PERFORMANCE OF HIGH SPEED MULTI-HULL SHIPS

by

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Abstract

The purpose of this study is to investigate the resistance and seakeeping performance of high-speed multi-hull vessels. Three catamaran and one trimaran variant were evaluated. Parameters such as the transom depth and the separation between the demi-hulls were varied to determine the effects on the calm water wave resistance and seakeeping performance in head seas. The calculations were performed using the time-domain Rankine panel method, SWAN-2.

The effects of high aspect ratio foils/winglets attached to the multi-hull designs were also investigated. In particular, the heave and pitch motions in head waves were reevaluated including the effects caused by the presence of such appendages. Foils and winglets were placed in various longitudinal locations on the hulls of both the catamarans and the trimaran. The resulting heave and pith RAOs were evaluated for various high Froude numbers.

Finally, a total logistics cost analysis was performed for the catamaran variants to investigate the potential economic benefits in comparison with those of a high-speed monohull ship (*FastShip*) in the trans-Atlantic trade route. In particular, the total logistics cost savings and the latent and stimulated demand were evaluated and compared with those that *FastShip* generates on the same trading route.

Thesis Supervisor: Paul D. Sclavounos

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Chapter 1

1 Introduction

One of the most significant recent seaborne transport trends has been the widespread deployment of large high-speed vessels, operating worldwide. The popularity of passenger, car, and container transport is increasing, with many shipping companies investing heavily in new ships. The increasing demand for fast sea transportation has boosted the interest in unconventional ship types, which could possibly reduce the problem of high fuel consumption, inevitably linked to the higher speed of conventional ships. The potential improvement of the seakeeping performance of the high-speed vessels is another area of current interest.

Interesting possibilities arise from multi-hull designs. The slenderness of the hulls, used in multi-hull designs, minimizes wave resistance at high-speeds. However, the unavoidable increase of the total wetted surface causes less favorable fuel economy at lower speeds. The interaction between the hulls alters the seakeeping properties of multi-hull designs compared to conventional monohulls.

Today numerical flow calculations allow naval architects to investigate different hull configurations before tank testing. Tank testing is still required in the final stage of design. However, computer based simulations are sufficiently accurate, and are widely used, to optimize hull forms before model testing begins.

Computer based simulations of free surface flows past ships have enjoyed rapid growth in use and popularity since the early 80s. In recent years they have been firmly established as a versatile and inexpensive tool at the disposal of the naval architect. The field has been rapidly evolving over the past 15 years, ultimately leading to the development of the fully three-dimensional boundary integral element method. Such methods, also known as panel methods, discretize the boundaries of the fluid into elements with an associated singularity strength, impose appropriate boundary conditions, and most of them use linear potential flow theory represent the flow past the ship. The Rankine panel methods is a subgroup of the aforementioned methods, which employ the Rankine source as the elementary singularity.

The objective of this thesis is to investigate the resistance and seakeeping performance as well as the economic viability of high-speed multi-hull designs. A time-domain Rankine panel method, SWAN-2, was used for the evaluation of the calm water wave resistance and seakeeping performance in head seas of such designs. Geometrical complexities, inherited in such designs, such as multi-hull configurations and transom sterns, can be readily incorporated in the later version of SWAN-2.

Chapter 2 provides the background theory and methodology used for the hydrodynamic analysis. In particular, it provides overviews of the basic time-domain Rankine panel method and methods used for the calculation of the steady wave resistance. The incorporation of transom sterns in the method is also briefly discussed. Finally, it provides a quick review of a method, which incorporates high aspect ratio winglets in the calculation of the seakeeping performance of ships.

Chapter 3 presents the multi-hull designs tested. Three different catamaran designs were tested using three different separations between the demi-hulls. The distinct difference between the first two designs exists in the transom geometry. For the third catamaran a quite different design philosophy was adopted, of using asymmetric demi-hulls. In addition a trimaran configuration was also tested and is presented in the same chapter.

Chapter 4 and 5 present the steady and unsteady SWAN-2 results, respectively, of the calculations made for the three catamarans and the trimaran. In Chapter 6 calculations were performed to incorporate high aspect ratio winglets or foils in the seakeeping performance of the catamaran and trimaran variants in head seas. The head sea heave and pitch RAOs, including the winglet/foil effects, were calculated and are also included.

Chapters 7 and 8 investigate the economic viability of catamaran designs as an alternative to the high-speed monohull design, namely *FastShip* (TGN770), in the trans-Atlantic trading route. In particular, Chapter 7 presents the North Atlantic freight market and benefits that a high-speed service will provide to the shippers in terms of total logistic cost savings. A quick review of the methodology behind the MIT total logistics cost analysis model is also provided. Chapter 8 includes the results of an operating cost savings analysis performed for the catamaran designs, accompanied with a total logistics cost comparison with TGN770.

Finally, Chapter 9 includes the main conclusions drawn from this thesis for the potential use of multi-hull designs.

Chapter 2

2 Literature Review

2.1 Theoretical Approach

2.1.1 Problem Definition

Figure 2.1.1-1 displays a ship advancing with a time dependent forward speed U(t) in ambient waves. The Cartesian coordinate system x=(x,y,z) is fixed on the ship and is translating with velocity U(t) in the positive x-direction. The origin of the coordinate system is taken on the calm water surface which coincides with the z=0 plane. The ambient waves are propagating toward the ship with an absolute frequency ω_0 creating an angle β with the x-axis (β=180 means head waves). With the assumption of potential flow, the disturbance fluid velocity v(x,t) is defined as the gradient of the velocity potential Φ(x, t), v=$\nabla\Phi$. By virtue of continuity, Φ is a subject to the Laplace equation in the fluid domain:

(2-1) $$\nabla^2\Phi = 0$$

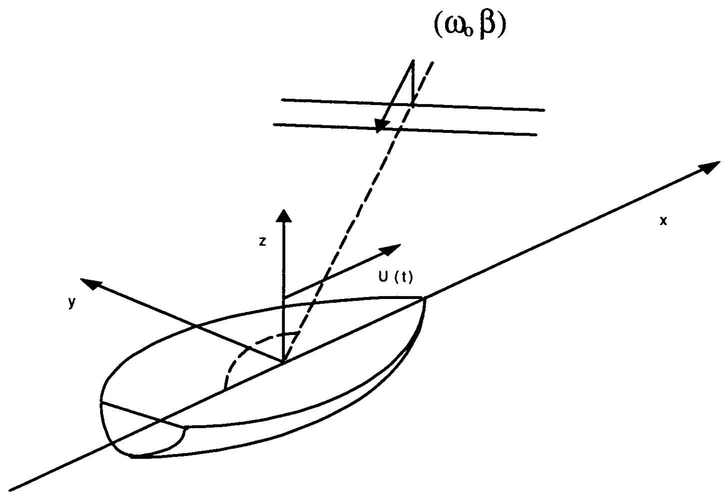


Figure 2.1.1-1:Cordinate System

The body also performs time-dependent motions about the frame of reference in the six rigid-body degrees of freedom. Its displacement can be written as:

(2-2) $$\vec{\delta}(\vec{x},t) = \vec{\xi}_T(t) + \vec{\xi}_R(t) \times \vec{x}$$

where $\vec{\xi}_T(t) = (\xi_1, \xi_2, \xi_3)$ is the rigid body translation and $\vec{\xi}_R(t) = (\xi_4, \xi_5, \xi_6)$ is the rigid body rotation.

A direct application of Newton's Law leads to the equations of motion for the vessel:

(2-3) $$\mathrm{M}\ddot{\vec{\xi}}(t) = \vec{F}_D(\ddot{\vec{\xi}}, \dot{\vec{\xi}}, \vec{\xi}, t) - C\vec{\xi}(t)$$

where M is the inertial matrix for the body and C is the matrix of hydrostatic restoring coefficients. To obtain the hydrodynamic forces, $\vec{F}_D(\ddot{\vec{\xi}}, \dot{\vec{\xi}}, \vec{\xi}, t)$, the potential boundary value problem must be solved.

The position of the free surface is defined by the wave elevation ζ(x,y,t). Two free surface conditions relate the potential with the wave elevation, the kinematic and dynamic free surface conditions. The kinematic condition requires that a fluid particle on the air-water interface at **t**=0 will stay there for all the times. Mathematically:

(2-4) $$\left[\frac{\partial}{\partial t} - (\vec{U} - \nabla\Phi)\cdot\nabla\right]\zeta = \frac{\partial\Phi}{\partial t}, \qquad \text{on } z=\zeta(x,y,t).$$

The dynamic condition states that the fluid pressure on the free surface is equal to the atmospheric pressure, which is equal to zero. From the Bernoulli equation it follows that:

(2-5) $$\left[\frac{\partial}{\partial t} - \vec{U}\cdot\nabla\right]\Phi + \frac{1}{2}\nabla\Phi\cdot\nabla\Phi + g\zeta = 0 \qquad \text{on } z=\zeta(x,y,t)$$

By eliminating the wave elevation ζ from (2-4) and (2-5), a more compact free surface condition can be found which involves Φ explicitly and ζ implicitly.

The no-flux body boundary condition imposed on the wetted surface of the hull is given by:

(2-6) $$\frac{\partial\Phi}{\partial n} = \vec{U}\cdot\vec{n} + \vec{v}\cdot\vec{n}$$

where $\vec{v} = \frac{\partial\vec{\delta}}{\partial t}$, is the oscillatory velocity of the ship hull due to the wave induced motions. Initial conditions are also imposed for the disturbance potential and the body displacement and velocity. The gradients of the disturbance potential are also required to vanish at a sufficiently large distance from the vessel at any given finite time.

2.1.2 Linearization of the free surface conditions

For the linearization of the free surface conditions to be justified two conditions must hold. The first one requires the wave slope to be small and the second one the hull shape to be sufficiently "streamlined", i.e. thin or slender. Although the linearization at zero forward speed is trivial, in the case of finite forward speed the linearization is not so simple. The "streamlined" ship assumption justifies that the fluid disturbance velocity caused by the ship forward speed and its oscillatory motions in waves is small compared to its forward speed U. The total velocity potential may therefore broken down into two parts, namely, the basis-flow potential φ_o and the disturbance flow potential φ_D as follows:

(2-7) $$\Phi=\varphi_o+\varphi_D \qquad \text{where} \qquad |\nabla\varphi_D| << |\nabla\varphi_o|$$

A similar decomposition is adapted for the wave elevation ζ.

The Neumann-Kelvin linearization is the simplest one and it assumes that the basis flow is a uniform stream, the resulting wave elevation for the basis flow is zero, and the resulting free surface conditions are:

(2-8) $$\left(\frac{\partial}{\partial t}-U\frac{\partial}{\partial x}\right)\zeta_1=\frac{\partial\varphi_1}{\partial z} \qquad \text{at } z=0$$

(2-9) $$\left(\frac{\partial}{\partial t}-U\frac{\partial}{\partial x}\right)\varphi_1=-g\zeta_1 \qquad \text{at } z=0$$

The N-K model can be rationally justified only for ships with very small beam and draft. For conventional ships with beam and draft of comparable magnitude, a more accurate model exists which accounts for the ship's finite thickness.

The Double-Body Linearization, first proposed by Gadd [5] and Dawson [4], models the flow past the ship and its positive image above the free surface and may be chosen as basis flow. The resulting basis flow elevation ζ_o follows from the Bernoulli's equation in the form:

(2-10) $$\zeta_o=\frac{U}{g}\frac{\partial\varphi_o}{\partial x}-\frac{1}{2g}\nabla\varphi_o\cdot\nabla\varphi_o \qquad \text{on } z=0$$

With substitution and use of the linearization assumptions, the following equations can be derived:

(2-11) $$\left[\frac{\partial}{\partial t}-(\vec{U}-\nabla\varphi_o)\cdot\nabla\right]\zeta_1=\frac{\partial^2\varphi_o}{\partial z^2}\zeta_1+\frac{\partial\varphi_1}{\partial z} \qquad \text{on } z=0$$

(2-12) $$\left[\frac{\partial}{\partial t}-(\vec{U}-\nabla\varphi_o)\cdot\nabla\right]\varphi_1=-g\zeta_1+\left[\vec{U}\cdot\nabla\varphi_o-\frac{1}{2}\nabla\varphi_o\cdot\nabla\varphi_o\right] \qquad \text{on } z=0$$

Several variations of the Double-Body linearization have been suggested in the literature for the steady and unsteady ship flows. The popular version of (2-11), (2-12) is that of Dawson (1977) [4], because he was the first to implement it in a Rankine Panel Method.

2.1.3 Linearization of the body boundary conditions

Linear theory allows the decomposition of the wave disturbance into independent incident, radiated and diffracted components. The derivation of the linearized body boundary conditions in the seakeeping problem dates back to Timman & Newman (1962) [21] and Ogilvie & Tuck (1969) [20]. The body boundary condition of the radiation disturbance potential, linearized about the mean surface of the hull, takes the form:

(2-13) $$\frac{\partial \varphi_1}{\partial n} = \sum_{j=1}^{6} \left(\frac{\partial \xi_1}{\partial t} n_j + \xi_j m_j \right)$$

where

(2-14) $$\left(n_1, n_2, n_3\right) = \vec{n}$$

(2-15) $$\left(n_4, n_5, n_6\right) = \vec{x} \cdot \vec{n}$$

(2-16) $$\left(m_1, m_2, m_3\right) = (\vec{n} \cdot \nabla)(\vec{U} - \nabla \varphi_o)$$

(2-17) $$\left(m_4, m_5, m_6\right) = (\vec{n} \cdot \nabla)\left[\vec{x} \times (\vec{U} - \nabla \varphi_o)\right]$$

The m-terms, m_j, provide a coupling between the steady basis flow and the unsteady body motion.

2.2 Rankine Free Surface Panel Method

2.2.1 Green's integral equation

The Laplace equation in the fluid domain bounded by the mean free surface, $S_{\overline{F}}$, (z=0) and the mean translating position of the ship hull, $S_{\overline{B}}$, may be enforced by the application of Green's theorem for the velocity potential $\varphi(\mathbf{x})$ and the Rankine source potential:

(2-18)
$$G(\vec{x};\vec{\xi}) = \frac{1}{2\pi|\vec{x}-\vec{\xi}\,|}$$

Application of Green's second identity leads to a boundary integral formulation of the perturbation potential.

(2-19)
$$\varphi(\vec{x},t) + \iint_{S_{\overline{F}} \cup S_{\overline{B}}} \varphi(\vec{\xi},t)\frac{\partial G}{\partial n}(\vec{x};\vec{\xi})d\xi - \iint_{S_{\overline{F}} \cup S_{\overline{B}}} \frac{\partial \varphi(\vec{\xi},t)}{\partial n} G(\vec{x};\vec{\xi})d\xi = 0$$

The contribution from a closing surface at infinity vanishes due to the decay of $\varphi(\mathbf{x})$ and $G(\mathbf{x},\xi)$, as $x \rightarrow \infty$ for fixed values of ξ.

2.2.2 Numerical implementation

In the above formulation there are three unknowns, namely, the velocity potential, φ, the wave elevation, ζ, and the normal velocity, φ_n. To solve for these unknowns, the linearized free surface conditions, which form a pair of evolution equations, and the integral equation are satisfied numerically by a time domain Rankine panel method.

The Rankine panel method discretizes the hull surface below the waterline and a portion of the mean free surface. Each of the unknowns is approximated independently by a set of bi-quadratic spline functions that provide continuity of value and the first derivative across panels. The evolution equations employ an explicit and an implicit Euler integration to satisfy the kinematic and dynamic free surface conditions respectively.

A numerical, wave absorbing beach is used to satisfy the radiation condition, since only a finite portion of the free surface is considered by the panel method. Thus, a solution for the wave flow is produced and the ship's equations of motion are integrated at each time step in order to satisfy the radiation body boundary conditions.

A more detailed discussion of the formulation, numerical method, and applications can be found in the work of Kring [18], Nakos and Sclavounos [11] and Sclavounos, et al.[14], [9]

2.3 Calm Water Resistance

The net fore-and–aft force on the ship due to the fluid pressure acting normally on the hull, is defined as the wave-making resistance. The potential flow can be determined from the boundary value problem, formulated in the preceding sections. Thus, the pressure can be readily determined from the Bernoulli equation.

The linearization of the free surface conditions (2-11), (2-12) requires the decomposition of the wetted surface into the mean wetted surface portion, $S_{\overline{B}}$, which lies below the z=0 plane, and an extra surface, δS_B, representing the difference between the exact and the mean wetted surface. The integration of the pressure over δS_B may be collapsed into a line integral. The magnitude of this integral is proportional to the square of the wave elevation and is therefore inconsistent with the double-body linearization of the free surface conditions, which omits terms of comparable order.

Nakos and Sclavounos (1994) [12], show that the only consistent definition of the wave resistance follows from conservation of momentum and give the solution to this inconsistency. In line with this definition, the wave resistance may be calculated by applying the momentum theorem to a control volume bounded by the exact wetted surface of the hull, by the exact free surface and by a closing surface at infinity. By virtue of the radiation condition, the closing surface may be replaced by a vertical surface, S_∞, normal to the ship's axis at a large distance downstream. The ship's wave resistance can be calculated from the following integral equation:

(2-20)
$$R_W = -\frac{\rho g}{2}\int_{C_d}\zeta^2 dy - \frac{\rho}{2}\iint_{S_d}\left[-\frac{\partial\varphi^2}{\partial x}+\frac{\partial\varphi^2}{\partial y}+\frac{\partial\varphi^2}{\partial z}\right]dS$$

where C_d is the intersection of S_∞ with the z=0 plane, and S_d is the part of S_∞ lying below z=0. Equation (2-20) can be evaluated either in terms of far field quantities through wave cut analysis, or in terms of near field quantities through pressure integration.

2.3.1 Wave Cut Analysis

By considering a cut of the wave pattern perpendicular to the steady track of the vessel for $-\infty < y < +\infty$, the transverse Fourier transform of the wave elevation $\zeta(x,y)$ and its x-derivative are given respectively by :

(2-21)
$$F(x,k_y) = \int_{-\infty}^{+\infty}\zeta(x,y)e^{ik_y y}dy$$

(2-22)
$$F(x,k_y) = \int_{-\infty}^{+\infty}\frac{\partial\zeta(x,y)}{\partial x}e^{ik_y y}dy$$

In the limit as $x\rightarrow\infty$ the vessel's free wave spectrum is defined as:

(2-23)
$$H(k_y;x) = 2\left[F(x,k_y)+i\frac{F(x,k_y)}{k_y}\right]e^{ik_x x}, k_y \in \left[-\infty,+\infty\right]$$

where the wavenumbers k_x and k_y are normalized by g/U^2 . The wave resistance, is :

(2-24) $$R_W = \frac{\rho U^2}{8\pi}\int_0^{\infty}\left|H(k_y)\right|^2 \frac{\sqrt{1+4k_y^2}}{1+\sqrt{1+4k_y^2}}\,dk_y$$

2.3.2 Pressure Integration

Similarly, the same process discussed for wave-cut analysis can be carried out in terms of near field quantities. The momentum theorem can be applied on the fluid enclosed by the linearized free surface, the ship's hull and the closing surface at infinity. In this case there is a momentum flux across the linearized free surface, which may be evaluated in terms of the wave elevation using Newman-Kelvin free surface conditions. Application of Stokes' theorem to the integral over $S_{\overline{F}}$, and substitution into (2-20), an equivalent expression for the wave resistance by using pressure integration can be derived:

(2-25) $$R_W = \iint_{S_{\overline{B}}} p n_1 dS - \frac{\rho g}{2}\oint_{wl} \zeta^2 \frac{n_1}{\cos\gamma}\,dl$$

where γ is the flare angle of the hull.

