropriate and is used herein. For an area, one could use D^2, where D is the width of the cushion, which for both models tested at IMD was approximately 0.91 m. This area is a measure of the cushion footprint and so PD^2 would be a measure of the craft weight. So, resistance would in this case be given relative to the craft weight: $CF = F/PD^2$. To some extent, an ACIB acts like a water plow with an area given approximately by HD, where $H = P/\rho g$ is the depth of a trough formed by hydrostatic pressure, ρ is the density of water and g is the acceleration due to gravity. The cushion pressure acts over this area to give the force PHD. Resistance as a fraction of this force is $CF = F/PHD$. The present data suggest that this is a better non-dimensional representation of resistance. One could present the forward speed U nondimensionally as a Froude Number: $CS = U/\sqrt{gD}$. However, in earlier work [4], the propagation speed of the air cavity under the sheet was found to be given approximately by $U_B = \sqrt{1.3\, g\Delta h}$, where Δh is the height of the cavity. Using this speed instead to nondimensionalize U gives CS = U/U_B. The present data suggest that this CS is more appropriate. Below CF = F/PHD and CS = U/U_B are used. Nondimensional representations of cushion pressure and flow were also developed. For cushion pressure, the thickness of ice corresponding to the cushion pressure was nondimensionalized by the sheet thickness itself: (CH = $P/\sigma gh$ where σ is the density of ice and h is the sheet thickness). Each CH value quoted herein is a run average. The cushion flow Q was non-dimensionalized by the flow $Q_o = U_o D^2$, where from Bernoulli $U_o = \sqrt{2P/\epsilon}$ where ϵ is the density of air: ($CQ = Q/Q_o$).

Fig. 3 shows nondimensional resistance data for the round model generated during intact and pre-broken sheet runs over a 40 mm thick sheet. As mentioned previously, the close agreement suggests that the breaking component of resistance is insignificant. Surprisingly, the resistance curve for the pre-broken sheet is slightly higher than the intact sheet curve. Observations of video records showed that this is due, at least in part, to craft-ice contact caused by a vertical rotation of the broken ice pieces as they entered the cushion. Fig. 4 is for a 30 mm thick sheet and shows that craft with larger CH generate slightly larger CF. Video records show they also have greater ice breaking action and more craft-ice contact. The larger CF is probably caused by this. Recall that for a given sheet a larger CH implies a deeper and faster moving cavity beneath the sheet. Fig. 5 shows that data obtained from sheets, each with a different thickness but with approximately the same CH, collapse approximately to the same line. In addition, it shows that the present data are in agreement with tank data obtained by ARCTEC for a rectangular planform model having approximately the same CH and D [5].

Fig. 6 shows intact and pre-broken sheet data for the sidewall model. To generate this data, channels in the sheets for the sidewalls were precut so the resistance penalty due to the normal shearing action of the walls was not present. Fig. 7 shows this resistance penalty. Like Fig. 3, Fig. 6 shows that the resistance for intact sheets is typically lower than that for pre-broken sheets. It also shows that the difference in intact resistance for the two thicknesses tested is insignificant. Fig. 7 shows that for total resistance there is a transition at CS near unity. Also, when the sidewall penalty is subtracted out, the remaining resistance seems to have an upper limit slightly above unity. It appears that there the plow mechanism is fully active. The extra resistance beyond unity is probably due to friction.

A comparison of sidewall model data with that of the round model shows that resistance levels for both models are similar, provided the resistance penalty for the sidewall model is subtracted from its data and the CH values are approximately the same. For a given CH, CQ for the sidewall model was usually around half the CQ for the round model. This implies that the sidewall craft uses less power to generate its cushion: so the resistance penalty is counteracted to some extent.

It should be noted that the field CH needed to break ice is usually around 1.1, which is much lower than that needed by the tank models. ARCTEC observed a similar phenomenon in their tank data. This is probably due to tank ice being much tougher than field ice, partly because it has fewer imperfections. During operation of the round model at the field CH level, the ice could be seen to follow the depressed water surface, and an air cavity was not formed under the sheet, even when on the basis of CH it was to be expected.

