Technical Meeting — 13 February 2019

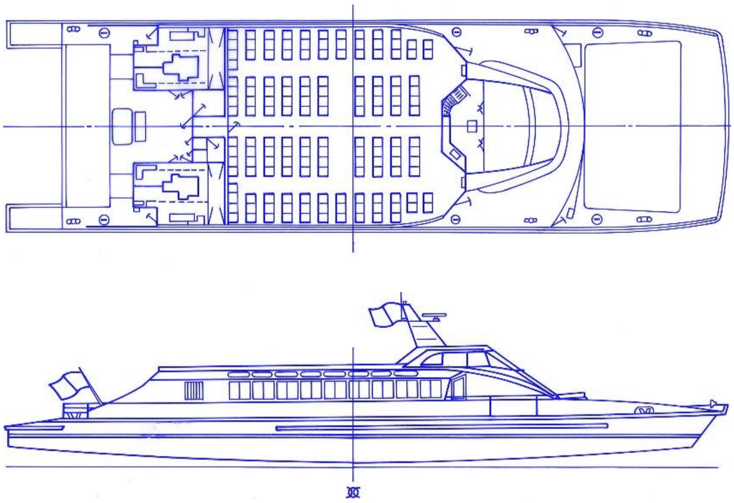
Lawry Doctors, Professor Emeritus at UNSW Sydney, gave a presentation on *Recent Studies of the Hydrodynamics of River Vessels* to a joint meeting with the IMarEST attended by 31 on 13 February in the Harricks Auditorium at Engineers Australia, Chatswood.

Introduction

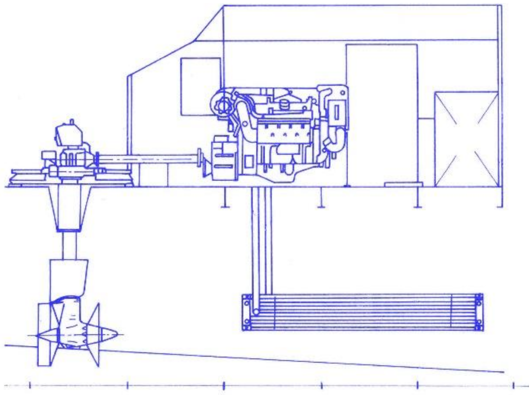
Lawry began his presentation by noting that in 1991 he had been asked to do some hydrodynamic analysis work on the RiverCats, which were then being designed by Grahame Parker. He then showed some photographs and drawings of the vessels.

RiverCat *Dawn Fraser* during the presentation on Sydney Harbour
(Photo courtesy Lawry Doctors)

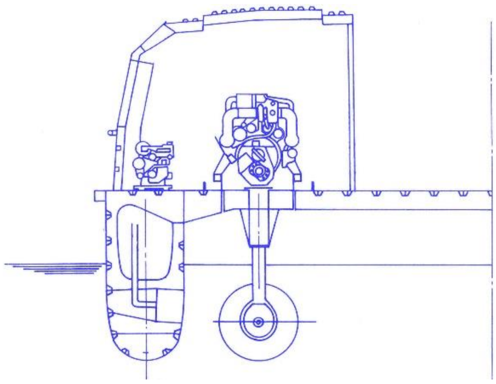
RiverCat *Shane Gould* in operation on the Parramatta River
(Photo courtesy Lawry Doctors)



General arrangement of the RiverCats
(Drawing courtesy Grahame Parker)



Machinery profile of the RiverCats
(Drawing courtesy Grahame Parker)



Machinery section of the RiverCats
(Drawing courtesy Grahame Parker)

Grahame Parker wanted the demihulls as slender as possible, and achieved this by placing the propulsion machinery on the main deck and driving through Z-drives into clear water. The demihulls are extremely slender, with a length/beam ratio of 30, and so they have very low wave-making resistance; in fact, the lowest Lawry has seen on any vessel of this type.

Theory

Lawry then said that he would give some theoretical equations for everyone to understand the practical implications. He was very proud of the fact that the theoretical equations for ship resistance were first developed by the Australian, John Henry Michell, a professor of mathematics at the University of Melbourne. Michell's paper *The Wave Resistance of a Ship*, was published in the *Transactions of the Royal Society* in 1898. What is astonishing is that all his numerical calculations were done without the benefit of any sort of calculator, but with pencil and paper!