2.4 Deep Transom Sterns

2.4.1 Description of the flow

The majority of the modern ships have transom sterns. The deep transom stern is defined as the truncated after-body of a ship ending in a flat vertical section below the still waterline. For ships with such a stern the formulation of the problem presented in the preceding section does not apply. The flow separation at the sharp lower edge of the transom is triggered by viscous effects and requires an implicit enforcement of the correct behavior in the potential flow mathematical model. The principal properties of such a formulation are briefly reviewed below. Further details can be found in Mantzaris [19].

For low speeds or for deeply immersed transoms, a stagnation pressure at the stern characterizes the flow past the transom. In this case the stern remains wet and viscous effects are dominant in the regime. As the speed increases or the stern immersion decreases the flow detaches at the sharp edge of the transom and the transom itself remains dry. According to Saunders [23], the transition point from wet to dry transom often occurs at transom Froude numbers

$$F_{nT} = \frac{U}{\sqrt{g z_T}} \approx 4.0 \qquad \text{(2-26)}$$

where z_T, is the depth of immersion of the transom at zero forward speed. Most of the high speed ships are operating in this region. In the case where the lower edge of the transom lies above the undisturbed free surface, the flow detaches at some point at the keel before reaching the stern.

From the three flow regimes described previously only the one with the dry transom can be successfully simulated in the potential flow model described in the preceding sections.

2.4.2 Transom conditions

In order to enforce the flow detachment at the transom edge some additional continuity conditions must be imposed at that point.

The first one is that the wave elevation just after the transom must be equal with the instantaneous transom depth.

$$\zeta_T = z_T \qquad \text{(2-27)}$$

The wave slope at the transom must be equal to the slope of the hull at the transom

(2-28) $$\frac{\partial \zeta_T}{\partial x} = \frac{\partial z_T}{\partial x}$$

(2-29) $$\frac{\partial \zeta_T}{\partial y} = \frac{\partial z_T}{\partial y}$$

Finally, the velocity potential at the transom, φ_T, and its normal derivative, $\frac{\partial \varphi_T}{\partial n}$, should be equal on the body and in the free surface wake.

2.5 Winglets on Monohull Designs

The potential benefit in seakeeping performance from the addition of foils or winglets on advanced high-speed marine vehicles is currently an area of research. In the following section the principal properties of a method to include such appendages in calculation of seakeeping characteristics of a ship, will briefly reviewed. Further details may be found in Sclavounos and Huang [15].

2.5.1 Heave and Pitch motions in Regular Waves

Assume a ship which advances with speed, U, in unidirectional harmonic waves of amplitude A, absolute frequency, ω_o, and heading β relative to the positive x-axis taken to coincide with the intersection of the ship's center plane with the calm water surface. The apparent frequency of the waves, known as the encounter frequency, is defined by:

(2-30) $$\omega = \left| \omega_o - \frac{\omega_o^2}{g} U \cos\beta \right|$$

In response to the ambient waves the ship will undergo an oscillatory motion in all six degrees of freedom. From those, the surge, heave and pitch motions are strongly coupled. By introducing the complex notation the three time harmonic quantities can be defined as follows:

$$\xi_1 = \Re\{\Xi_1 e^{i\omega t}\} \tag{2-31}$$

$$\xi_3 = \Re\{\Xi_3 e^{i\omega t}\} \tag{2-32}$$

$$\xi_5 = \Re\{\Xi_5 e^{i\omega t}\} \tag{2-33}$$

where Ξ_j, are the complex surge-heave-pitch amplitudes, governed by the coupled system of equations:

$$(M_{11} + A_{11})\ddot{\xi}_1 + B_{11}\dot{\xi}_1 + A_{13}\ddot{\xi}_3 + B_{13}\dot{\xi}_3 + (M_{15} + A_{15})\ddot{\xi}_5 + B_{15}\dot{\xi}_5 = x_1(t) \tag{2-34}$$

$$A_{31}\ddot{\xi}_1 + B_{31}\dot{\xi}_1 + (M_{33} + A_{33})\ddot{\xi}_3 + B_{33}\dot{\xi}_3 + A_{35}\ddot{\xi}_5 + B_{35}\dot{\xi}_5 + C_{35}\xi_5 = x_3(\mathrm{t}) \tag{2-35}$$

$$(M_{51} + A_{51})\ddot{\xi}_1 + B_{51}\dot{\xi}_1 + A_{53}\ddot{\xi}_3 + B_{53}\dot{\xi}_3 + C_{53}\xi_3 + (M_{55} + A_{55})\ddot{\xi}_5 + B_{55}\dot{\xi}_5 = x_5(t) \tag{2-36}$$

where M_{ij} is the ship inertia matrix, $A_{ij,}$, B_{ij} , are the hydrodynamic added mass and damping matrices, and C_{ij} is the hydrostatic restoring matrix. The complex vector Xj denotes the complex amplitude of the hydrodynamic exciting forces.

$$x_1(t) = \Re\{X_1 e^{i\omega t}\} \tag{2-37}$$

$$x_3(t) = \Re\{X_3 e^{i\omega t}\} \tag{2-38}$$

$$x_5(t) = \Re\{X_5 e^{i\omega t}\} \tag{2-39}$$

2.5.2 Winglet interaction with the hull

Foils or winglets mounted on the ship hull will alter its seakeeping properties. The dominant aspects of this interaction come from the oscillatory motion of the hull and the ambient wave orbital speed.

Figure 2.5.2-1 illustrates a ship moving at constant speed U, in regular waves of absolute frequency ω_0, and heading β relative to the positive x-axis taken to coincide with the intersection of the ship center plane with the calm water surface. A winglet is mounted on the ship's hull at a draft z_W, and offsets longitudinally and transversely by x_W and y_W respectively, relative to the origin of the Cartesian coordinate system (x,y,z), assumed to translate with the ship's mean forward speed U.

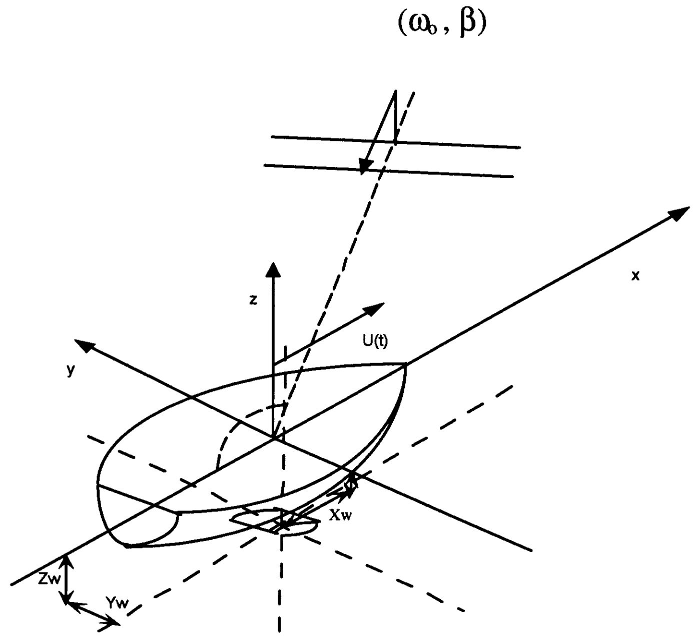


Figure 2.5.2-1: A ship with a winglet as appendage

The incident wave potential can be defined by the expression

(2-40)
$$\varphi = \Re\left\{ \frac{igA}{\omega_o} e^{kz - ikx\cos\beta - iky\sin\beta} \right\}$$

where k is the wavenumber and A the wave amplitude.

The winglet attached to the hull will alter the heave and pitch motions of the vessel due to the lift force it carries. The lift and thrust or drag acting on the winglet depend upon the heave and pitch instantaneous angles of attack. The heave angle of attack is defined by the following expression:

(2-41)
$$a_3(t) = \frac{V(t)}{U - u(t)} \approx \frac{V(t)}{U} = \Re\{\alpha_3 e^{i\omega t}\}$$

where

(2-42) $$V(t) = -\dot{\xi}_3(t) + v(t)$$

and (u,v) is the ambient wave field velocity vector at the position of the winglet. The vertical inflow velocity v(t) at the position of the winglet is given by:

(2-43) $$\varphi = \Re\left\{i\omega_o A e^{kz - ikx_W \cos\beta - iky_W \sin\beta}\right\}$$

The pitch angle of attack arises simply by the pitch oscillation of the hull, and is defined by the following expression:

(2-44) $$a_5 = -\dot{\xi}_5(t) = \Re\left\{\alpha_5 e^{i\omega t}\right\}$$

It is assumed that the radiation and diffraction wave disturbances do not alter appreciably the inflow velocity to the winglet mounded on the hull. This assumption is valid for high aspect ratio winglets mounted on the hull or for a foil mounted between the two hulls of a catamaran.

From the three modes of motion which are coupled by the equations (2-34) - (2-36), the surge may be ignored due to the weak coupling with the heave and pitch. By including the winglet interaction with the hull, a new set of damping, restoring coefficients and exciting forces can be defined (Reference [15]):

(2-45) $$B_{33}^{w} = B_{33} + \frac{1}{U} f$$

(2-46) $$B_{35}^{w} = B_{35} - \frac{x_w}{U} f$$

(2-47) $$B_{53}^{w} = B_{53} - \frac{x_w}{U} f$$

(2-48) $$B_{55}^{w} = B_{55} - \frac{x_w^2}{U} f$$

(2-49) $$C_{33}^{w} = C_{33}$$

(2-50) $$C_{35}^{w} = C_{35} + f$$

(2-51) $$C_{53}^{w} = C_{53}$$

(2-52) $$C_{55}^{w} = C_{55} - x_w f$$

(2-53) $$X_3^{w} = X_3 + \frac{i\omega_o}{U} e^{-kz_w - ikx_w \cos\beta - iky_w \sin\beta} f$$

(2-54) $$X_5^{w} = X_5 - \frac{i\omega_o}{U} x_w e^{-kz_w - ikx_w \cos\beta - iky_w \sin\beta} f$$

where $$f = \frac{\pi \rho U^2 S}{1 + \frac{2}{A}}$$

and A is the aspect ratio and S the planform area of the winglet.

The winglet added mass is proportional to its planform area and is therefore negligible compared to that of the ship's hull. In contrast, the lift force is proportional to the square of the ship forward speed and contributes an important correction to the damping and restoring coefficients and exciting forces. An important parameter in the previous expressions is the longitudinal position of the winglet or foil, x_w, which contributes appreciably to the magnitude of the coefficients, allowing the designer some latitude to select.

Chapter 3

3 Multihull Designs

3.1 Catamaran designs

The increasing demand of fast sea transportation in recent years has boosted the interest in unconventional ship designs, which could possibly reduce the problem with high fuel consumption, inevitably linked to the higher speeds of conventional hull designs. An interesting possibility is the catamaran. In recent years catamarans have been established as the leading commercial high-speed marine vehicle.

For commercial catamaran operation, the objective is to maintain an efficient service schedule in all weather conditions. High-speed allows the operator to complete more round trips, thereby increasing revenues. Catamarans possess good transport efficiency at moderately high speeds in comparison to other high-speed designs. Their slender demi-hulls present a relatively small residuary resistance, which is the dominant component of resistance in high speeds. They also offer the following desirable design characteristics:

- Large deck area
- High transverse stability
- Shallow draught
- Compared to monohulls more flexibility in hullform design

While catamarans have good resistance characteristics at high displacement and semi-planing speeds, they have poor performance at low speeds due to high frictional resistance generated by the relatively larger wetted surface area.

3.1.1 Catamaran hull forms tested

For the purposes of this study, three demi-hull forms were considered. Each one exhibits realistic geometrical complexities found in real catamaran designs (i.e. transom sterns). The first two demi-hull designs were intentionally selected to exhibit the same length to beam and length to maximum draft ratios. In addition the two designs share the same offsets from bow to midships.

However, the after part of the demi-hulls is quite different in the two designs. The first design exhibits a shallow transom, and thus named "shallow transom" design, and the second one a deep transom, and thus named "deep transom" design. Because of the sharing aforementioned ratios, the two designs also share the same transom beam to length ratio. However, the transom depth to length ratio is bigger in the case of the "deep transom" design. The purpose of the selection of these two designs is to investigate the effects of transom geometry on the resistance and seakeeping performance of the catamaran designs.

In addition to the different demi-hull design, the separation between the demi-hulls was also considered as a variable. The extent of the interaction between the hulls for different separation to length ratios and the effects on the resistance and the seakeeping performance, is also a point of investigation in this study. Specifically, three distinct separations ratios were considered, S/L=0.2, 0.4, infinite. The last one is not a realistic catamaran design. However, it provides an insight to the resistance and seakeeping performance assuming no interaction between the demi-hulls. Such results can be used as a reference point to determine the extent of positive or negative interaction between the demi-hulls in realistic separation ratios.

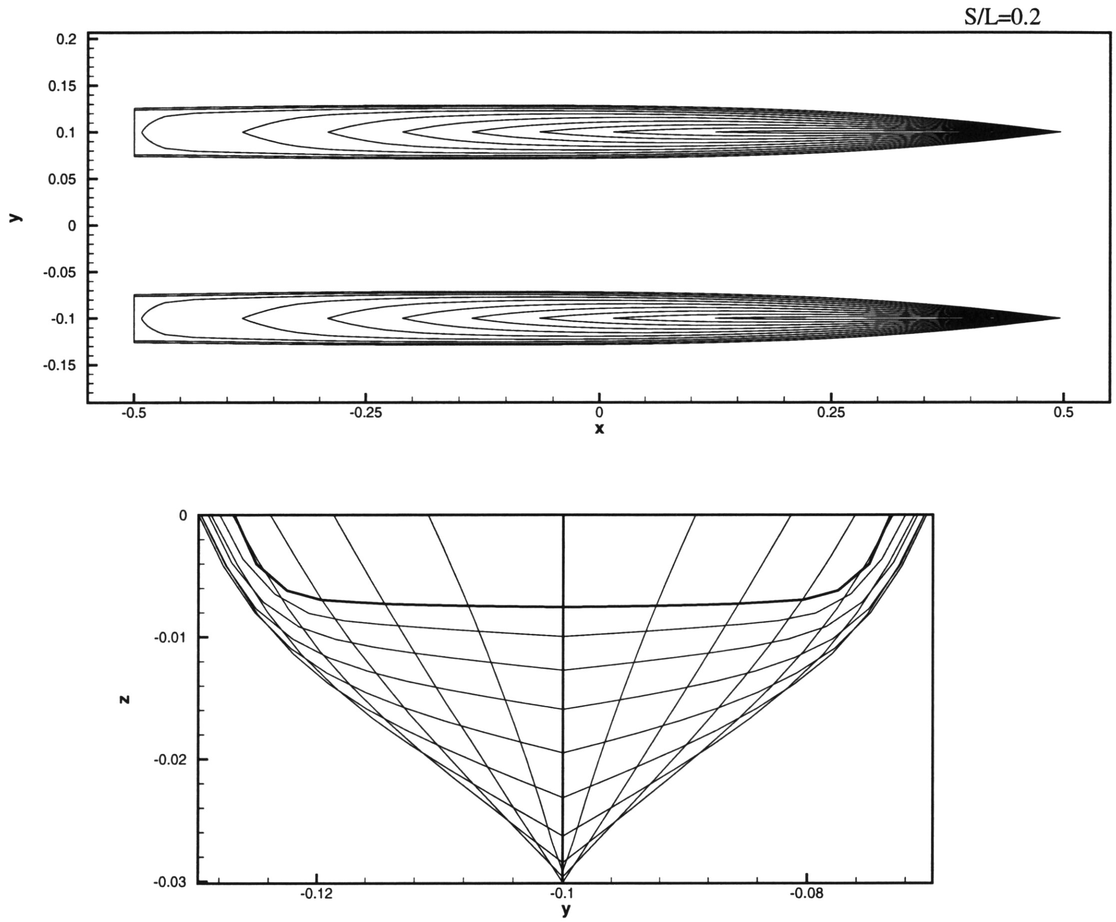


Figure 3.1.1-1: Waterlines and body plan of the demi-hulls for the "shallow transom" catamaran. All the dimensions are normalized by the LBP of the design.

Figure 3.1.1-1 includes the waterlines and the body plan of the demi-hulls used in the "shallow transom" catamaran design. Both drawings indicate the hull below the design waterline. The wide shallow transom is clearly indicated by the thick line in the body plan. All the dimensions are normalized by the waterline length of each demi-hull. A separation ratio of S/L=0.2 was used, in the waterline drawing.

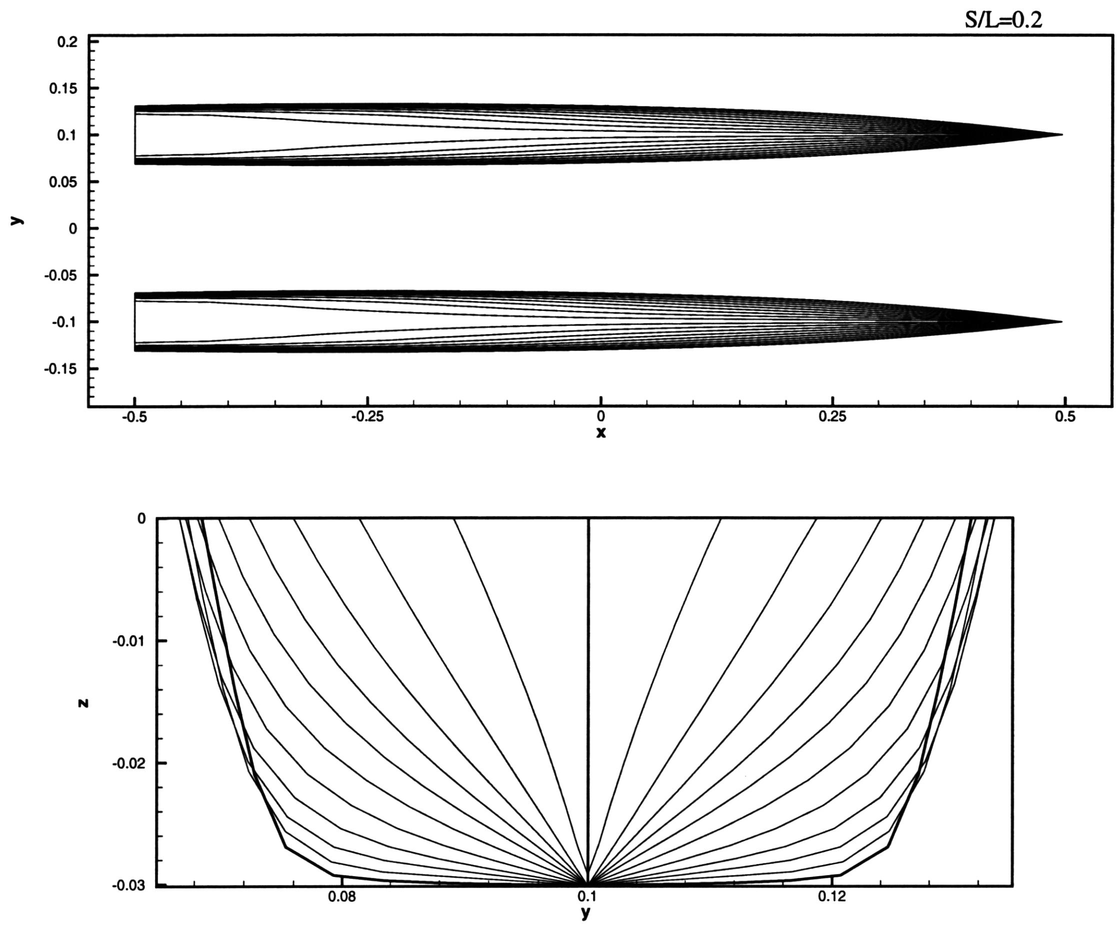


Figure 3.1.1-2: Waterlines and body plan of the demi-hulls for the "deep transom" catamaran. All the dimensions are normalized by the LBP of the design.