The data set obtained in the present exploratory work is quite small. Not all of it is reported herein. Some more can be found in [6]. A much larger set would be needed to confirm the scaling laws and fully understand the resistance mechanisms. Finally, in some high speed runs, a transition to a high resistance wave mode of ice breaking was observed in which large amplitude flexural-gravity waves were generated by the motion over the sheet [7,8]. This and the low speed mode will soon be explored in greater detail at IMD and MUN.

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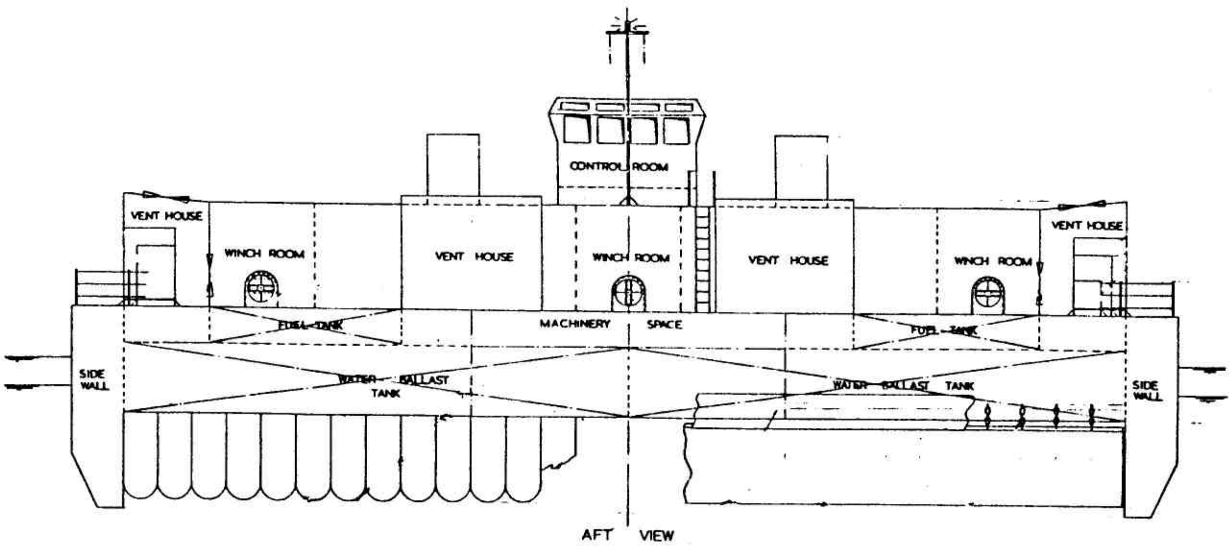
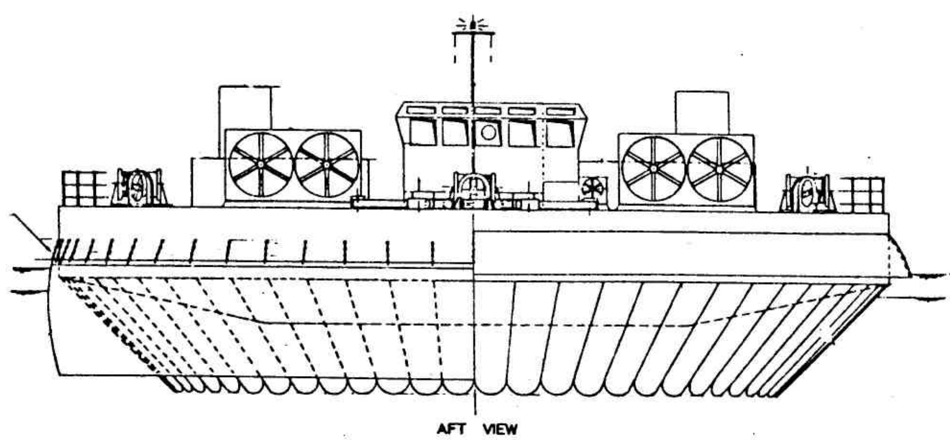
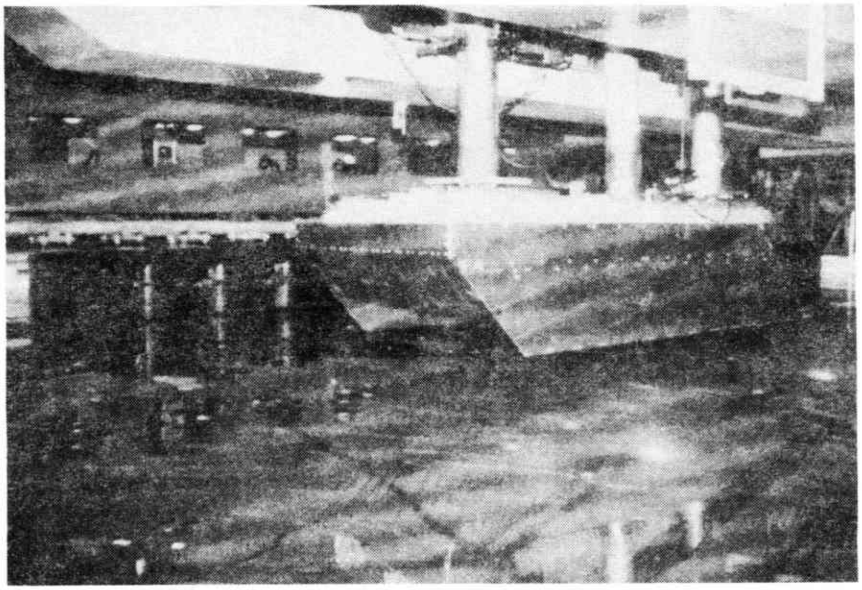