The final result is that the wave resistance of the ship is given by:

$$R_W = \frac{\rho g}{\pi} \sum_{i=0}^{\infty} \in \Delta k_y k k_x^2 (u^2 + v^2) / \frac{df}{dk}$$

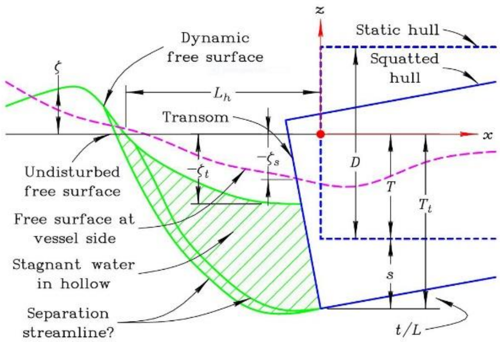
where R_W is the resistance related to the waves generated by the vessel, and which we want to minimise. In 1991 there was great interest in the minimisation of wave generation, saving fuel and minimising damage to riverbanks. The summation means that we need to add all the wave components in the spectrum, and the *i* refers to the transverse waves behind the vessel.

The Kochin functions in the above equation for R_W are given by

$$u + iv = \int_S b(x,z) e^{ik_x x} \frac{\cosh[k(z+d)]}{\cosh(kd)} dS$$

It can be seen that this involves the local breadth, *b,* of the demihull. Michell's theory only considered the case of deep water, and it was left for Sretensky to extend this to the case of finite depth of water in 1937, and this is accounted for in this equation by *d.* So the theory now takes everything into account, including the separation of the demihiulls.

A feature of these vessels is the transom stern. The first specific work on the resistance due to transom sterns was done by Oving in 1985, who came up with a formula for the way in which a transom stern ventilates.



Idealisation of transom ventilation
(Diagram courtesy Lawry Doctors)

As the vessel starts from rest, the lowering of pressure at the aft end means that the water level at the transom drops. As the speed increases, the water level drops further until, at sufficiently high speed, the water flow separates from the underside of the transom and breaks clear. At intermediate speeds there is partial separation. This gives additional drag due to the deletion of the water pressure acting forward on the transom. So the hydrostatic drag due to the transom is the integral of the lack of pressure on the transom:

$$R_{H1} = \rho g \int_{-T_t}^{\zeta_t} b(x_t\,, z)(z - \zeta_t) dz$$

There is, in fact, also a contribution from the bow:

$$R_{H2} = -\rho g \int_{-T_t} b(x_t\,, z) z dz$$

and so the total hydrodynamic resistance is given by:

$$R_H = R_{H1} + R_{H2}$$

The total resistance of the vessel R_T is then given by:

$$R_T = R_W + R_H + f_F R_F + R_A + R_a + R_M$$

where

f_F = frictional form factor (due to Hughes)
R_F = frictional resistance
R_A = correlation resistance
R_a = air resistance (very small on the RiverCats)
R_M = momentum resistance (only applicable to air-cushion-type vessels)

and we ignore any interactions between terms.

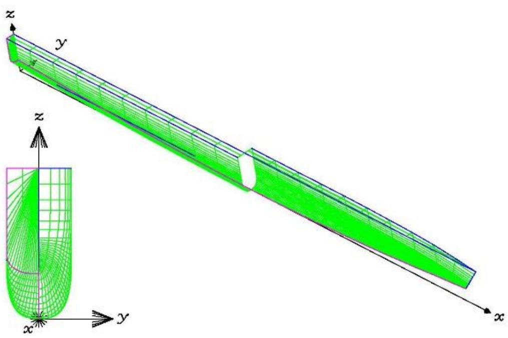
Some consider a good measure of a vessel's efficiency to be the Transport Factor, defined as:

$$\text{TF} = \frac{WV}{P}$$

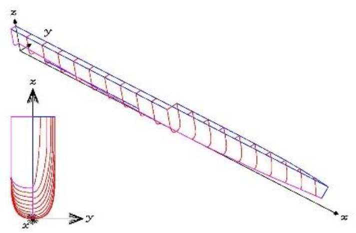
where *W* is the weight of the vessel (as a force, rather than the displacement, to keep the transport factor non-dimensional), *V* is the speed, and *P* the power. Depending on the application, we could take *W* as the total weight or the cargo deadweight, *V* as the maximum or service speed, and *P* as the maximum power, MCR power, or even the effective power (i.e. at the propeller).