Figure 3.1.1-2 includes the waterlines and the body plan of the demi-hulls used in the "deep transom" catamaran design. The deep transom is clearly shown by the thick line in the body plan. By comparing the two previous figures the differences in the after part of the demi-hull's design can be easily identified.

Despite sharing geometrical analogies, the different after body of the demi-hulls results in a much larger displacement for the case of the deep transom catamaran, since the two designs have the same waterline length.

A third catamaran design was created for direct comparison with a high-speed monohull design, TGN770 (*FastShip*). The design was created by separating the port and starboard side of the TGN770 hull. As a result two asymmetric side hulls were created.

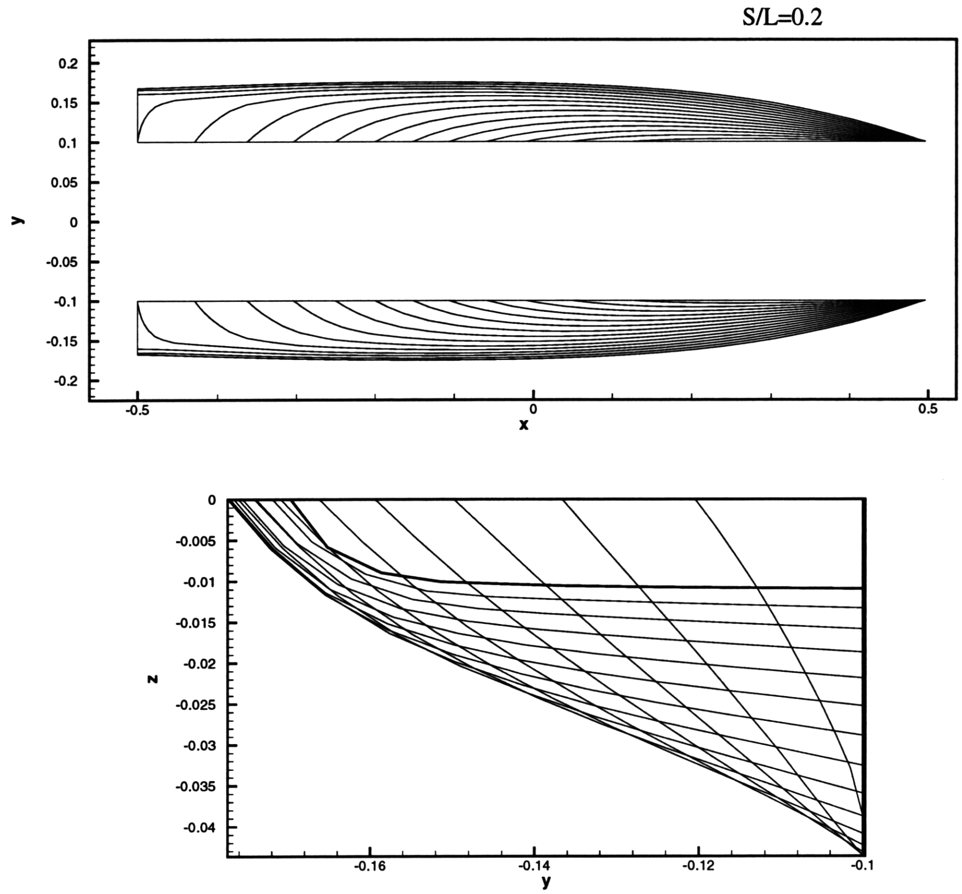


Figure 3.1.1-3: Waterlines and body plan of the demi-hulls for the "Asymmetric demi-hull" catamaran. All the dimensions are normalized by the LBP of the design.

Figure 3.1.1-3 includes the waterlines and the body plan of the demi-hulls used in the "asymmetric demi-hull" design. One separation ratio (S/L=0.2) was used for that design. Both monohull (TGN770) and catamaran designs share the same geometrical analogies (i.e. same total transom area, same displacement and same maximum depth to length ratio). However, the catamaran design exhibits more wetted surface area, due to the additional wetted surface of the inner sides of the demi-hulls. The beam to length ratio of each demi-hull is half of the one of TGN770's hull. The slenderness of the demi-hulls positively affects the resistance. However, the interaction between the demi-hulls will also alter the resistance and seakeeping properties of the catamaran design compared with those of the monohull design.

PRINCIPAL CHARACTERISTICS FOR TGN770 AND THE CATAMARAN VARIANTS

Principal particulars					
	TGN770		"Asymetric demi-hull" Catamaran	"Shallow transom" catamaran	"Deep transom" catamaran
Condition	1/2 load(of fuel)	Full load	Full load	Full load	Full load
L=LWL (m)	229	229	240.1	296.6	246.4
B_m (m)	40	40	37.0	35.2	32.8
T (m)	10.2	10.44	10.5	8.9	7.4
T design (m)	10	10			
Displacement (m^3)	31,220	33,500	33,500	33,500	33,500
C_B (design)	0.38	0.38			
S_{wet} (m^2)	7,970	8,353	12,092	12,227	10,398
Weight (mtonnes)	32,030	34,370			
LCG (m)	-5	-6.5	-4.2	-5.2	-31.3
VCG (m)	7	7	10.5	8.9	7.4
Roll radius of gyration (m)	14	12.7	12.0	14.8	12.3
Pitch & Yaw RG (m)	67.2	64.6	60.0	74.1	61.6
Dimensionless characteristics					
B_m/L	0.175	0.175	0.154	0.1188	0.1333
T/L	4.454E-02	4.560E-02	4.36E-02	0.03016	0.03016
Tdes/L	4.367E-02	4.367E-02			
Disp/L^3	2.600E-03	2.790E-03	2.42E-03	1.28E-03	2.24E-03
S_{wet}/L^2	1.52E-01	1.59E-01	2.10E-01	1.39E-01	1.71E-01
LCG/L	2.18%	2.84%	1.76%	1.76%	12.72%
VCG/L	3.06%	3.06%	0.00%	0.00%	0.00%
Roll RG/L	6.11%	5.55%	5.00%	5.00%	5.00%
Pitch & Yaw RG/L	29.34%	28.21%	25.00%	25.00%	25.00%

Table 3-1: Principal characteristics for the catamaran designs and the TGN770 monohull

Table 3-1 includes the normalized principal characteristics of each catamaran variant, as well as, those of the monohull TGN770 hull. The same table also includes the full-scale characteristics of *FastShip*. The catamaran variants were scaled up to exhibit the same displacement as the one of *FastShip*. The resulting full-scale characteristics are included in the same table.

The “shallow transom” design exhibits the lower non-dimensional displacement. As a result the full-scale length of the design is the bigger compared with the ones of the other designs.

3.2 Trimaran hull

An interesting proposal for the solution to the problem related to high fuel consumption linked to the high speed of conventional ships, is also the trimaran design. By making the main hull very slender the increase in the wave resistance at higher speeds can be kept within reasonable limits. The required stability can be obtained from side-hulls, which can be relatively small and slender, thus producing little resistance. A certain increase in the total wetted surface is unavoidable causing less favorable fuel economy at lower speeds, but considerable potential gains at sufficiently high speeds is possible.

One point of interest is the interference effect between the main hull and the side-hulls. By proper positioning of the side hulls a considerable wave reduction may be possible, resulting in lower wave resistance.

Other advantages of the trimaran hulls are the large deck area and the increased stability, intact and damaged. This has made the concept interesting both for naval applications, especially aircraft carriers, and civil transportation, where the wide and square decks facilitate Ro-Ro concept.

3.2.1 Trimaran hull evaluated

A trimaran hull configuration was also evaluated for resistance and seakeeping performance. The main hull of the design was generated by using the offsets of the deep transom demi-hull described in the preceding sections, giving extra displacement (compared with the shallow transom design) which is essential for slender trimaran designs. A 12.5 length to beam ratio was used to make the main hull slender. The maximum depth was set to 3% of the waterline length of the main hull.

Modified Wigley hulls were used as side hulls for the trimaran design. The modified Wigley hull is a mathematical hull and the offsets are given by the following parametric equation:

(3-1) $$\frac{2y}{B}=\left[1-\left(\frac{2x}{L}\right)^2\right]\left[1-\left(\frac{z}{T}\right)^2\right]\left[1+\left(\frac{2x}{L}\right)^2\right]+\left(\frac{z}{T}\right)^2\left[1-\left(\frac{2x}{L}\right)^2\right]^4\left[1-\left(\frac{z}{T}\right)^8\right]$$

where B is the maximum beam, L is the waterline length and D is the maximum draft.

The length of each side hull was fixed to be 30% of the waterline length of the main hull. The length to maximum beam ratio was set to 15 to increase the slenderness of the side hulls compared with one of the main hull. The maximum depth of the side hulls was adjusted to 2.5% of the main hull waterline length, slightly smaller than the main hull depth. The side hulls were offset by 20% of the main hull length longitudinally, with respect to the origin at the center of the main hull. Finally, the side hulls were offset transversely by 13% of the main hull length.

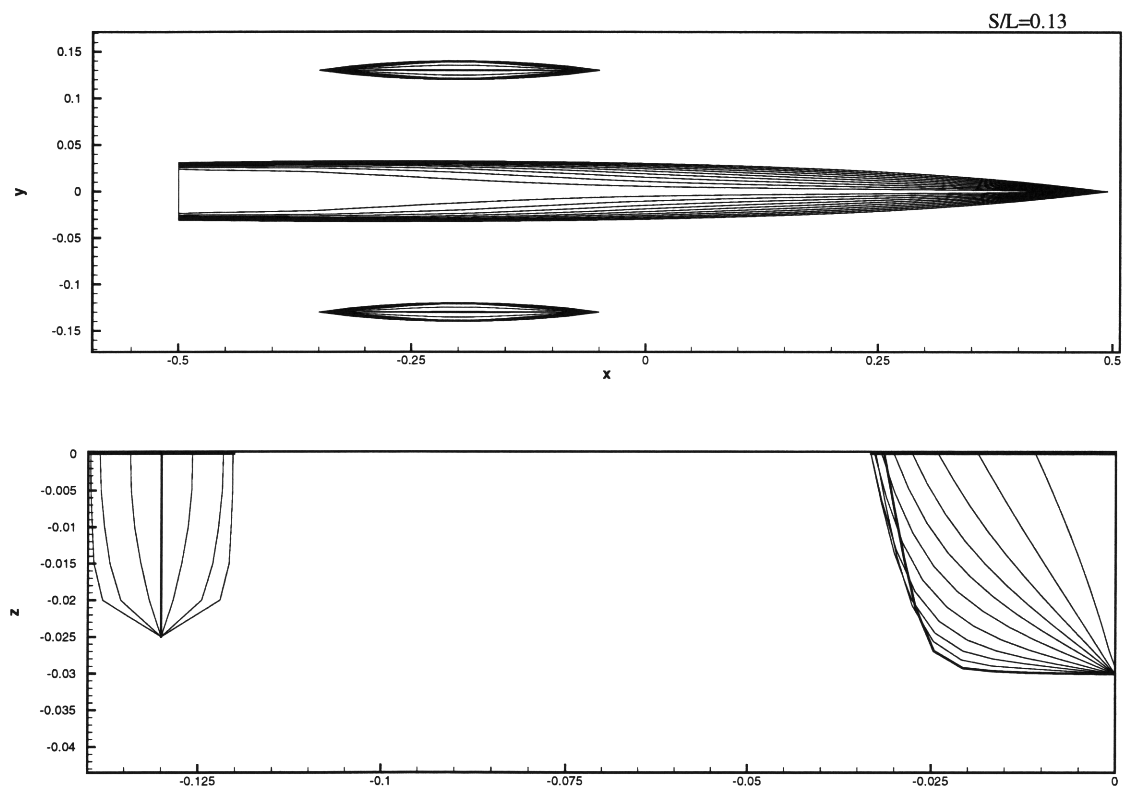


Figure 3.2.1-1: Waterlines and body plan of main hull and side-hulls of the trimaran design. All the dimensions are normalized by the LBP of the design.

Figure 3.2.1-1 includes the waterlines and the body plan of the trimaran design used for the evaluation. The location of the side hulls is clearly indicated in the waterline drawing.

Chapter 4

4 Steady Problem

4.1 Introduction

A time-domain Rankine source panel method code, SWAN-2 (Ship Wave Analysis) was used for the evaluation of the catamaran and trimaran designs presented in the Chapter 3. Both calm water resistance and seakeeping computations were completed.

Advanced marine vehicles such as catamarans and trimarans designs possess several characteristics, which are quite different than conventional ships and as such present new technical challenges. The technical challenges for such vessels include operations at high speed, as well as, geometrical complexities such as transom sterns and multiple hulls. The experimental data available for these kinds of vessels is limited and typically proprietary.

Numerical modeling techniques are new, easy, and robust methods of evaluating the performance of this kind of vessels, and as such are invaluable to a designer.

4.2 Catamaran designs

The time-domain version of SWAN was used for the prediction of steady wave patterns and calm water resistance. The extent of the interaction between demi-hulls were examined for typical high-speed catamarans. Calculations were carried out for two different catamaran designs for various forward speeds and separations between the hulls. Three different separation ratios were considered, specifically, S/L=0.2, 0.4 and infinity. The last one represents a catamaran design with no interaction between the demi-hulls. In essence, the resistance of such a fictional design is two times the resistance of each demi-hull.

A catamaran design with asymmetric hulls was also evaluated for calm water resistance in various speeds. The Froude number for the calculations ranged from 0.4 to 0.8.

The demi-hulls of the two first catamaran designs have a length to beam ratio of 12.5. The difference between the two designs is the transom geometry. Specifically, the first design has a low B_T/D_T and the second one a high B_T/D_T, where B_T and D_T are the waterline beam and draft at the transom respectively. Assuming both designs have the same beam at the transoms, we can define the first one as "deep transom" catamaran and the second one as "shallow transom" catamaran. Finally, for the catamaran with the asymmetric hulls a lower length to beam ratio is used (L/B=11.4). Detailed characteristics of the designs can be found in Chapter 3.

4.2.1 Wave patterns predictions

The steady wave patterns due to the different catamaran hull forms and separations were predicted for a wide range of Froude numbers. Some of the calculated wave patterns predictions are included in the following figures.

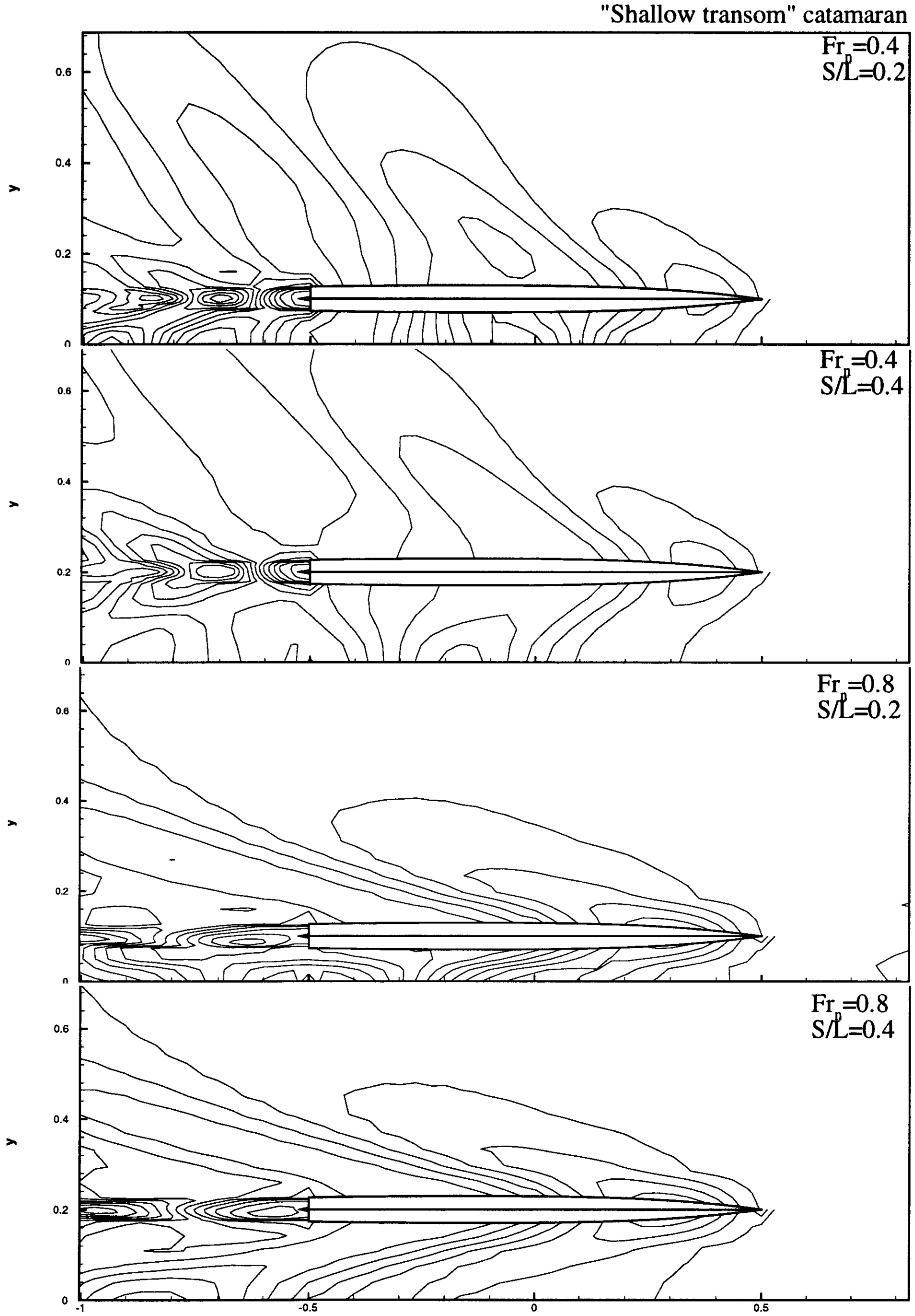


Figure 4.2.1-1: Contour plots for the wave elevation for the "shallow transom" catamaran for two different Fr_n and separation ratios (S/L)