SIDEWALL MODEL

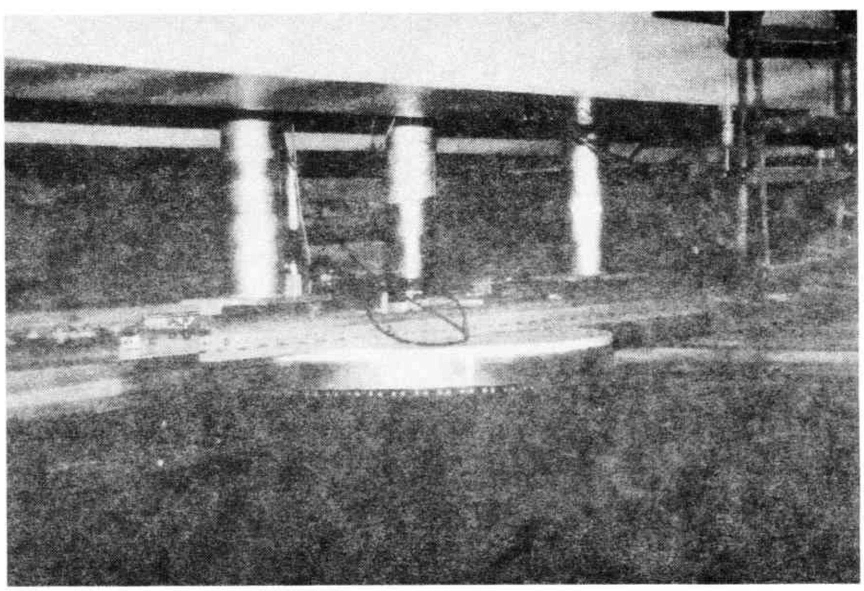


ROUND MODEL

Fig. 1 Schematics of Circular and Sidewall ACIB Craft.



SIDEWALL MODEL



ROUND MODEL

Fig. 2 IMD ACIB Craft.