Analysis

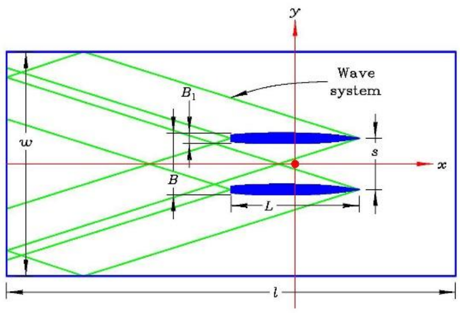
Here Lawry showed some diagrams of his modelling of the RiverCats. The extreme slenderness of the hulls can be seen in the mesh diagrams.



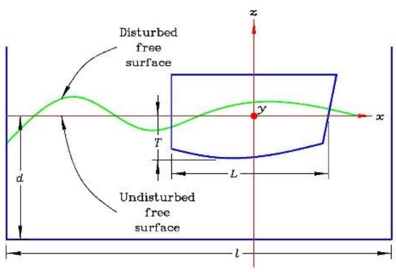
Input mesh for RiverCat demihull
(Diagram courtesy Lawry Doctors)



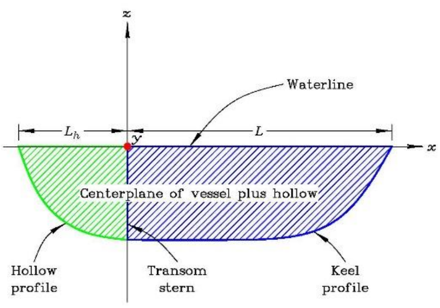
Input sections for RiverCat demihull
(Diagram courtesy Lawry Doctors)



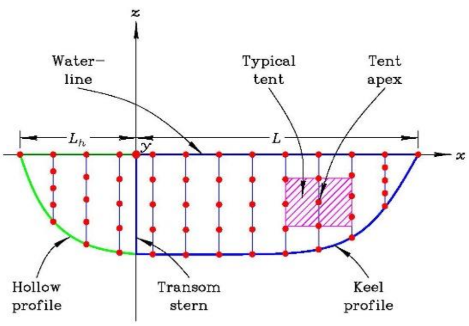
Notation plan for a catamaran in a towing tank
(Diagram courtesy Lawry Doctors)



Notation profile for a catamaran in a towing tank
(Diagram courtesy Lawry Doctors)



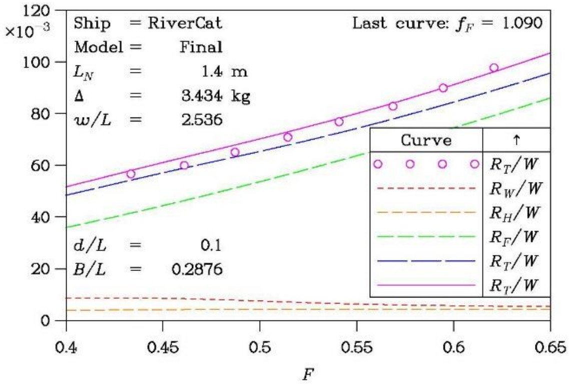
Centreplane source distribution for computer
(Diagram courtesy Lawry Doctors)



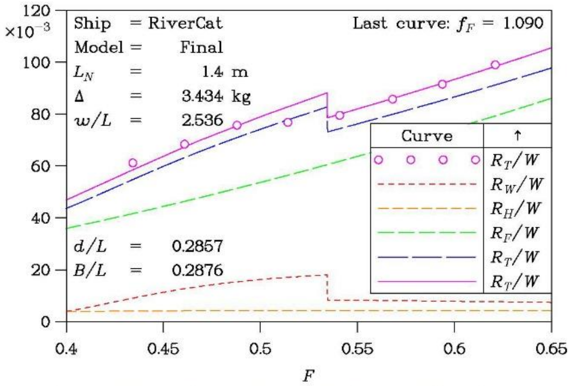
Discretisation of centreplane source distribution
(Diagram courtesy Lawry Doctors)

It can be seen in the towing-tank notation diagrams that all of the principal factors affecting resistance are taken into account: *B*, *b*, *s*, *w* and *d*. It is fascinating that the towing tank has finite width and depth, and that these both affect the results. The wave system comes off both demihulls, and these waves reflect off the sides of the tank and provide interesting interaction effects. This is similar to the Parramatta River, which is limited in both width and depth. The flaw in the Parramatta River is that the cross section is not rectangular!
The computer models the hull of the vessel and the wave hollow behind the hull in order to generate the wave system. The source panels are distributed over the centreplane of the hull.