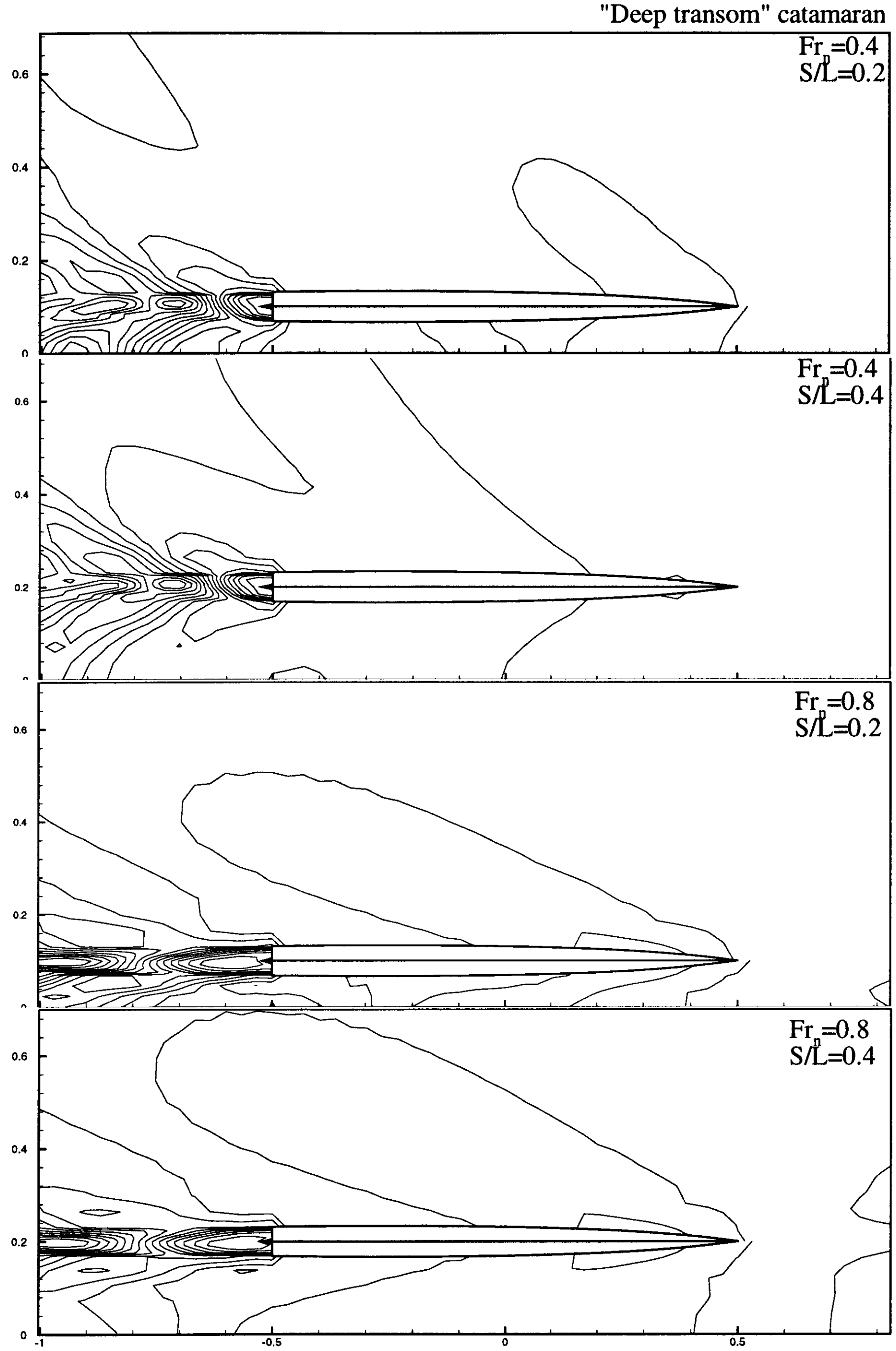


Figure 4.2.1-2: Contour plots for the wave elevation for the "deep transom" catamaran for two different Fr_n and separation ratios (S/L)

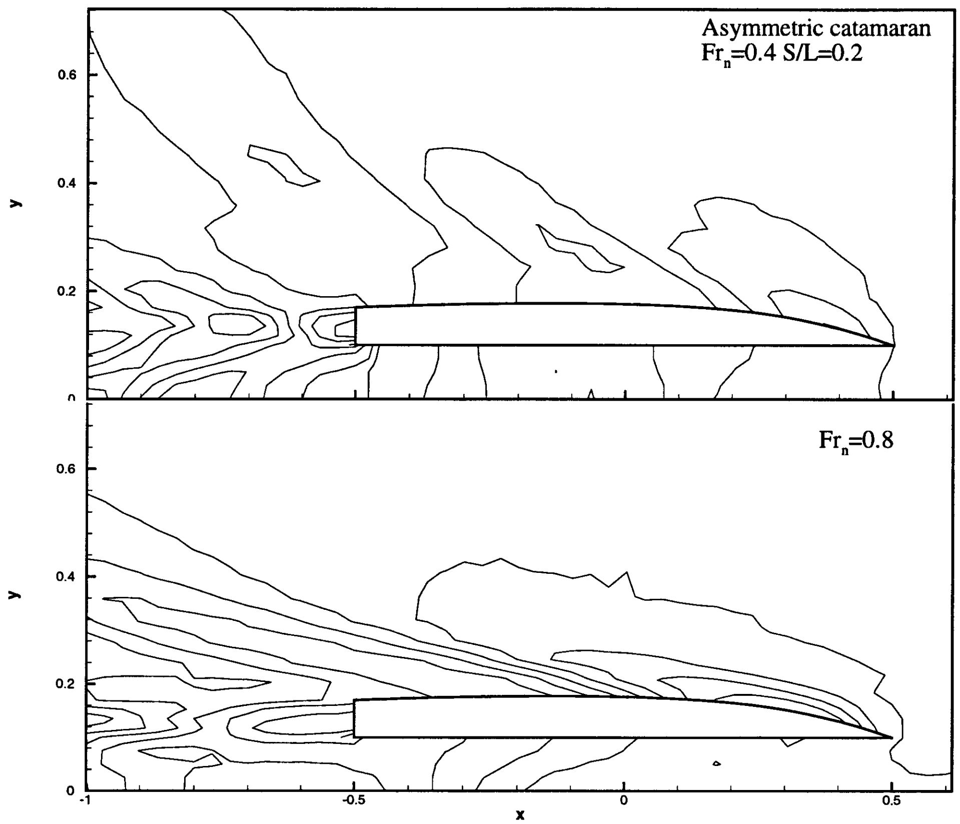


Figure 4.2.1-3: Contour plots for the wave elevation for the "asymmetric demi-hull" catamaran for two different Fr_n.

The flow around each demi-hull is asymmetric due to the interference from the other demi-hull. The interference increases as the separation decreases. For the correct modeling of the flow behind the catamaran a trailing vortex sheet was used. The vortex sheet models the wake behind the catamaran restricts the flow so that the velocity at the trailing edge of each demi-hull is finite.

Figure 4.2.1-4 includes 3-D snapshots of the wave patterns calculated by SWAN-2 for the "shallow transom" catamaran for Froude numbers of 0.4, 0.6 and 0.8. The smooth wave pattern even at high speeds verifies the correct modeling of the demi-hulls as lifting surfaces in the numerical method. The wave pattern in all the speeds fall within the Kelvin sector. However, there is a clear transfer of energy from transverse to divergent waves as the speed increases.

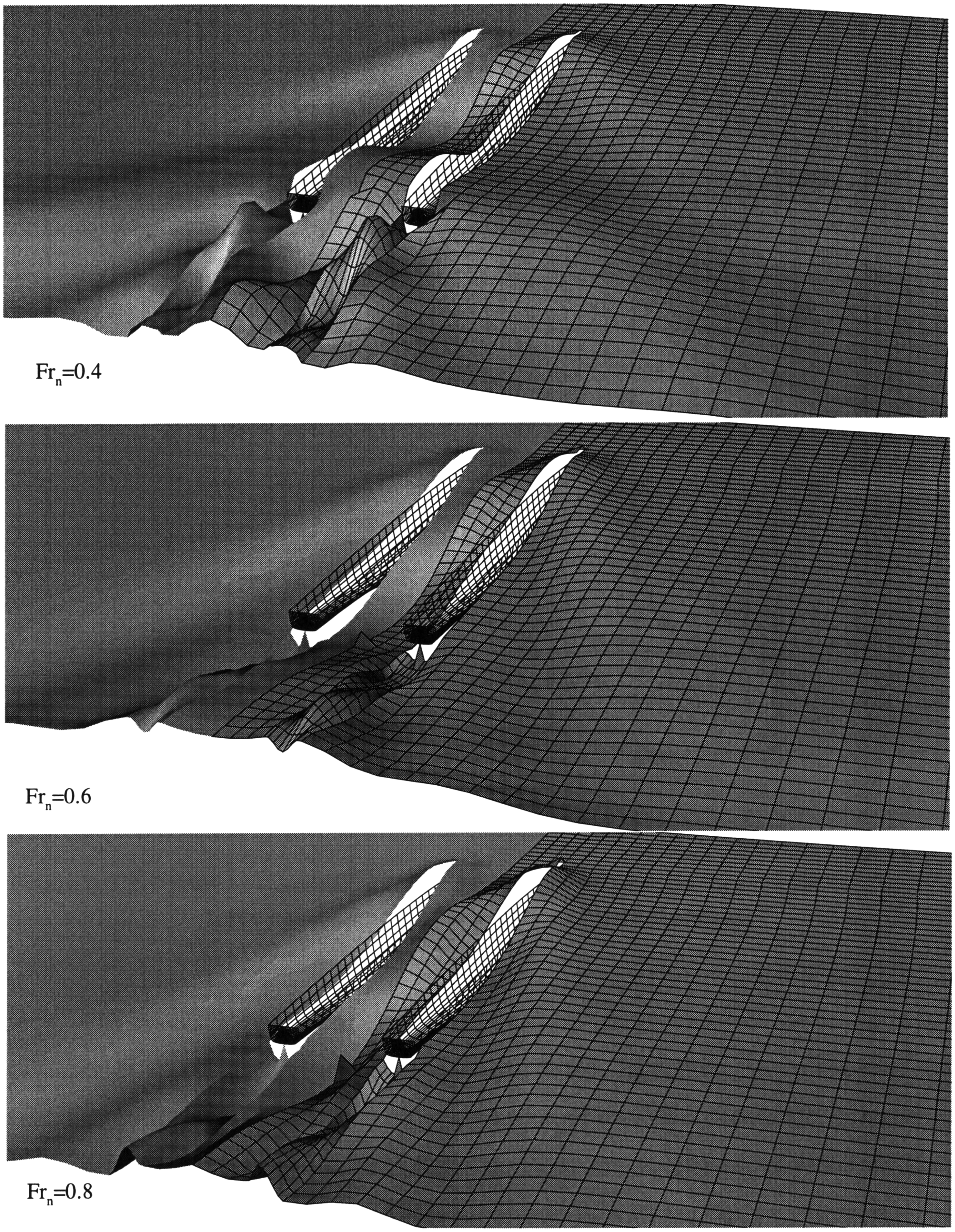


Figure 4.2.1-4: The calm water wave pattern of the "shallow transom" catamaran (S/L=0.2) for Fr_n=0.4, 0.6, and 0.8

4.2.2 Calm water wave resistance

The SWAN-2 predictions of the wave resistance coefficient of the three catamaran designs are illustrated in Figure 4.2.2-1. The waterline terms and the additional resistance caused by the dry transom were not included in this figure.

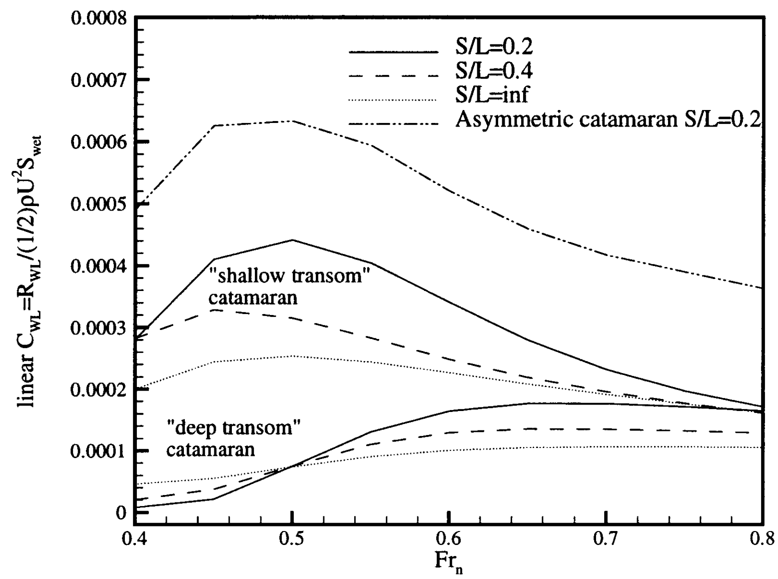


Figure 4.2.2-1 : SWAN-2 predictions for calm water wave resistance coefficient for the three catamaran designs in various forward speeds

The results indicate that the "deep transom" catamaran has the lower wave resistance in the range of the Froude numbers tested. In addition a variation of the resistance coefficient can be observed as a function of demi-hull separation. In general, as the separation between the demi-hulls increases the coefficient is reduced. That indicates a "negative" interaction between the demi-hulls of the designs. However, for the "deep transom" design the results indicate a "positive" interaction between the demi-hulls for Froude numbers lower than 0.5.

Figure 4.2.2-2 plots the calm water wave resistance coefficients including the waterline terms, and the dry transom cavity drag, for the three catamaran designs. The waterline terms are generated by the wave elevation around the hull. For the dry transom condition to be included, an additional hydrostatic term, cavity drag, must be added to the wave resistance.

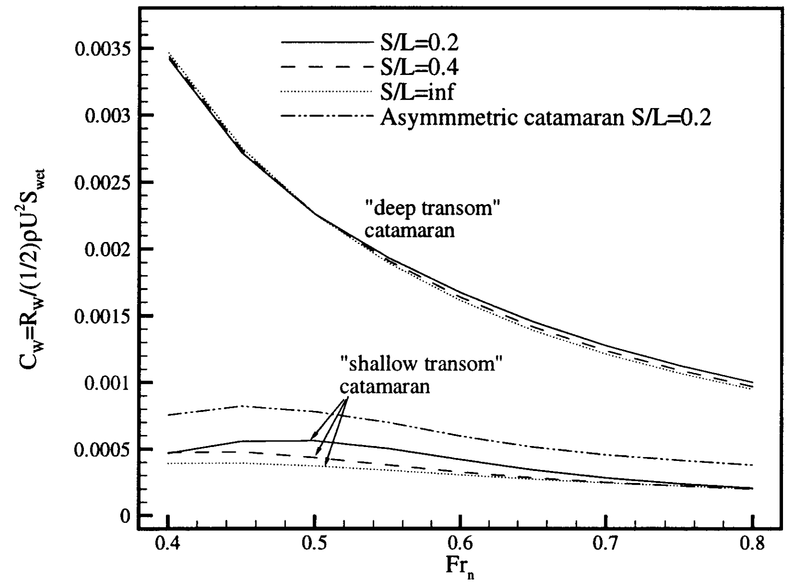


Figure 4.2.2-2: SWAN-2 predictions for calm water wave resistance coefficients, including waterline terms and dry transom cavity drag, as a function of Froude number and the separation between hulls for the three catamaran designs

The resulting linear first order wave resistance in Figure 4.2.2-1, gives the advantage to the "deep transom" design. However, this is not the case in Figure 4.2.2-2. The large cavity drag generated by the deep transom is dominant. Consequently, the wave resistance of this design becomes significantly larger than the ones of the other two designs. Moreover, the separation between the demi-hulls for the same design has a minimal effect on the wave resistance coefficient.

However, this is not the case for the "shallow transom" catamaran, where the same hydrostatic term seems to be comparable in magnitude with the linear term, resulting in larger wave resistance coefficient for lower separation ratios (S/L). The resistance results for the asymmetric demi-hull design fall between the other two designs, being closer to the “shallow transom” variant. The transom of this design is geometrically similar with the “shallow transom” catamaran, and this supports the resistance results.

4.2.3 Residuary resistance

For the purpose of calculating the residuary resistance coefficient of the previous design lifting effects must also be included in the calculation. The lifting effects appear on ships with transoms at high speeds, resulting in the generation of induced drag. This part of the resistance is a function of the geometry of the transom, and was neglected in the previous calculations.

There is no easy way of calculating the induced drag, and the only way to estimate it is by subtracting the wave resistance coefficient from the residual resistance coefficient, given from experimental results.

Because of limited experimental results, the same induced drag coefficient was used for all the designs. This component of resistance depends upon the shape of the transom stern, which is similar between *FastShip* and the shallow transom catamaran. Therefor, their induced resistance is likely to be the same. It was derived from experimental data for the *FastShip (TGN770)*. *FastShip* is the monohull design optimized to run at 0.435 Froude number and has a geometrically similar transom with the ones used in the catamaran designs.

Figure 4.2.3-1 plots the result for the estimated residual resistance coefficient for various Froude numbers. The same figure also plots the experimental residual resistance results for *TGN770* hull for comparison. The experimental results were obtained from tank testing at SSPA and cover only a small portion of the considered Froude number range.

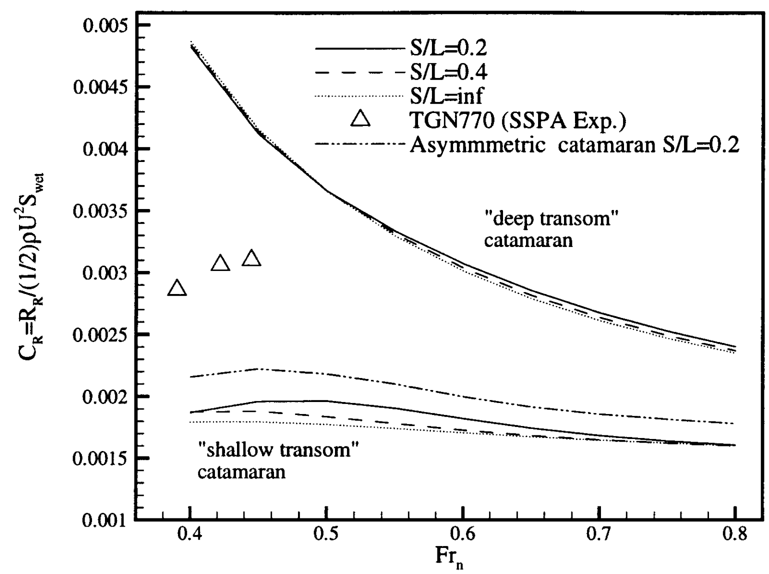


Figure 4.2.3-1: Residual resistance coefficient predictions as a function of Froude number and the separation between hulls for the three catamaran designs. Experimental data are also given for TGN770 hull.