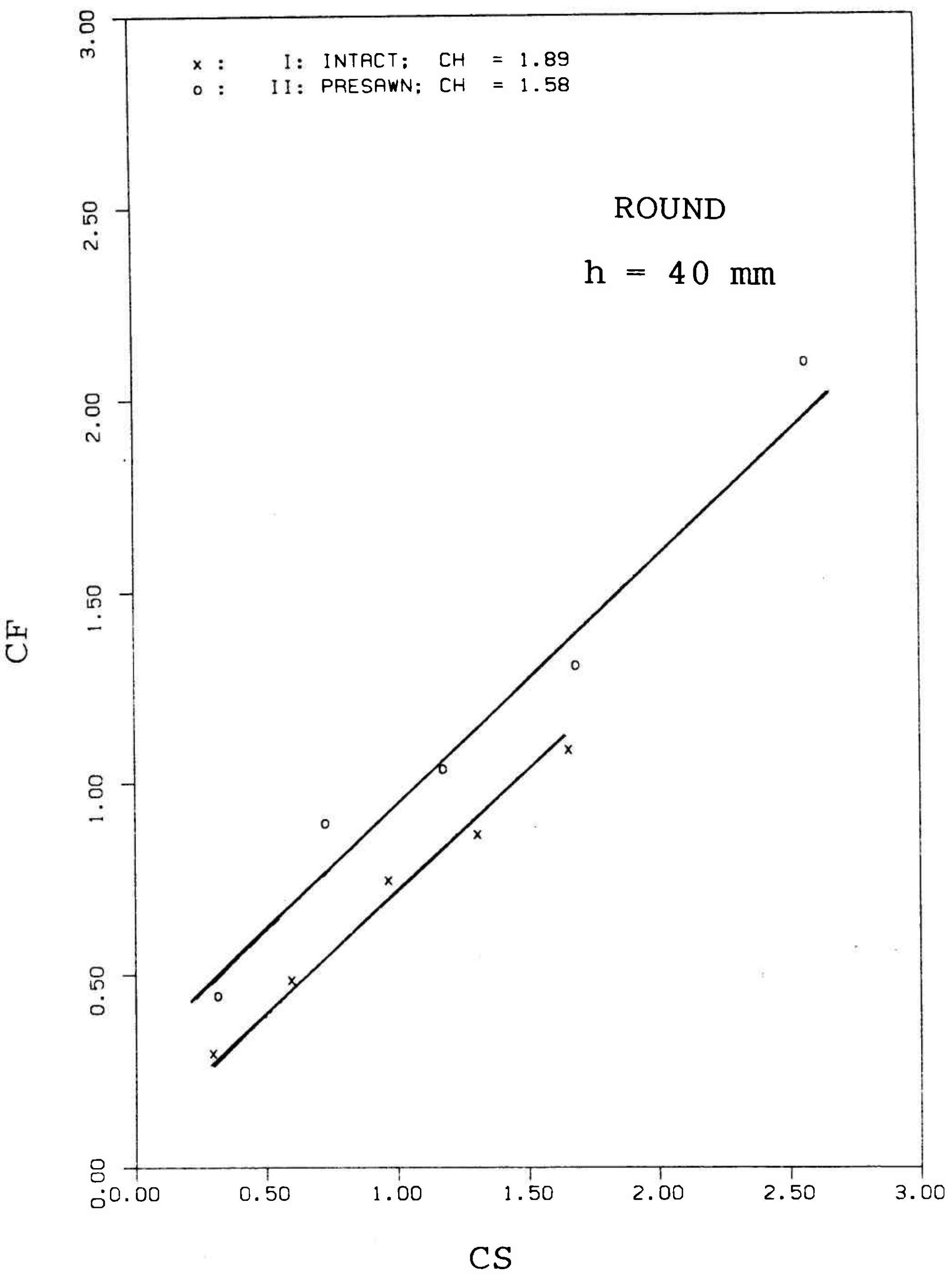


Fig. 3 Intact and Pre-broken Sheet Resistance Data for Round Model.