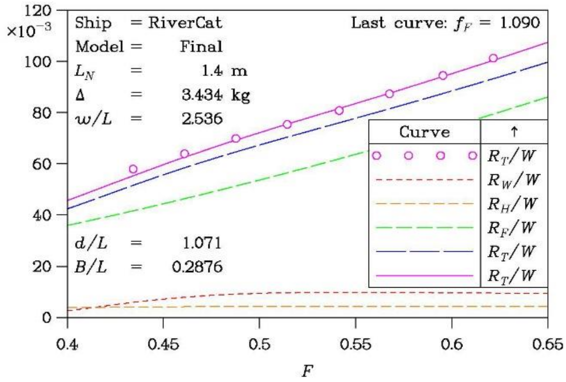
Experimental Results
Lawry then showed a series of graphs of the comparison between the towing-tank results and his latest computer predictions, noting that his current program has been refined since his analysis for Grahame Parker in 1991. The abscissas of all graphs are the length Froude number, $F_n = vL/\nu$, and the ordinates are the scale for non-dimensionalised resistances, *R/W*. The symbols represent the experimental points, and the curves represent the computer predictions. The blue R_T/W curve is with a frictional form factor of 1.0, and the purple R_T/W curve is with a frictional form factor of 1.09.



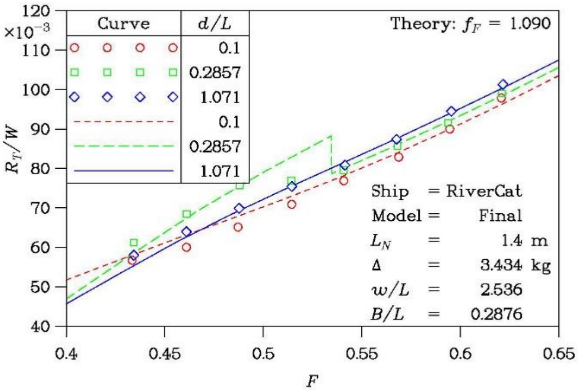
Experiments on RiverCats at *d/L* = 0.1
(Graph courtesy Lawry Doctors)



Experiments on RiverCats at *d/L* = 0.2857
(Graph courtesy Lawry Doctors)



Experiments on RiverCats at *d/L* = 1.071
(Graph courtesy Lawry Doctors)



Experiments on RiverCats at all *d/L* ratios
(Graph courtesy Lawry Doctors)

The graphs show that, in general, the resistance of the RiverCats increases monotonically with speed. The wave-making component and the hydrodynamic component (due to the transom) are both small, and the principal contributor to the total resistance is the frictional component.

The case of $d/L = 0.1$ corresponds to a water depth of 3.5 m for the RiverCats.

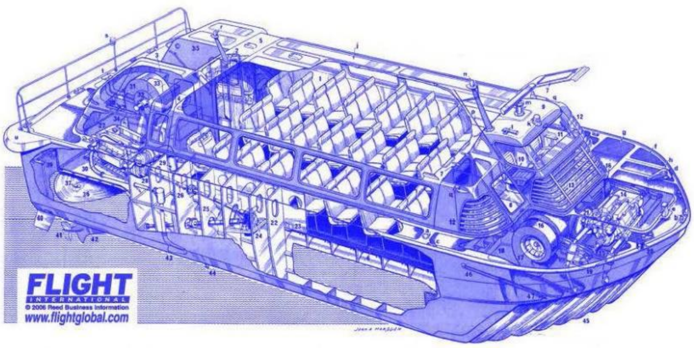
For $d/L = 0.2857$, a jump decrease occurs in the wave-making resistance at a depth Froude number $F_{nd} = 1.0$, due to the loss of the transverse component of the wave pattern at that speed. The experimental points do not "jump" as do the predictions, *due to the unsteady effects,* which occur in a practical towing-tank test.

For $d/L = 1.071$, there is close agreement between the experimental results and predictions over the whole range of speeds.

This last graph shows that, overall, the latest computer predictions agree well with the experimental results.