The interaction effects between the demi-hulls are still observable in Figure 4.2.3-1, especially for the case of the "shallow transom" catamaran. However, even in the case of low separation between the demi-hulls this design exhibits the lowest residual resistance coefficients in the range of Froude numbers tested. The "asymmetric demi-hull" catamaran also performs well with coefficients slightly larger than those of the "shallow transom" design. Both designs are well below the SSPA experimental results for the TGN770 monohull.

4.2.4 Frictional Resistance

The following ITTC 57 expression was used for the calculation of frictional resistance of each design:

$$C_{fo} = \frac{0.075}{\left(\log_{10} \mathrm{Re} - 2.0\right)^2} \qquad (4\text{-}1)$$

where Re is the Reynold number and C_{fo}, the frictional resistance coefficient of a flat plate. The ratio between the real frictional coefficient $C_{f,\mathrm{Real}}$,and that of the flat plate, C_{fo}, defines the form factor coefficient.

(4-2) $$1+k=\frac{C_{f.\mathrm{Real}}}{C_{fo}}$$

The difference between the real frictional resistance and the flat plate frictional resistance is mainly due to the curvature of the hull. This curvature affects the pressure distribution along the length of the ship. A regression formula based on monohull designs was used to determine the form factor , *k*, of each design(Reference [1]) . For the previous calculations an effective beam was used for the catamaran designs (equal to two times the beam of each demi-hull), and the speed was assumed to be 40 Knots for all the variants. The resulting form factors are included in Table 4-1.

4.2.5 Total Calm Water Resistance

The purpose of this study is a direct comparison of the catamaran variants with the *FastShip* in the trans-Atlantic route. For that reason, the total effective resistance of the variants was calculated for a speed of 40 knots. The variants were scaled-up to have the same displacement as the *FastShip,* and thus the same weight. The assumption is that the catamarans with the same weight as the *FastShip* can have the same load capacity as the *FastShip.* The "shallow transom" catamaran was almost 300 m in length. Because of this large length this variant was actually running in lower Froude numbers that the others. The characteristics of *TGN770* hull in full load and half load (of fuel) condition are included in Table 4-1. The same table includes the characteristics of the catamaran designs using the aforementioned assumption.

PRINCIPAL CHARACTERISTICS AND RESISTANCE RESULTS FOR TGN770 AND CATAMARAN VARIANTS

Physical constants	g(m/sec)	(kg/m3)	(m2/sec)	Knot/(m/sec)
	9.81	1026	1.19E-06	0.5144
	kW/hp			
	0.7457			

Principal particulars					
	FastShip (TGN770)		**"asymmetric demi-hulls" Catamaran**	**"shallow transom" Catamaran**	**"deep transom" Catamaran**
Condition	**1/2 load(of fuel)**	**Full load**	**Full load**	**Full load**	**Full load**
L=LWL (m)	229	229	240.1	296.6	246.4
B_m (m)	40	40	37.0	35.2	32.8
T (m)	10.2	10.44	10.5	8.9	7.4
T design (m)	10	10			
Displacement (m^3)	31,220	33,500	33,500	33,500	33,500
C_B (design)	0.38	0.38			
S_{wet} (m^2)	7,970	8,353	12,092	12,227	10,398
Weight (mtonnes)	32,030	34,370			
LCG (m)	-5	-6.5	-4.2	-5.2	-31.3
VCG (m)	7	7	10.5	8.9	7.4
Roll radius of gyration (m)	14	12.7	12.0	14.8	12.3
Pitch & Yaw RG (m)	67.2	64.6	60.0	74.1	61.6
Dimensionless characteristics					
B_m/L	0.175	0.175	0.154	0.1188	0.1333
T/L	4.454E-02	4.560E-02	4.36E-02	0.03016	0.03016
Tdes/L	4.367E-02	4.367E-02			
$Disp/L^3$	2.600E-03	2.790E-03	2.42E-03	1.28E-03	2.24E-03
S_{wet}/L^2	1.52E-01	1.59E-01	2.10E-01	1.39E-01	1.71E-01
LCG/L	2.18%	2.84%	1.76%	1.76%	12.72%
VCG/L	3.06%	3.06%	0.00%	0.00%	0.00%
Roll RG/L	6.11%	5.55%	5.00%	5.00%	5.00%
Pitch & Yaw RG/L	29.34%	28.21%	25.00%	25.00%	25.00%

Resistance calculations		SSPA exper.	SWAN-2	SWAN-2	SWAN-2
Cruising speed (Knots)	40	40	40	40	40
Cruising speed (m/sec)	20.58	20.58	20.58	20.58	20.58
Fr_n	0.43	0.43	0.42	0.38	0.42
Re_n	3.96E+09	3.96E+09	4.15E+09	5.13E+09	4.26E+09
Wave resistance Coef. (from SWAN), C_w			7.50E-04	4.00E-04	2.60E-03
Induced drag coef. C_I			1.40E-03	1.40E-03	1.40E-03
Residual drag coef. C_R		3.10E-03	2.15E-03	1.80E-03	4.00E-03
Frictional Resistance coef. (ITTC) C_F			1.29E-03	1.26E-03	1.29E-03
Prismatic Coef. C_P			0.65	0.55	0.65
Lr/L			4.72E-01	5.88E-01	4.72E-01
form factor of bare hull k			0.16	0.12	0.10
$C_{F,REAL}$			1.50E-03	1.41E-03	1.42E-03
Total resistance coef. C_T		5.68E-03	3.65E-03	3.21E-03	5.42E-03
Resistance (kNt)		10,307	9,586	8,536	12,240
EHP		284,422	264,539	235,564	337,772
Power Gain		0%	6.99%	17.18%	-19%

Table 4-1: Principal characteristics and resistance calculations for FastShip and catamarans variants

The resulting effective resistance and effective power required are included in Table 4-1. Calculations were also made in the same table for the power gain/loss, by assuming the *FastShip's* resistance as the baseline value. For the calculations performed in the table, only the catamarans with separation ratio (S/L) of 0.2 were considered. The choice can be easy justified by Figure 4.2.3-1. In the range of the Froude numbers under consideration there is no considerable difference by selecting a different (feasible) separation ratio.

The results indicate that the "shallow transom" catamaran variant achieved a 17% lower resistance than the one exhibited by the baseline variant *(FastShip),* for the same speed of 40 knots. The "asymmetric demi-hull" variant also achieved a 7% lower resistance. Finally, the "deep transom" variant exhibits more resistance (19%).

4.3 Trimaran design

4.3.1 Wave pattern predictions

The time domain version of SWAN was used for the calculation of the steady wave patterns in various forward speeds for the trimaran design. The characteristics of the trimaran design were presented in the previous chapter. Figure 4.3.1-2 includes contour plots of the wave patterns predictions for the Froude numbers of 0.4, 0.6 and 0.8.

As in the case of the catamaran's demi-hull, the flow around the side hulls in trimaran designs is asymmetric. The asymmetry of the flow is due to the interaction of the inner surface of side hull and the main hull. For the correct formulation of the flow behind the side hulls a trailing vortex was used. The vortex sheets model the wake behind the side hull and restrict the flow ensuring that the velocity at the trailing edge of each side hull is finite.

Figure 4.3.1-2 includes 3-D snapshots of the steady wave patterns in the same Froude numbers. The deep transom of the main hull has a significant effect on the transverse waves generated in the wake. The wave patterns in all speeds fall within the Kelvin sector.

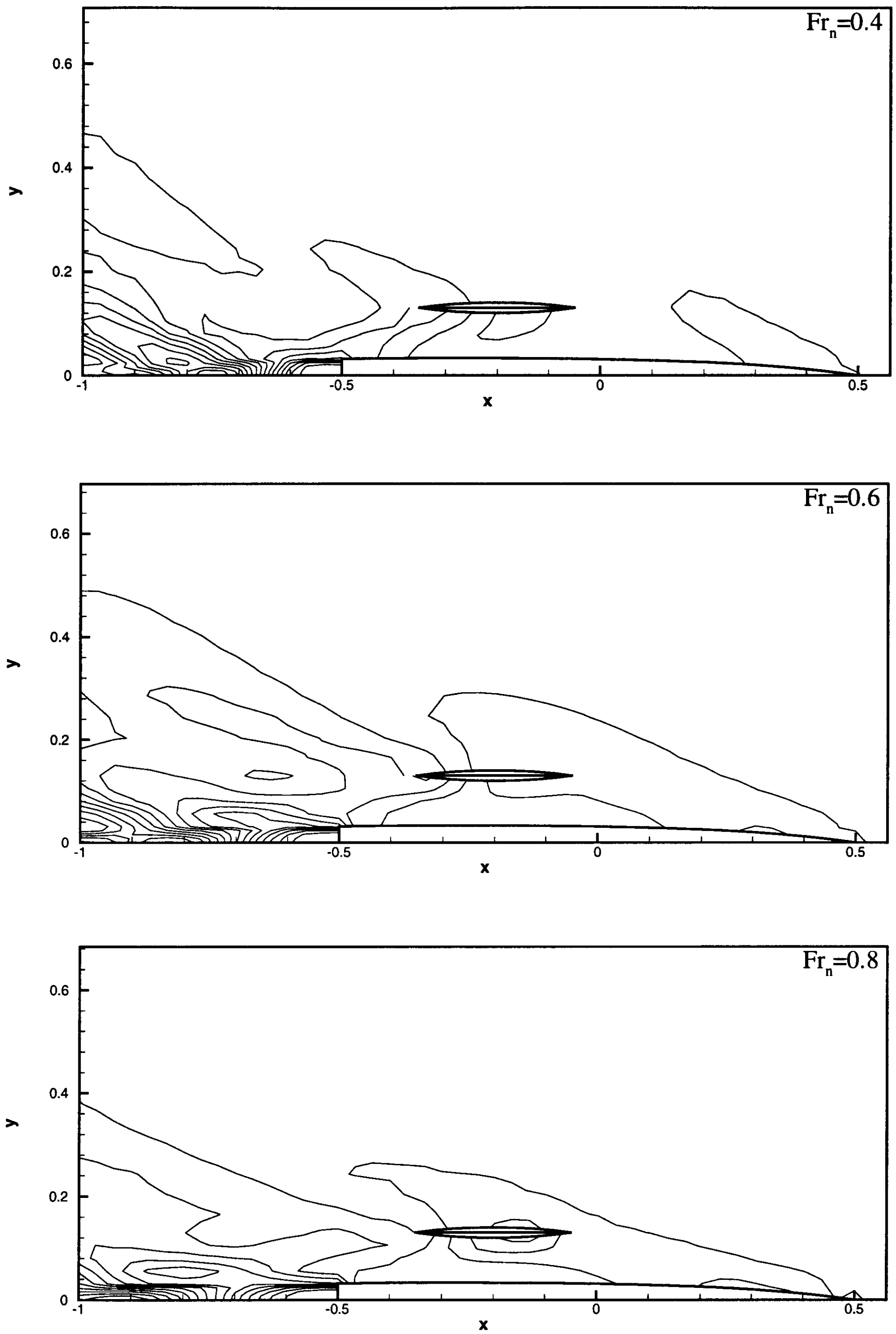
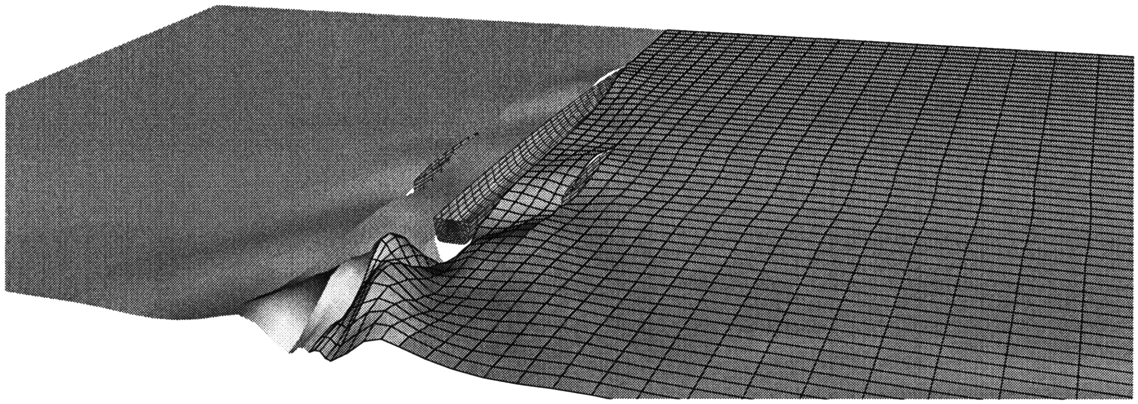
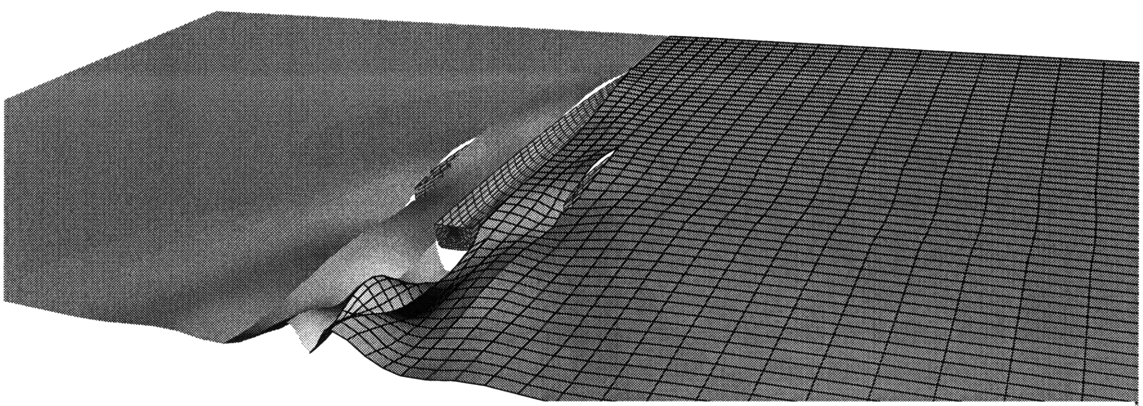


Figure 4.3.1-1: Contour plots for the wave elevation for the Trimaran design for Froude numbers 0.4, 0.6 and 0.8

$Fr_n=0.4$



$Fr_n=0.6$



$Fr_n=0.8$

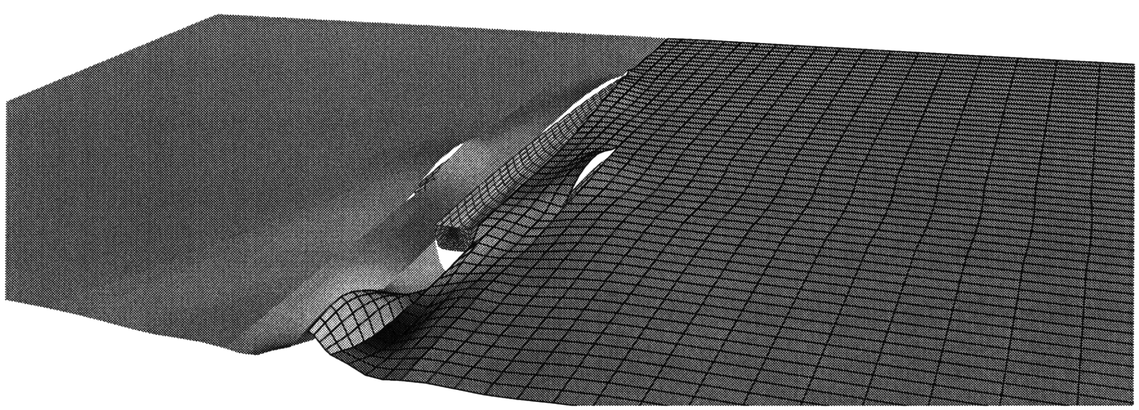


Figure 4.3.1-2: The calm water wave pattern of the trimaran design (S/L=0.13) for Fr_n=0.4, 0.6 and 0.8

4.3.2 Calm water wave resistance

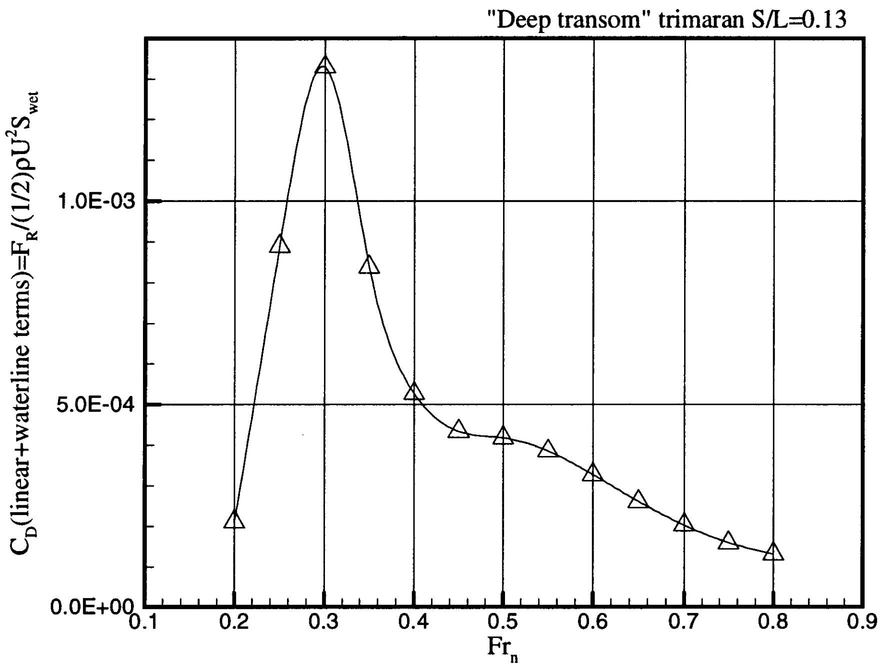


Figure 4.3.2-1: SWAN-2 calculated wave resistance coefficients including first order wave resistance and waterline terms for the trimaran design.

Figure 4.3.2-1 plots the SWAN-2 predictions for the trimaran's calm water wave resistance coefficient for a wide range of Froude numbers. The coefficients were calculated by using the linear first order theory and including the waterline terms.

The main hull of the trimaran design exhibits a deep transom. As in the case of the "deep transom" catamaran, that causes the dominance of the dry transom hydrostatic term over the other terms in the wave resistance coefficient. However, "dry transom" conditions occur whenever the transom Froude number (2-26) exceeds the value of 4.0 (Saunders [23]).

Chapter 5

5 Seakeeping Results

5.1 Introduction

The unsteady problem of motions in regular head seas is investigated next. The computations were made by using the time domain version of SWAN. Seakeeping computations were carried out in order to evaluate the effect of separation between the demi-hulls on the heave and pitch responses in regular head waves. For that reason, the "shallow transom" and the "deep transom" variant were used with various separation ratios (S/L), and forward speeds. A comparison between these two variants' responses also provides the effects of the transom geometry in the seakeeping properties of a catamaran design.