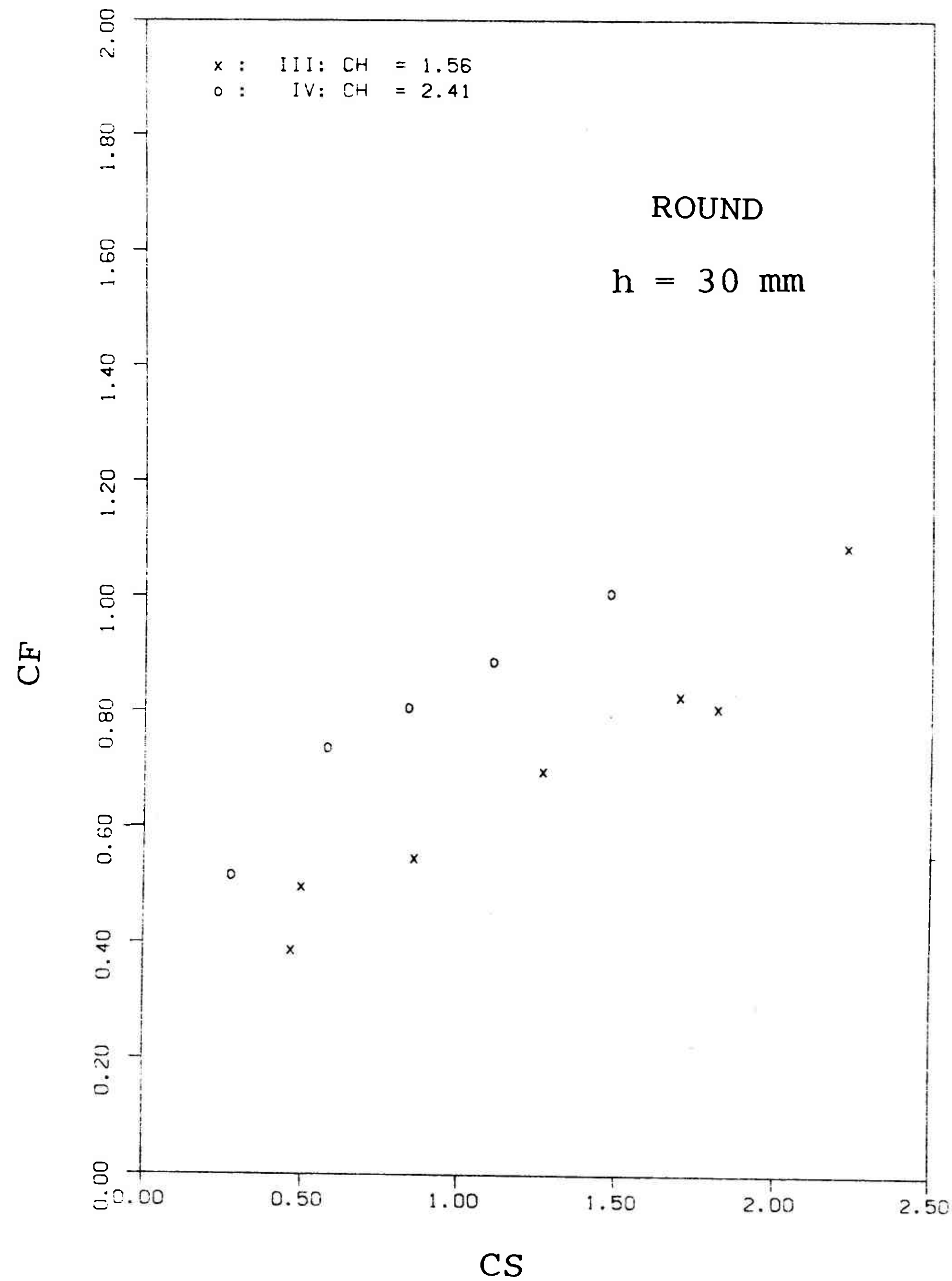


Fig. 4 Resistance Data for Round Model: CH Trend.