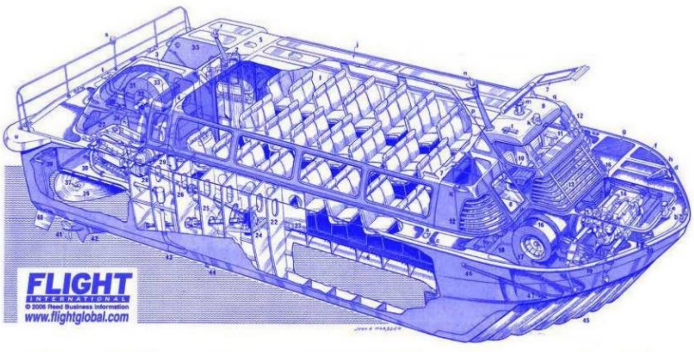
Other Marine Concepts

Lawry then said that there are other possibilities for reducing the resistance of vessels. One of these is the sidewall hovercraft.



Cutaway drawing of sidewall hovercraft Denny D2 Hoverbus
(Drawing from Flightglobal Cutaways website)

Sidewall hovercraft Denny D2 Hoverbus on trials
(Photo Scottish Maritime Museum)



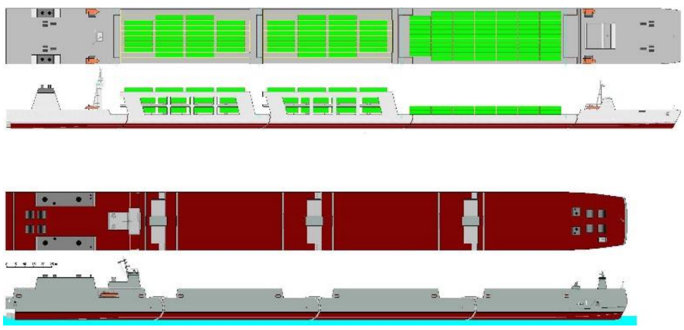
Cutaway drawing of sidewall Hovermarine HM2 Hoverbus
(Drawing from Flightglobal Cutaways website)

Sidewall hovercraft Hovermarine HM2 Hoverbus in operation
(Photo courtesy Lawry Doctors)

The sidewall hovercraft also has very slender demihulls (i.e. the side hulls), a cushion of air in between, and skirts fore and aft to seal and maintain the air pressure. Newton's Law tells us that the whole of the vessel's displacement must be supported by the water, and so waves will be generated. The slender demihulls and the low cushion pressure mean that the wave-making resistance will be low. However, the distribution of support will be different from that of a catamaran. If we can lift the hulls out of the water (or partly so), then the frictional resistance will decrease, and maybe the wave-making resistance too, but we cannot eliminate it. Like the RiverCats, there is no room in the side hulls for the propulsion engines, so they are placed on deck. These vessels often have trouble with the drive shafts and propulsion train.

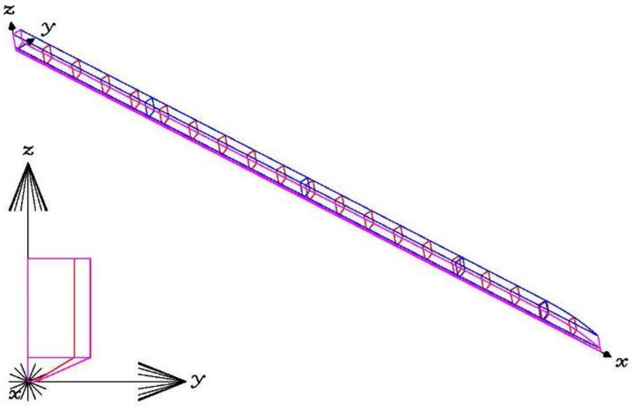
The photograph of the HM2 Hoverbus shows that the vessel had one poor operating condition, with quite a large wave generated at this low speed.

The High-Speed-Sealift SeaTrain surface-effect-ship concept was developed by Alion Science and Technology Corporation in the USA. A long vessel with high length/depth ratio tends to develop high stresses in a seaway. Alion's solution was to articulate the vessel by providing hinged joints to reduce the bending loads. The vessel could also operate into smaller ports by disconnecting at the joints, and they proposed both commercial and military versions.