Seakeeping computations were also carried out for the "asymmetric demi-hull" catamaran with separation ratio of S/L=0.2 in various forward speeds, again in regular head waves. Finally, for comparative analysis reasons, the FastShip's *(TGN770)* heave and pitch responses were calculated by using the time-domain version of SWAN in regular head waves in various Froude numbers.

5.2 Catamaran designs

5.2.1 Heave and Pitch RAO's

The time-domain version of SWAN seakeeping computation proceeds along the following lines. The frequency dependent added mass and damping coefficients are derived from forced heave and pitch motion oscillations at a prescribed frequency, starting from rest at zero heave and pitch displacement. The resulting force records converge quickly to a harmonic signal, which upon Fourier analysis leads to heave and pitch hydrodynamic coefficients.

In time-domain, seakeeping simulations in a regular or random stationary wave record are carried out by assuming that the hull is kept fixed at its mean position for $t<0$ and is released at $t=0$. The resulting heave and pitch motion records indicate that convergence to a harmonic signal of constant amplitude and oscillation frequency occurs rapidly. The convergence properties of the heave and pitch motions are discussed in more detail in Kring, [18].

Figure 5.2.1-1 illustrates the SWAN-2 heave and pitch prediction for the "shallow transom" catamaran. The computations were made for three different high-speed Froude numbers (0.4, 0.6, 0.8) and three different separation ratios ($S/L=0.2$, 0.4, ∞). The resulting RAOs indicate a small dependence on heave motion to the separation between the demi-hulls of the variant. However, this not the case for the pitch motions, where there is a stronger dependence on the separation. This dependence is due to the interaction between the hulls, and as it is proved from the computation, the lower the separation, the lower the peak oscillation amplitude of pitch motions. This picture is consistent in the different Froude number computations illustrated in the same figure. Finally, the results indicate an aggravation of heave and pitch motions in higher Froude numbers.

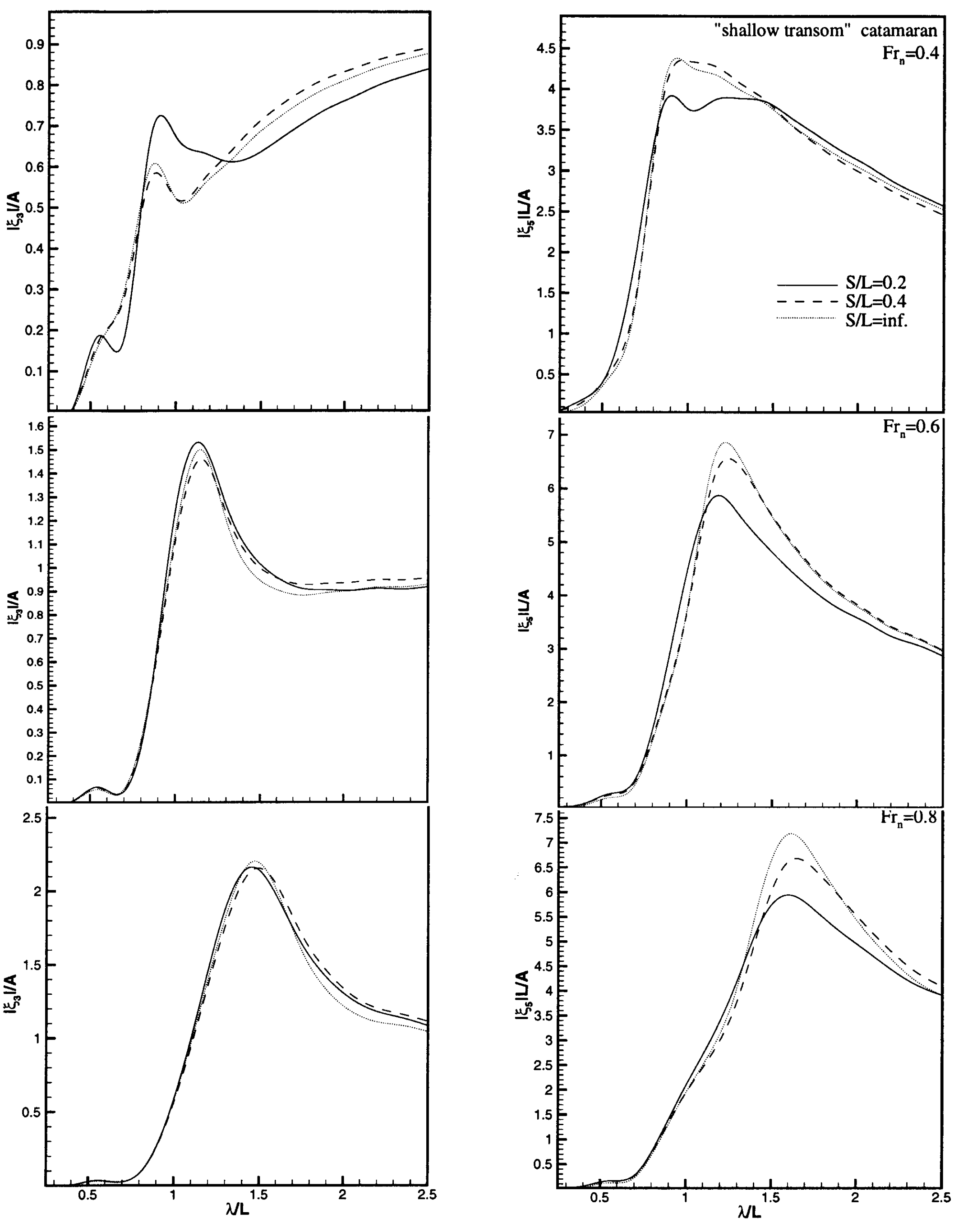


Figure 5.2.1-1: Comparison of RAO values for heave and pitch for the "shallow transom" catamaran at various separation ratios (S/L=0.2, 0.4, ∞) and Froude numbers (Fr_n =0.4, 0.6, 0.8)

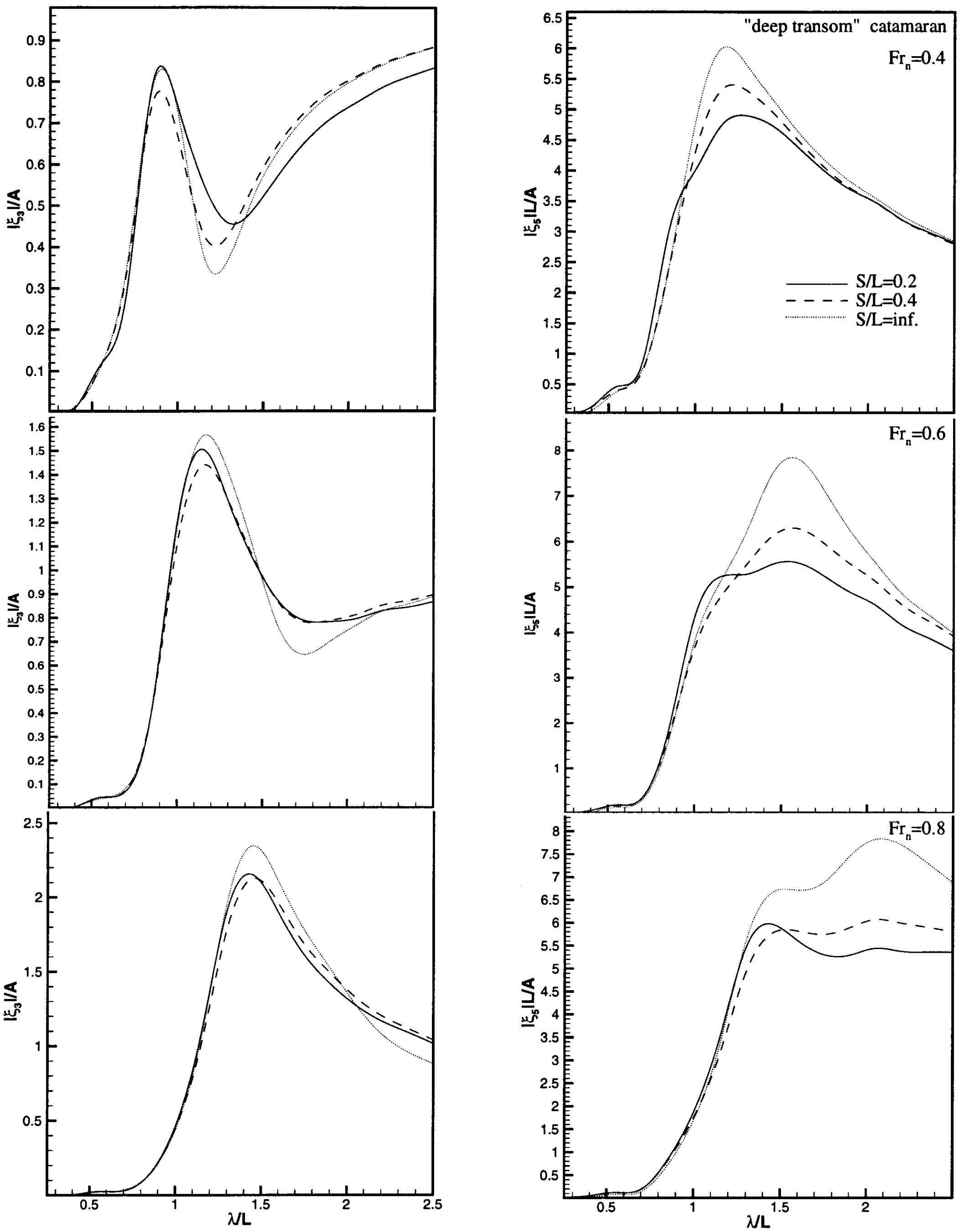


Figure 5.2.1-2: Comparison of RAO values for heave and pitch for the "deep transom" catamaran at various separation ratios (S/L=0.2, 0.4, ∞) and Froude numbers (Fr_n =0.4, 0.6, 0.8)

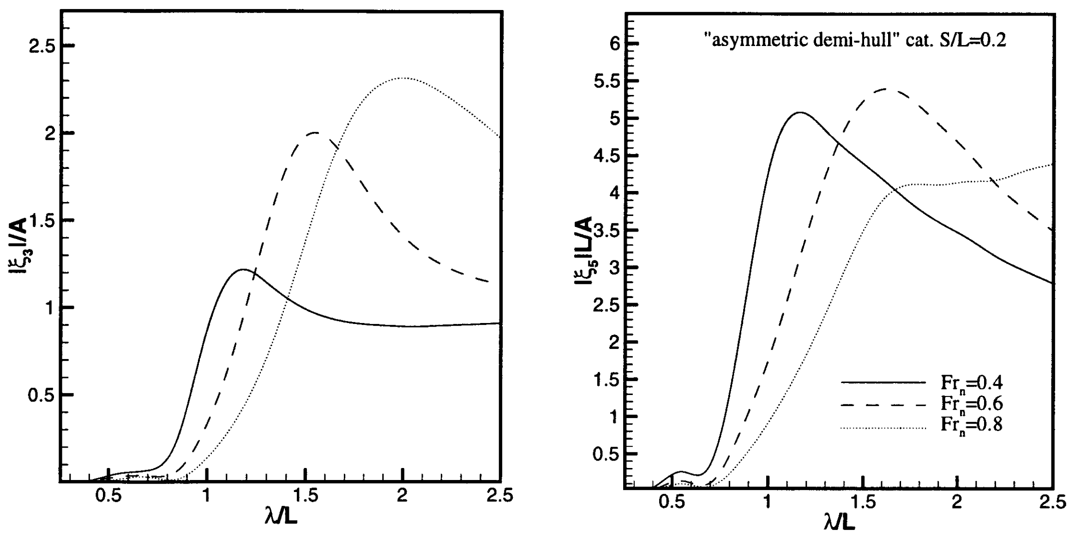


Figure 5.2.1-3: Comparison of RAO values for heave and pitch for the " asymmetric demi-hull" catamaran at various Froude numbers (Fr_n =0.4, 0.6, 0.8)

The same trends can be found in Figure 5.2.1-2, where the resulting heave and pitch amplitudes are plotted versus the normalized ambient wavelength (λ/L) for the "deep transom" catamaran. The same separation ratios and Froude numbers were used as in the case of "shallow transom" catamaran computations.

Figure 5.2.1-3 illustrates the resulting heave and pitch oscillation amplitudes for the "asymmetric demi-hull" variant in three different Froude numbers (0.4, 0.6, and 0.8). The higher Froude number causes the peaks of both the heave and pitch motions to increase and also shift towards lower ambient frequencies (larger wavelength). One point of interest is that the shifting dependence on Froude number is greater for heave than for pitch motions.

Figure 5.2.1-4 compares the different catamaran designs (S/L=0.2) with the *FastShip (TGN770)* for heave and pitch responses in various Froude numbers. The figure illustrates that the catamaran designs resonate in heave in higher frequencies than the monohull design. This shifting is more obvious in the case of the slender demi-hull configurations such as the shallow and the deep transom catamarans. Though less obviously, the same shifting also appears in the pitch oscillations.

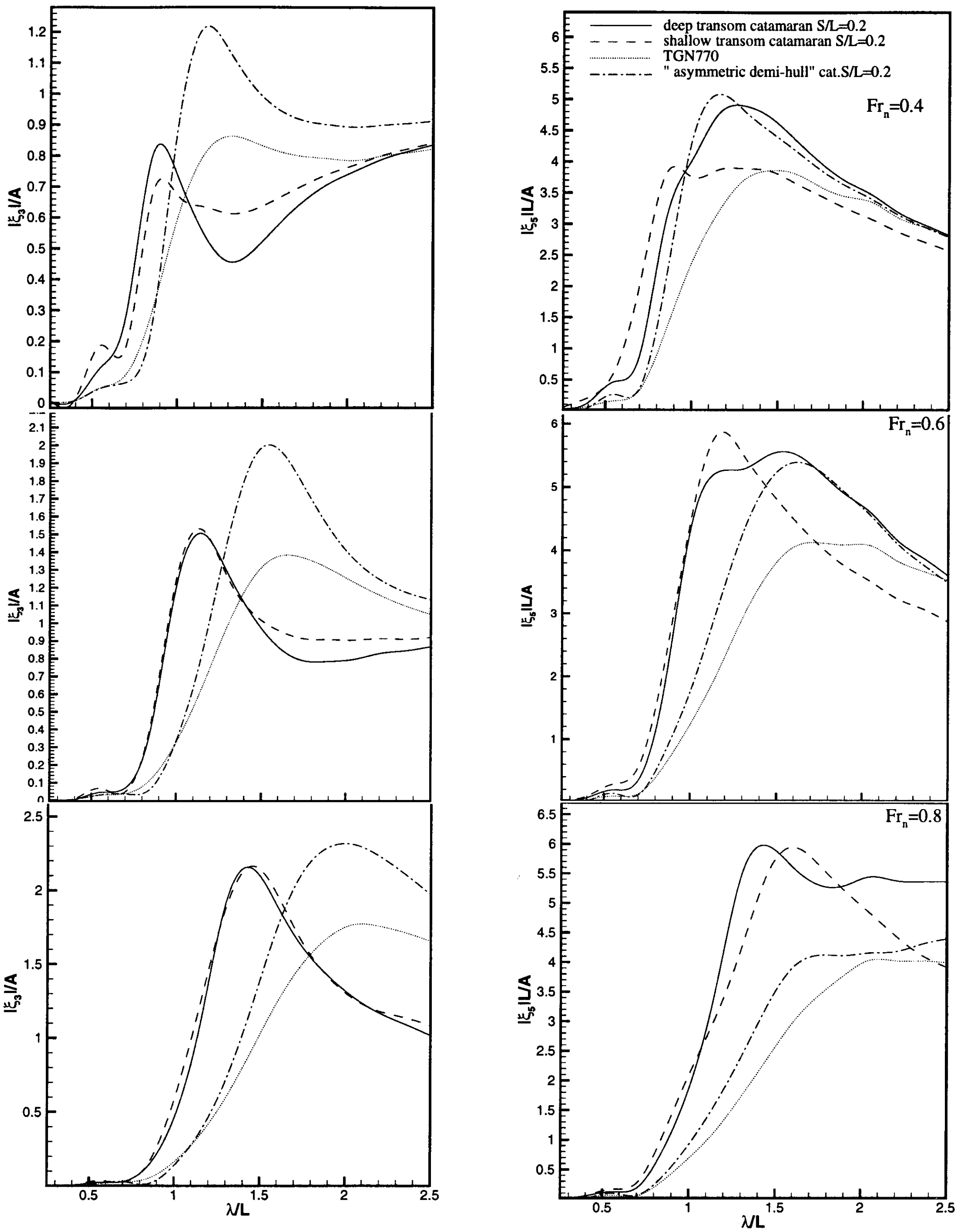


Figure 5.2.1-4: Comparison of RAO values for heave and pitch motions between the "shallow transom", "deep transom", "asymmetric demi-hull" catamarans (S/L=0.2) and the *FastShip (TGN770)* for various Froude numbers (Fr_n =0.4, 0.6, 0.8)

For the lower Froude number (Fr_n=0.4) the "shallow transom" seems to perform better in terms of heave response and equally well in terms of pitch response with the monohull design. However the picture changes for higher Froude number where the monohull performs much better than the catamaran variants in terms of peak heave and pitch amplitude responses. This performance difference is obvious in the pitching oscillations.

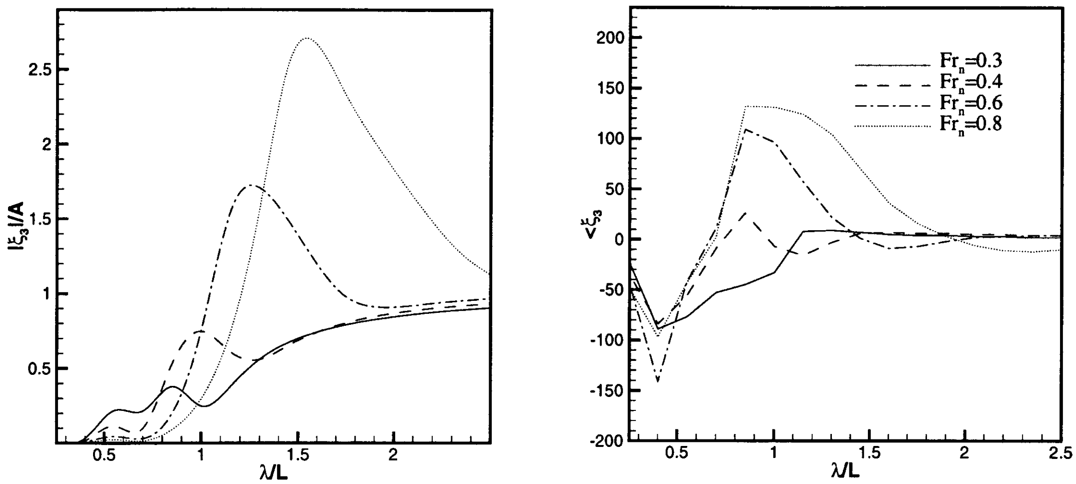
Finally, another point of interest arises from the effect of transom geometry on the catamaran heave and pitch motions. Both the “shallow transom” and the “deep transom” catamarans share the same design analogies with only difference the transom. By comparing these two variants in Figure 5.2.1-4, a weak dependence on the transom geometry appears for both the heave and pitch motions. The effect is more obvious in low Froude numbers (Fr_n=0.4).