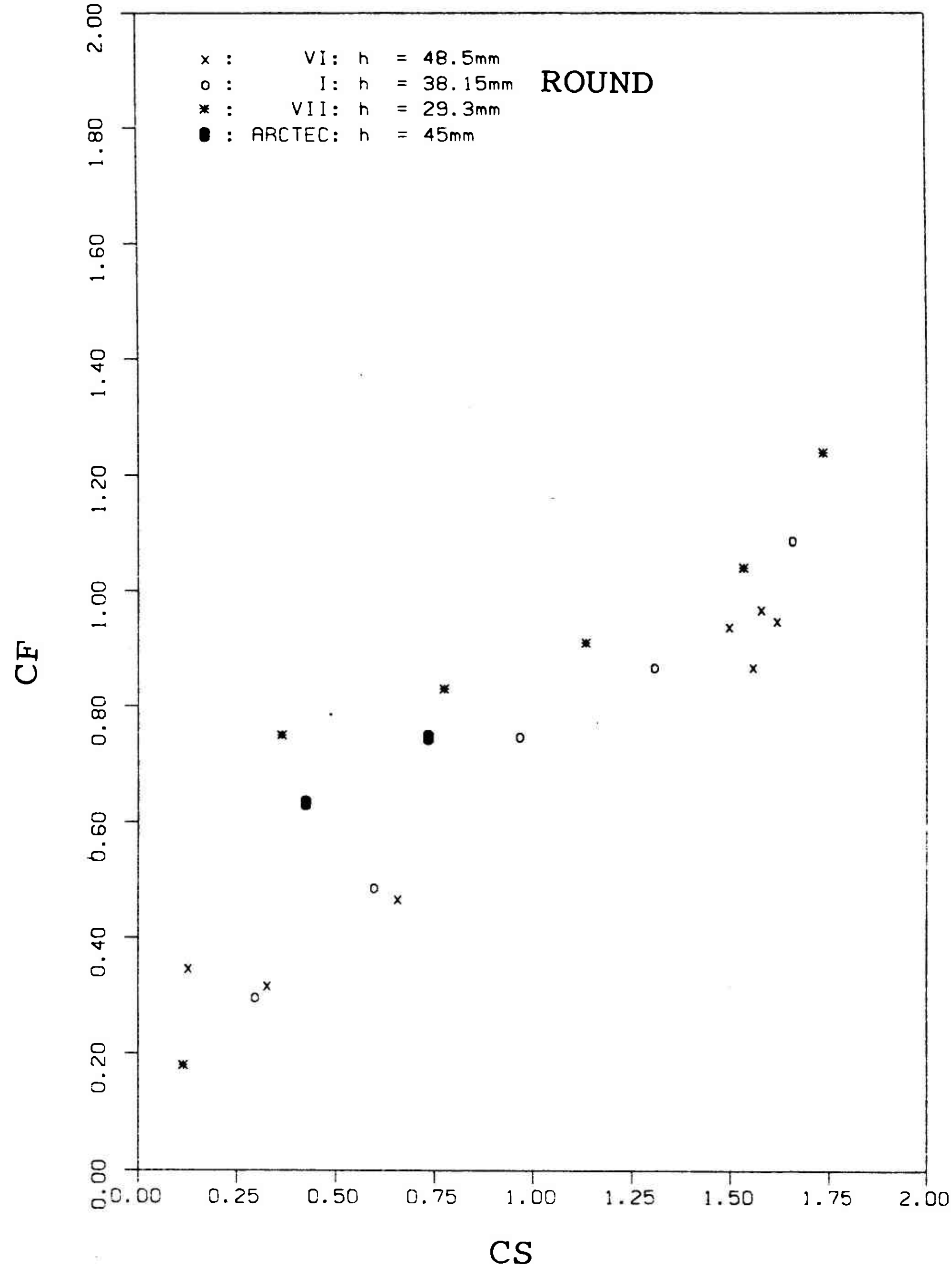


Fig. 5 Resistance Data for Round Model from Sheets with Different Thickness.