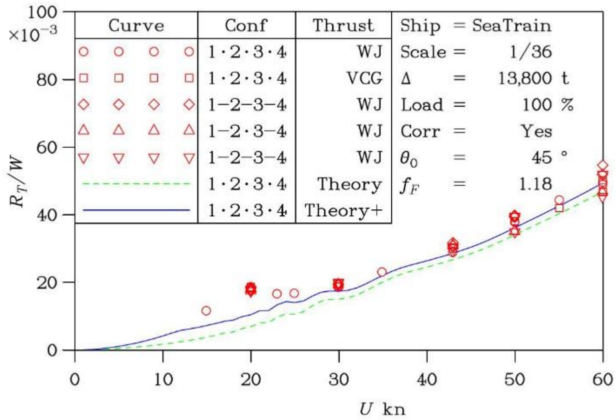

Alion's High-Speed-Sealift SeaTrain surface-effect-ship concept
commercial (top) and military (bottom) versions
(Diagram courtesy Alion Science and Technology Corp.)

1:20 scale model of the HSS SeaTrain surface-effect-ship
being tested on the Severn River near Annapolis, MD, USA
(Photo courtesy Alion Science and Technology Corp.)

Lawry had modelled this vessel and provided resistance predictions using his computer program.



Computer model of four-car HSS SeaTrain surface-effect-ship side hull
(Diagram courtesy Lawry Doctors)



Results of model tests and computer predictions
for HSS SeaTrain surface-effect ship
(Graph courtesy Lawry Doctors)

In the graphs the symbols represent the results of model tests, while the curves represent the theoretical predictions. In the configuration column, a bar between hulls indicates hulls locked together, while a dot indicates hulls free to articulate. For example, the configuration 1–2·3–4 indicates that Hulls 1 and 2 were locked together, as were Hulls 3 and 4, but that Hulls 2 and 3 were free to articulate.

The symbols show that there is little difference in resistance depending on the degree of locking or articulation. The results also show that the theoretical predictions agree well with the results of model tests.

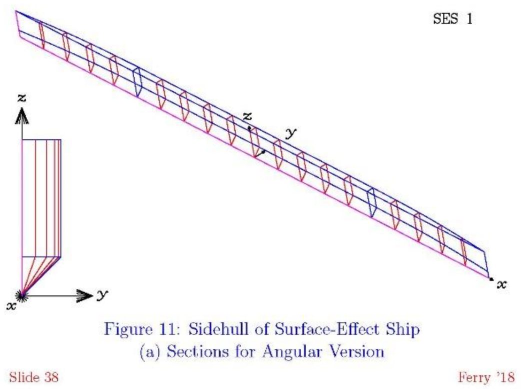
Parametric Studies

Lawry then said that it would be interesting to see what happened if we changed the dimensions of the RiverCat and a surface-effect ship, and whether we could reduce the resistance and improve the transport efficiency. He had tried varying the demihull beam and draft of both the RiverCat and an equivalent surface-effect ship for a length L = 35 m, displacement Δ = 55 t and demihull spacing s = 10 m:

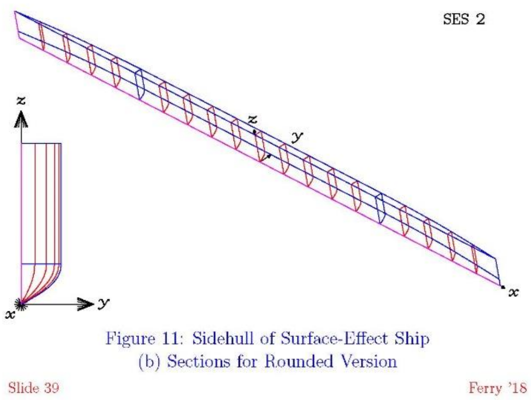
Table of candidate vessels
(Table courtesy Lawry Doctors)

Vessel	Demibeam B_1 (m)	Draft T (m)	Cushion Lift r_C
RiverCat 1	1.000	1.220	
RiverCat 2	1.414	0.866	
RiverCat 3	2.000	0.612	
SES 1	0.400	0.400	0.9136
SES 1	0.200	0.200	0.9784
SES 2	0.400	0.400	0.8845
SES 2	0.307	0.200	0.9641

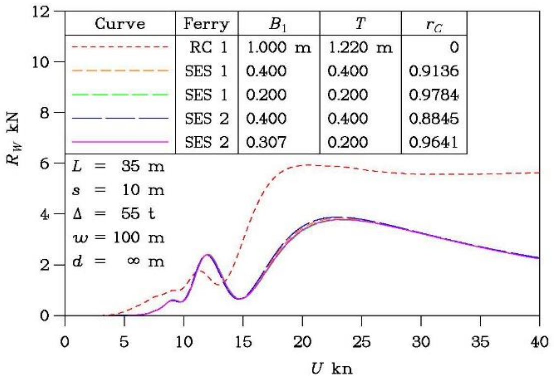
*Common values: Displacement $\Delta = 55$ t
Length $L = 35$ m, Demihull spacing $s = 10$ m