5.3 Trimaran design

5.3.1 Heave and Pitch RAO’s

Figure 5.3.1-1 illustrates the resulting heave and pitch RAOs amplitudes and phases for the trimaran hull. Four different forward speeds, with corresponding Froude numbers of 0.3, 0.4 0.6 and 0.8, were examined. The results indicate the expected increase and shifting towards lower ambient frequencies of the peak of both heave and pitch RAOs for higher Froude numbers.

A point of interest appears in the heave RAOs for low Froude numbers (i.e. 0.3, 0.4), where the normalized heave amplitude never exceeds the value of one. Nevertheless, at the limit of low ambient frequencies the RAO reaches the expected value of one. The same trend can be also observed in low ambient frequencies for some catamaran designs in the previous paragraphs.



"Deep transom" Trimaran design
(separation between main hull and side hulls S/L=0.13)

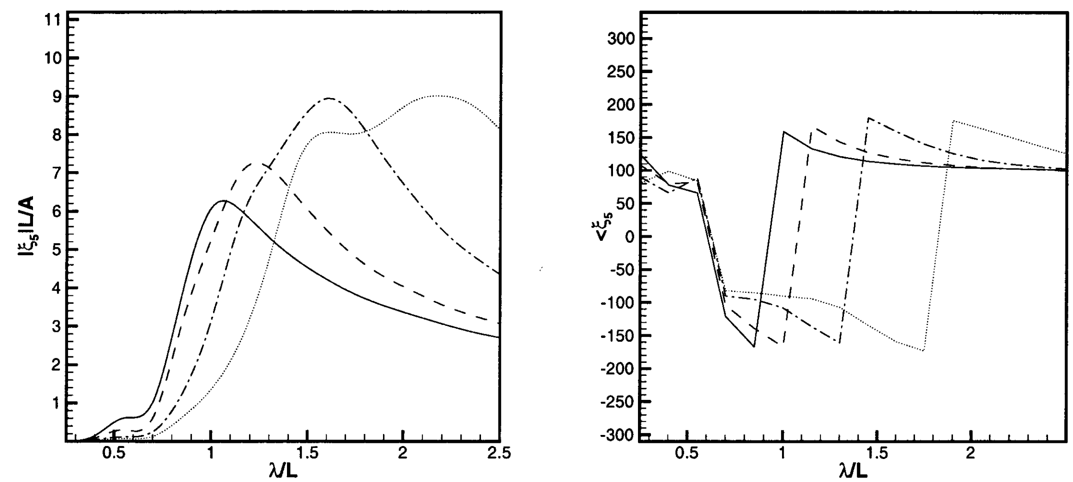


Figure 5.3.1-1: Heave and Pitch RAOs and phases for the trimaran design in Froude numbers 0.3, 0.4, 0.6 and 0.8

Chapter 6

6 Foils and Winglets for Catamaran and Trimaran Hulls

6.1 Introduction

The potential benefits from winglets or foils, mounted on the hull, in the seakeeping performance of a multi-hull design, is the subject of the present chapter. In particular, the problem of heave and pitch motions of a multi-hull ship in regular head seas is examined.

The geometrical characteristics of the multi-hull ships provide the opportunity of mounting high aspect ratio foils between the hulls, without burdening the structural design of the ship. As a matter of fact, a foil between the hulls, below the waterline, will provide additional support to the structural stiffness of the design. High aspect ratio winglets can also be mounted in the space between the hulls, without being exposed to hazards such as docking in port.

6.2 Seakeeping improvement

6.2.1 Heave and Pitch motions in regular head waves

Assume a ship which advances with speed, U, in head waves (β=180°), of amplitude, A, and absolute frequency, ω_o. The equation (2-30) which gives the encounter frequency of the waves reduces to:

(6-1) $$\omega = \omega_o + \frac{\omega_o^2}{g}$$

In response to the ambient waves the ship will undergo an oscillatory motion in all six-degrees of freedom. Surge, heave and pitch are coupled together by the system of equations (2-34)-(2-36).

Because surge is generally weakly coupled with the other two motions, it can be omitted from the system of equations. Thus, in the time-domain, the system of equations (2-34)-(2-36) reduces to:

(6-2) $$(M_{33} + A_{33})\ddot{\xi}_3 + B_{33}\dot{\xi}_3 + C_{33}\xi_3 + (M_{35} + A_{35})\ddot{\xi}_5 + B_{35}\dot{\xi}_5 + C_{35}\xi_5 = X_3(t)$$

(6-3) $$(A_{53} + M_{53})\ddot{\xi}_3 + B_{53}\dot{\xi}_3 + C_{53}\xi_3 + (M_{55} + A_{55})\ddot{\xi}_5 + B_{55}\dot{\xi}_5 + C_{55}\xi_{55} = X_5(t)$$

where $\xi_i = \xi_i(t)$ for i=3,5.

By using the complex notation for heave and pitch motions and excitation forces, the previous system of equations is described in the frequency domain by the following equation:

(6-4) $$-\omega^2[A(\omega) + M]\Xi(\omega) + i\omega B(\omega)\Xi(\omega) + C\Xi(\omega) = X(\omega)$$

where M is the 2x2 ship inertia matrix, A, B, are the 2x2 hydrodynamic added mass and damping matrices, and C is the 2x2 hydrostatic restoring matrix. The complex amplitudes of the hydrodynamic excitation forces and the harmonic responses are denoted by the complex vectors X, Ξ, respectively.

$$X = \begin{bmatrix} X_3 \\ X_5 \end{bmatrix} \qquad \Xi = \begin{bmatrix} \Xi_3 \\ \Xi_5 \end{bmatrix}$$

The solution of (6-4), in frequency domain provides the harmonic heave and pitch responses due to the excitation forces.

6.2.2 Foil/Winglet interaction with the hull in head waves

Paragraph 2.5.2 addresses the issue of winglets interaction with the hull in the case of regular ambient waves and monohull ships. The same paragraph provides a methodology for the correction of damping and restoring coefficients of the bare hull, as well as for the excitation forces acting on the bare hull due to the winglet interaction.

The same methodology can be readily used in the case of multi-hulls with foils or winglets moving with forward speed, U, in regular head waves (β=180°). Equations (2-45) throughout (2-52) will stay the same. Equations (2-53) and (2-54) are simplified for head waves to the following forms:

(6-5) $$X_3^w = X_3 + \frac{i\omega_o}{U} e^{-kz_w + ikx_w} f$$

(6-6) $$X_5^w = X_5 - \frac{i\omega_o}{U} x_w e^{-kz_w + ikx_w} f$$

where $$f = \frac{\pi \rho U^2 S}{1 + \dfrac{2}{A}}$$

and A is the aspect ratio and S the planform area of the foil/winglet.

6.3 Catamaran Designs

6.3.1 Corrected damping coefficients

The time-domain version of SWAN was used for the calculation of inertia matrix, M, added mass matrix, A, damping coefficient matrix, B, and excitation forces vector, X for the multi-hull variants described in Chapter 3.

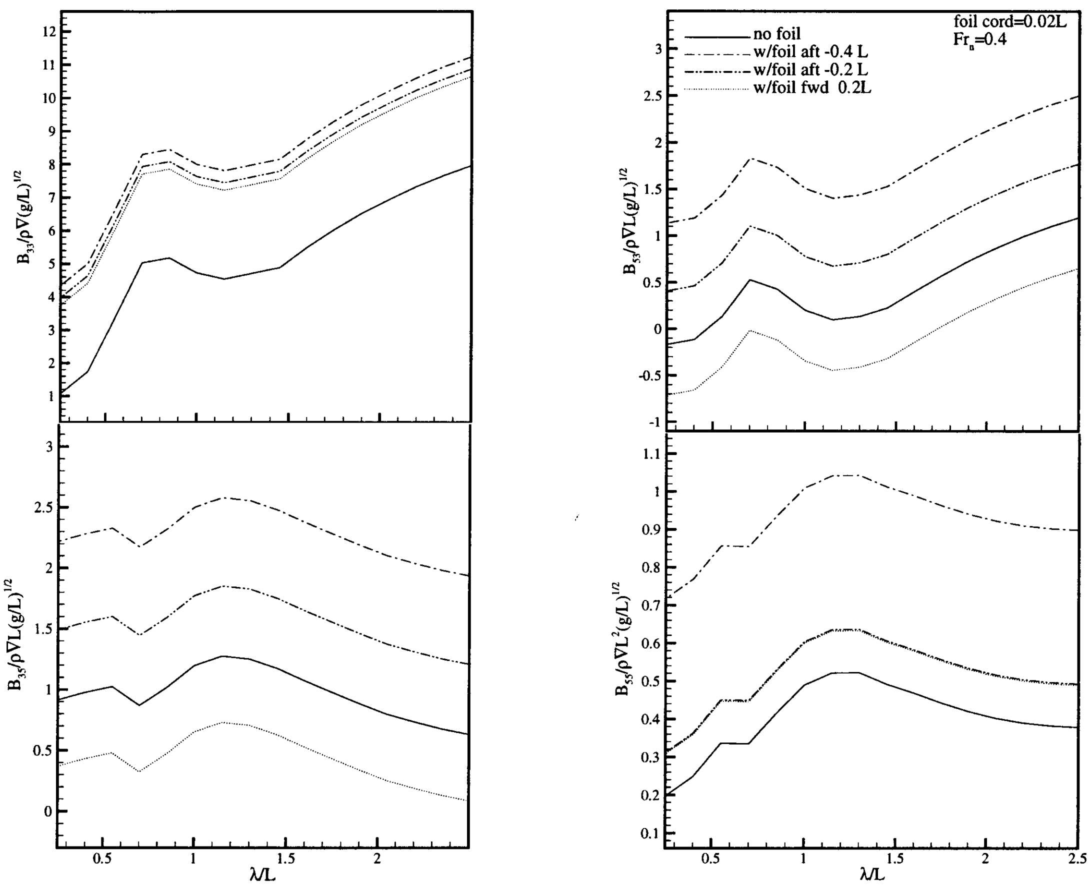


Figure 6.3.1-1: Heave and pitch damping coefficients for the "shallow transom" catamaran design (S/L=0.2) by using a foil mounted between the hulls (cord=0.02L) for various longitudinal locations at Fr_n=0.4

The frequency dependent added mass and damping coefficient were derived from the forced heave and pitch motion oscillations at a prescribed frequency, starting from zero heave and pitch displacements. The resulting force records converge quickly to a harmonic signal, which upon Fourier analysis leads to the heave and pitch hydrodynamic coefficients.

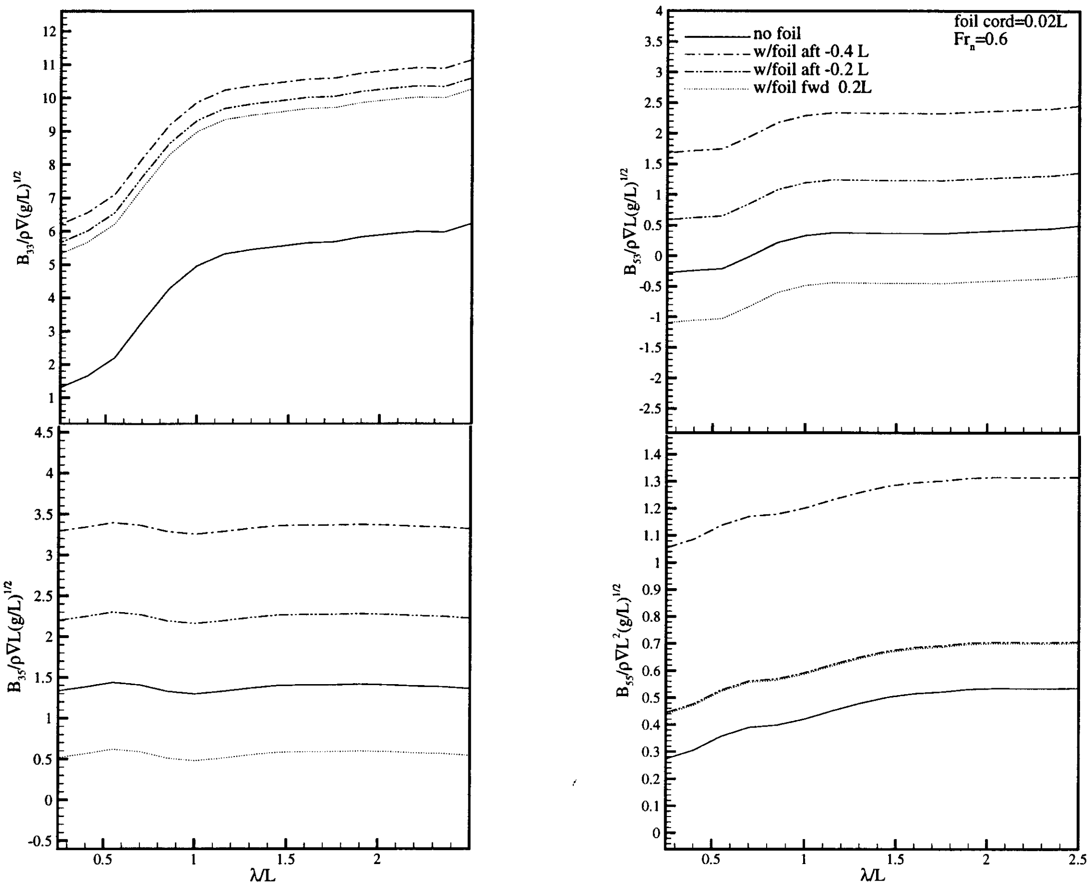


Figure 6.3.1-2: Heave and pitch damping coefficients for the "shallow transom" catamaran design (S/L=0.2) by using a foil mounted between the hulls (cord=0.02L) in various longitudinal locations at Fr_n=0.6

Figure 6.3.1-1, Figure 6.3.1-2, and Figure 6.3.1-3, each for different Froude number, illustrate the effect of the foil longitudinal location on the heave and pitch damping coefficients. For the calculations the foil cord length was assumed fixed and equal to 2% of the length of the ship. In all cases the foil is located at a depth equal to 1.5% of the ship's waterline length.

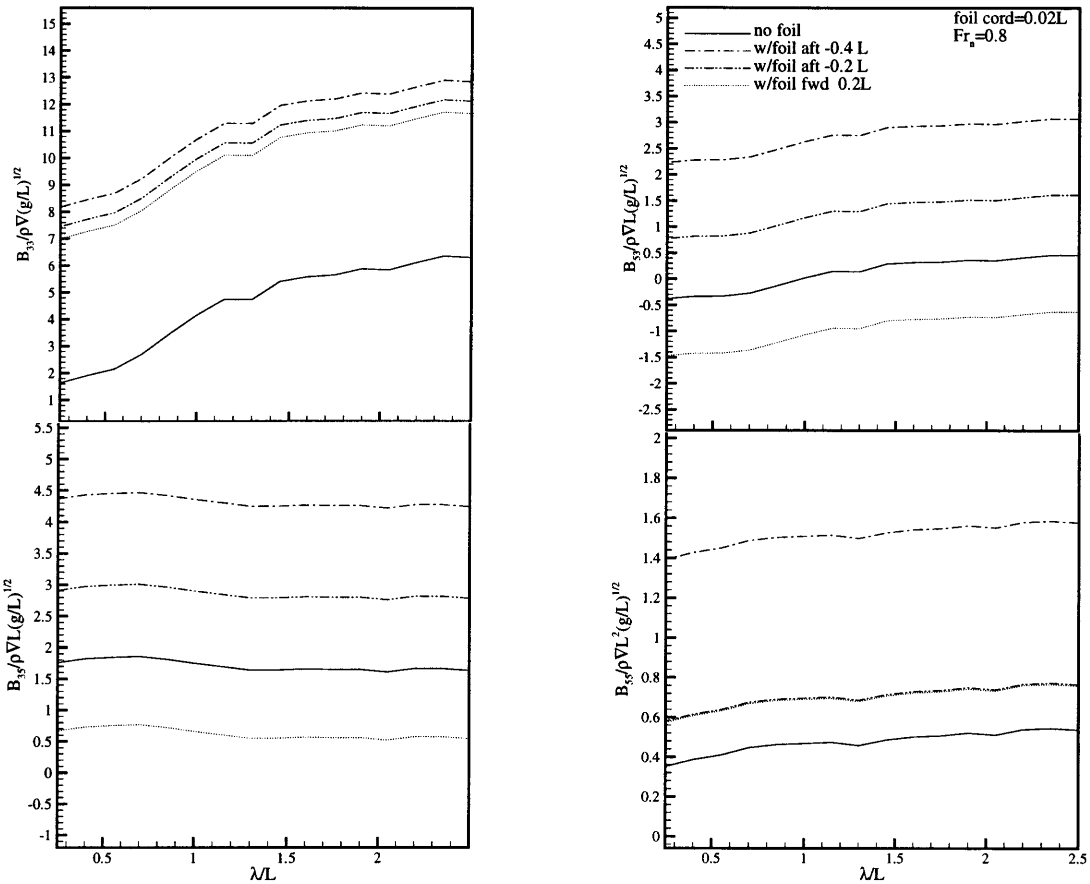


Figure 6.3.1-3: Heave and pitch damping coefficients for the "shallow transom" catamaran design (S/L=0.2) by using a foil mounted between the hulls (cord=0.02L) in various longitudinal locations at Fr_n=0.8

The solid line in the plots represents the SWAN-2 resulting damping coefficients for the "shallow transom" catamaran. These results were corrected using the equations (2-45) through (2-48) for various foil longitudinal locations.

As expected, the heave and pitch damping coefficients, B_{33}, B_{55}, increase over their bare hull values by almost the same amount for the after and forward location of the foil, corresponding to the amount of energy shed into the fluid domain by the high aspect ratio foil. In the case of heave damping coefficient the correction, using (2-6), is independent of the location of the foil. The differences that appear in previous figures for the various foil locations are due to the different span of the foil, which depends on the distance between the inner surfaces of the demi-hulls in each location.