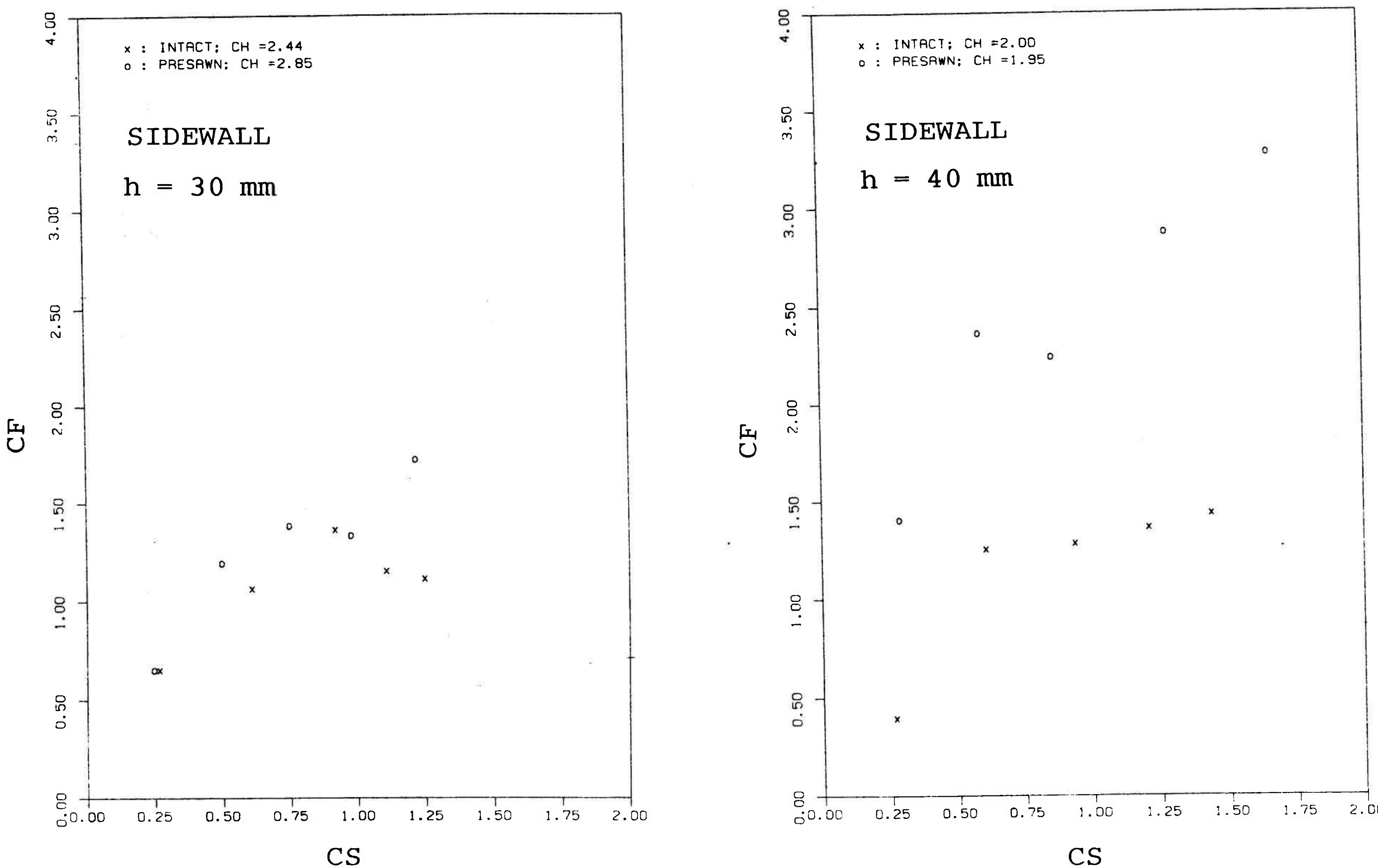


Fig. 6 Intact and Pre-broken Sheet Resistance Data for Sidewall Model.