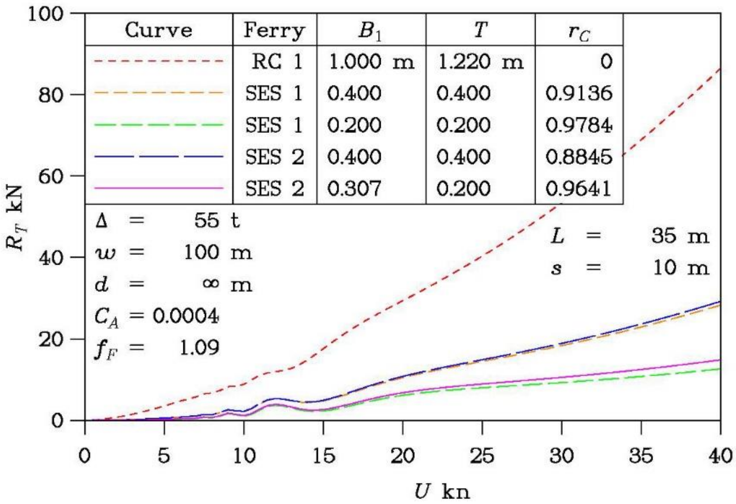
Computer model of hard-chine SES side hull
(Diagram courtesy Lawry Doctors)



Computer model of round-bilge SES side hull
(Diagram courtesy Lawry Doctors)



Comparison of wave resistance of vessels
(Graph courtesy Lawry Doctors)



Comparison of total resistance of vessels
(Graph courtesy Lawry Doctors)

The graphs show that the wave-making resistance of the SES vessels is about 60% of that of the RiverCats at the operating speed of 23 kn, and that there is little difference between the hard-chine and round-bilge versions of the SES. Reducing the draft of the SES vessel produces a worthwhile reduction in resistance. It is unfortunate that, in the real world, there are many constraints on a design, and one cannot reduce the draft of a vessel too much—if the draft is too low on an SES vessel, then air leaks out from the cushion!

Table of comparative transport factors
(Table courtesy Lawry Doctors)

Vessel name	Method of Analysis	Displacement Δ (t)	Propulsive Power P (kW)	Speed U (kn)	Transport Factor (TF)
Denny D.1	Proto†	4.16	52	17.6	7.08
Denny D.2	Proto†	29.4	328	23	10.4
Hovermarine HM.2	Proto†	17.5	477	35	6.46
SES SeaTrain	Model†*	13,800	74,930	43	40.0
RiverCat 1	Proto	55	670	23	9.52
RiverCat 1	Theory*	55	671	23	9.51
SES 1 at $T = 0.4$ m	Theory*	55	244	23	26.2
SES 1 at $T = 0.2$ m	Theory*	55	139	23	45.8

*Assumed overall propulsive efficiency of 0.63 to match prototype RiverCat
†First four vessels do not travel at equivalent Froude number

It is also interesting to compare the transport factors for these different vessels. The figures in the table are based on the total installed power (which does not include the power for the air cushion for the SES). The RiverCats show up well compared to the sidewall hovercraft, with about the same TF of about 10 as the D2 Hoverbus. However, the SES vessels all do much better, with the HSS SeaTrain operating with TF = 40. Boeing and Airbus aeroplanes operate with a TF of about 25 at 500 kn; i.e. they operate at 20 times the speed of the RiverCats and at twice the transport factor. But they do have it easy: they have only air to contend with, and air has a density of about 1/800 of that of water where we operate!

Conclusions

The RiverCats have shown themselves to be a marvellous design, with their slender hulls and extremely low wave-making resistance. There are other marine concepts, which also have low wave-making resistance, including sidewall hovercraft and surface-effect ships. In addition, calculations based on the theory are now able to make resistance predictions which are close to the experimental results.

Question time was lengthy, and elicited some further interesting points.

Lawry Doctors (L) accepting the “thank you” bottle of wine and certificate from Adrian Broadbent
(Photo Phil Helmore)

The vote of thanks was proposed, and the certificate and “thank you” bottle of wine presented, by Adrian Broadbent. The vote was carried with acclamation.