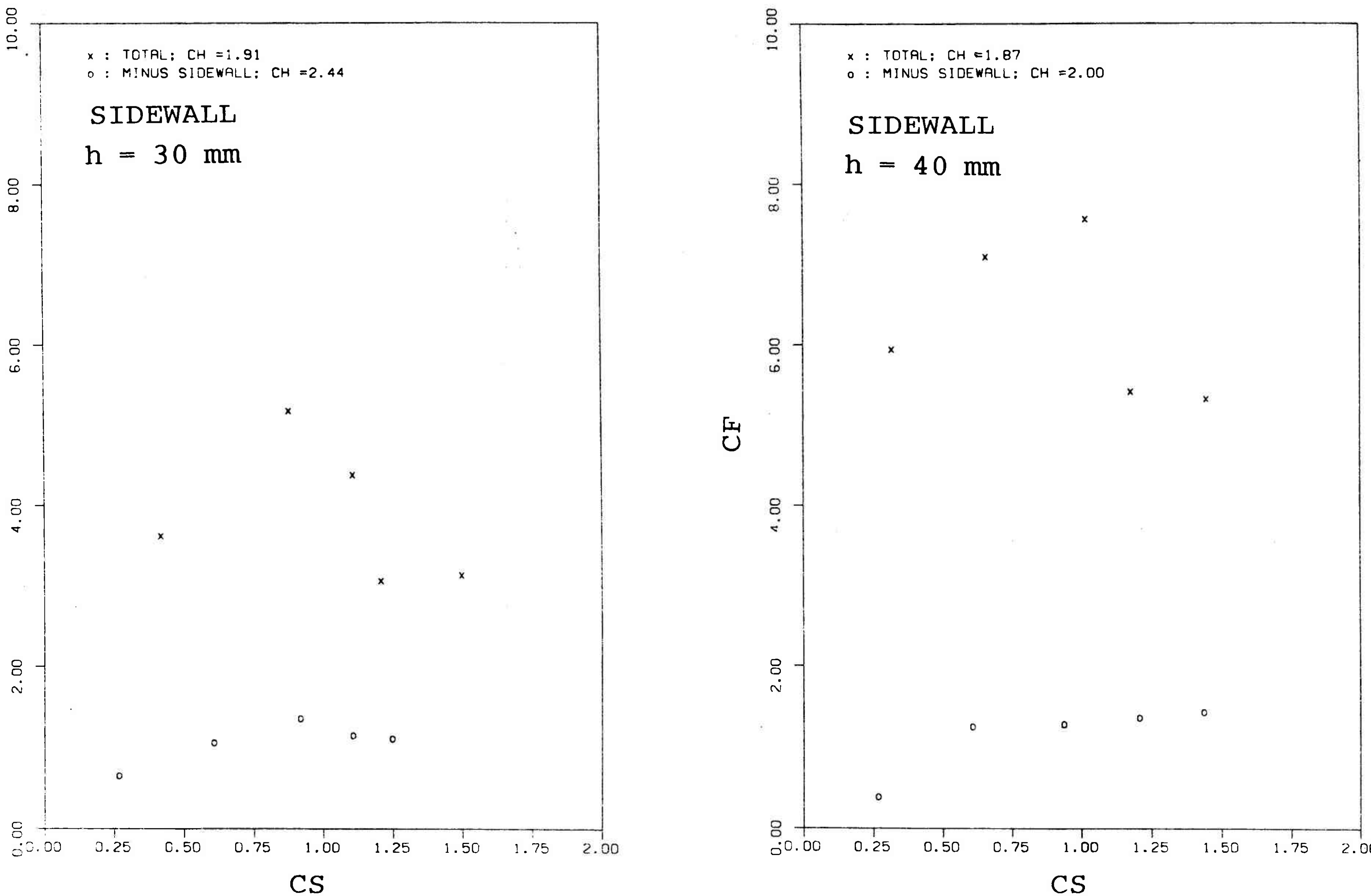


Fig. 7 Resistance Penalty due to Sidewalls.