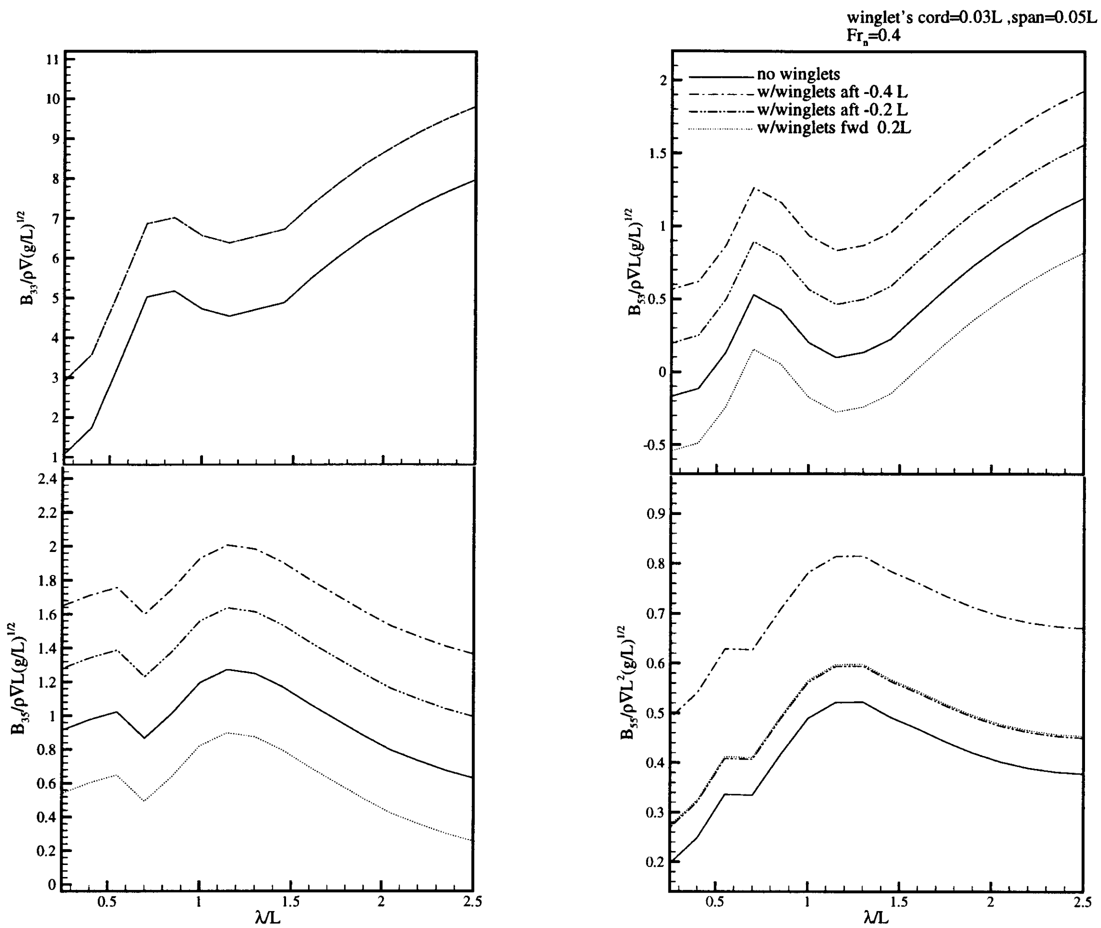


Figure 6.3.1-4: Heave and pitch damping coefficients for the "shallow transom" catamaran design (S/L=0.2) by using a pair of winglets mounted between the hulls (cord=0.03L, span=0.05L) in various longitudinal locations at Fr_n=0.4

It is obvious that the distance between the inner sides of the demi-hulls for the after -0.4L location is higher than the one for -0.2L location. As a result the foil in –0.4L location has a larger span, thus, larger effect on the heave damping coefficient, B_{33}.

The cross coupling coefficients, on the other hand, increase or decrease in magnitude depending on the forward or after longitudinal position of the foil. The after location of the foil increases the cross coupling coefficients and the forward decreases them.

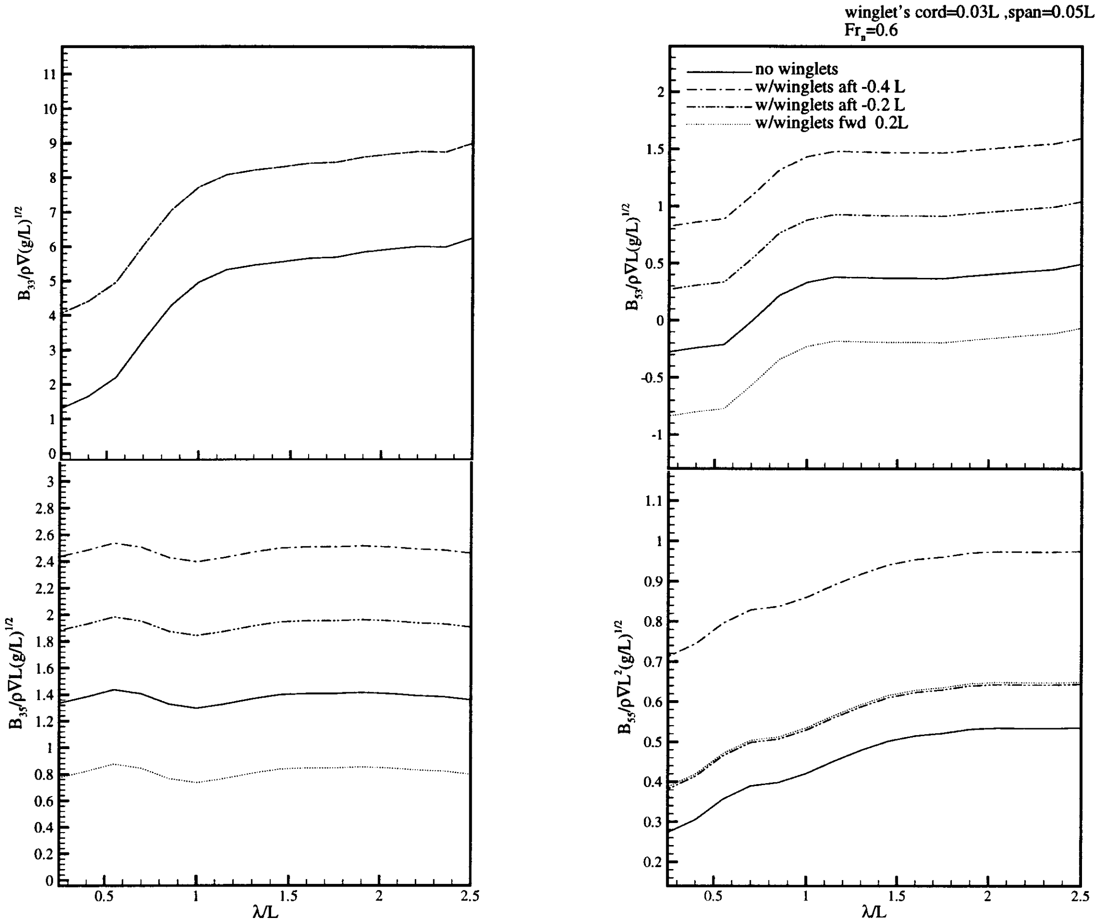


Figure 6.3.1-5: Heave and pitch damping coefficients for the “shallow transom” catamaran design (S/L=0.2) by using a pair of winglets mounted between the hulls (cord=0.03L, span=0.05L) for various longitudinal locations at Fr_n=0.6

The hydrodynamic coefficients in all cases are plotted versus the normalized ambient wavelength (λ/L). The same results may be plotted in a more conventional manner versus the encounter frequency by invoking relation (6-1) between the apparent and absolute wave frequency for the given speed and head waves. Moreover, in the limit of the long waves, or low frequencies, the damping coefficients tend to non-zero values, being consistent with seakeeping, which takes into account the so-called m-terms in the vessel hull boundary conditions.

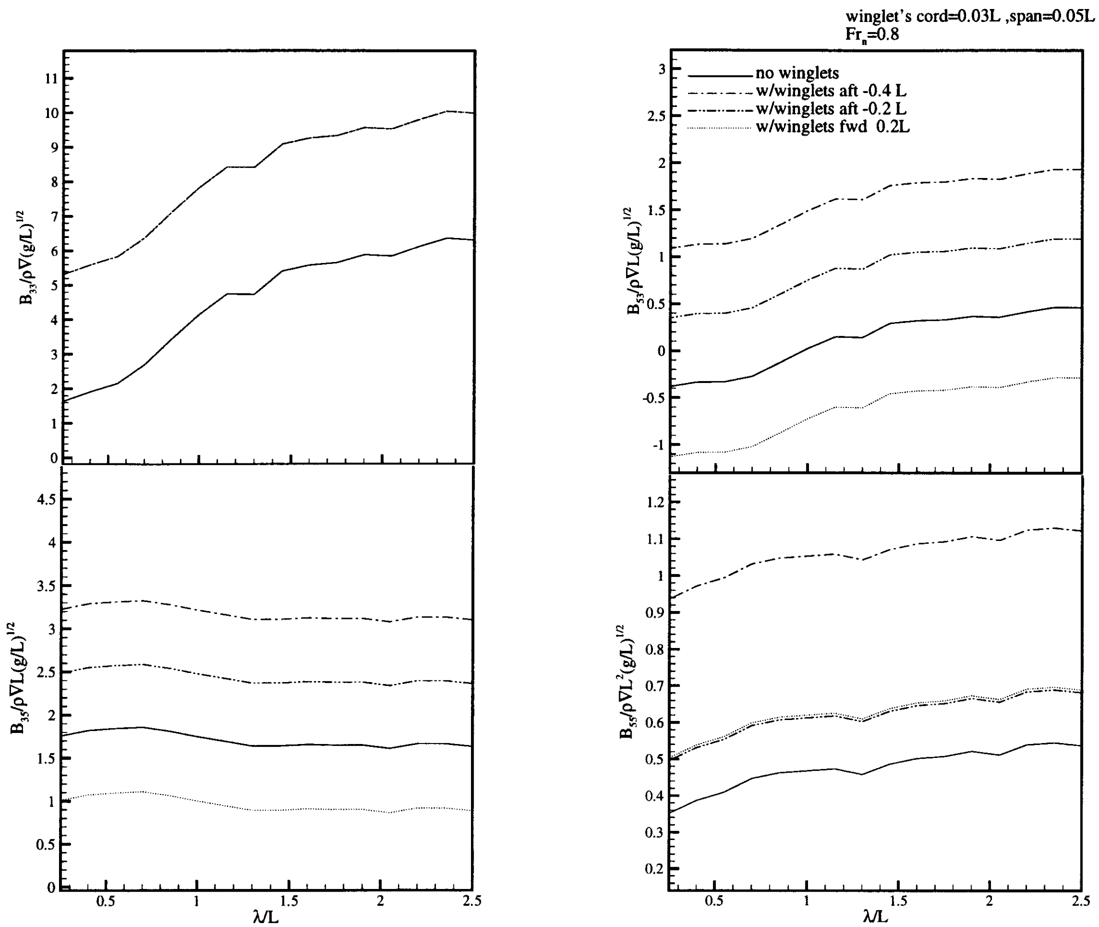


Figure 6.3.1-6: Heave and pitch damping coefficients for the "shallow transom" catamaran design (S/L=0.2) by using a pair of winglets mounted between the hulls (cord=0.03L, span=0.05L) for various longitudinal locations at Fr_n=0.8

Calculations for the corrected damping coefficients in head waves, were also performed using a pair of winglets mounted on the inside surfaces of the catamaran's demi-hulls in various longitudinal locations and various forward speeds. For the new calculations again the shallow transom catamaran was used with separation ratio S/L=0.2. The winglets used have a cord length of 3% and a span of 5% of the design's waterline length. Both winglets offset by the same longitudinal distance from the origin. Transversely, they are symmetrically located on the inner surface of each demi-hull. Finally, both winglets were located in a depth equal to 1.5% of the ship's waterline length.

Figure 6.3.1-4, Figure 6.3.1-5, and Figure 6.3.1-6 include the corrected damping coefficients, each one for different Froude number. The resulting coefficients exhibit the same trends as in the case of the foil, discussed previously.

6.3.2 Corrected Excitation Forces and resulting responses

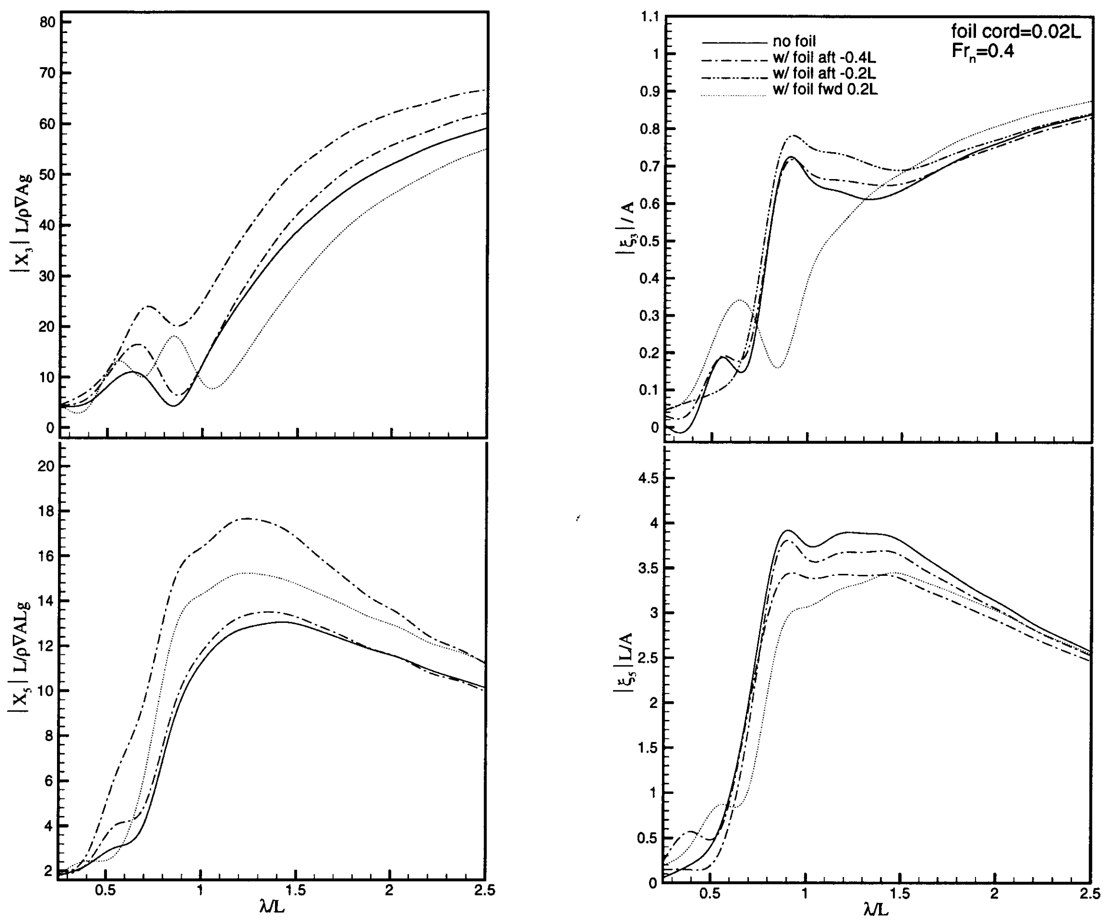


Figure 6.3.2-1: Corrected heave and pitch excitation forces and resulting heave and pitch RAOs for the "shallow transom" catamaran design (S/L=0.2) by using a foil mounted between the hulls in various longitudinal positions for Fr_n=0.4

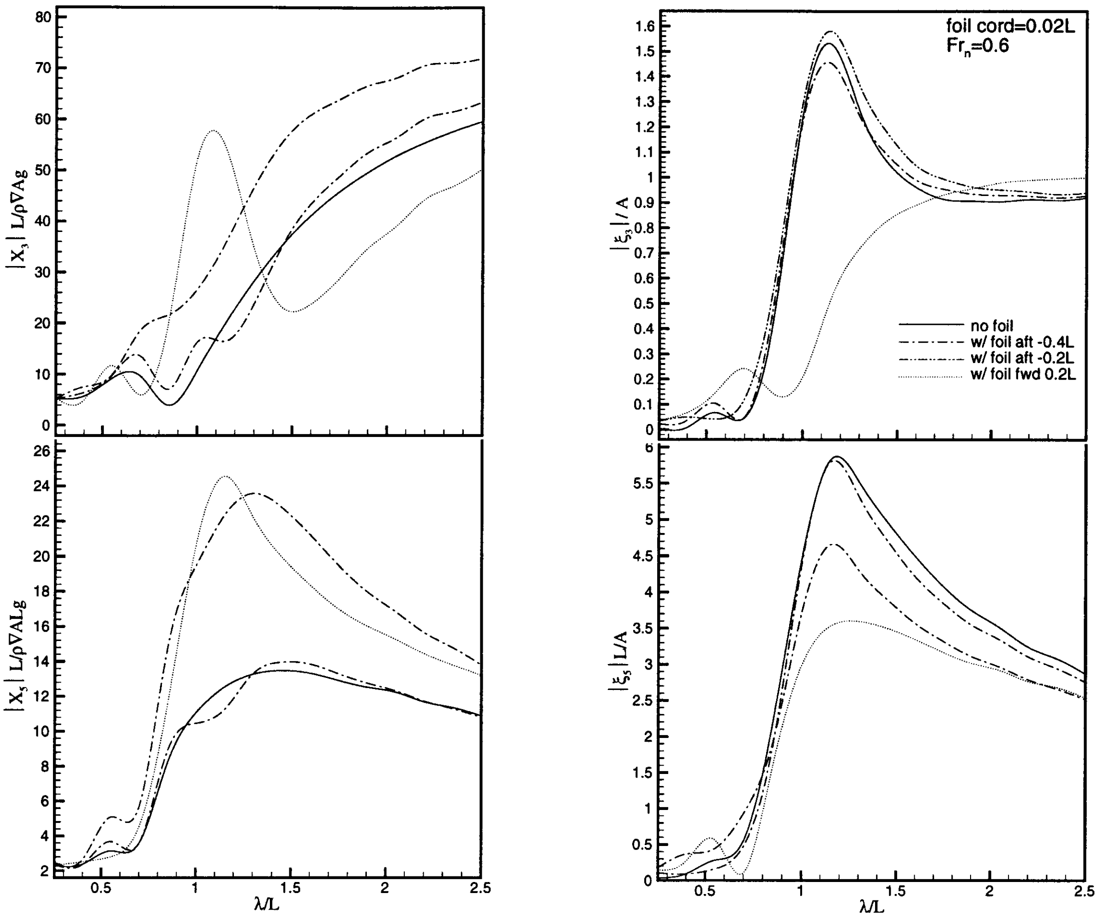


Figure 6.3.2-2: Corrected heave and pitch excitation forces and resulting heave and pitch RAOs for the "shallow transom" catamaran design (S/L=0.2) by using a foil mounted between the hulls in various longitudinal positions for Fr_n=0.6

Calculations were also performed for the correction of the heave and pitch excitation forces in the presence of a foil or a pair of winglets in various locations for the same Froude numbers used in the previous paragraph. Equations (6-5) and (6-6) were used for the correction of excitation forces. The resulting amplitudes of excitation forces are included in Figure 6.3.2-1 throughout Figure 6.3.2-6.

Although, in low Froude numbers, the resulting heave and pitch excitation forces are seen not to be affected appreciably by the presence or location of the foil or winglets, this is not the case for higher Froude numbers. In that case the effect of foil or winglets is seen to aggravate appreciably the heave excitation force. The affect is larger on the pitch excitation force, especially in the case of the highest Froude number of 0.8. The larger affects occur when the foil or the pair of the winglets are located forward. Then both the heave and pitch excitation forces exhibit a high peak value for λ/L about 1.5.

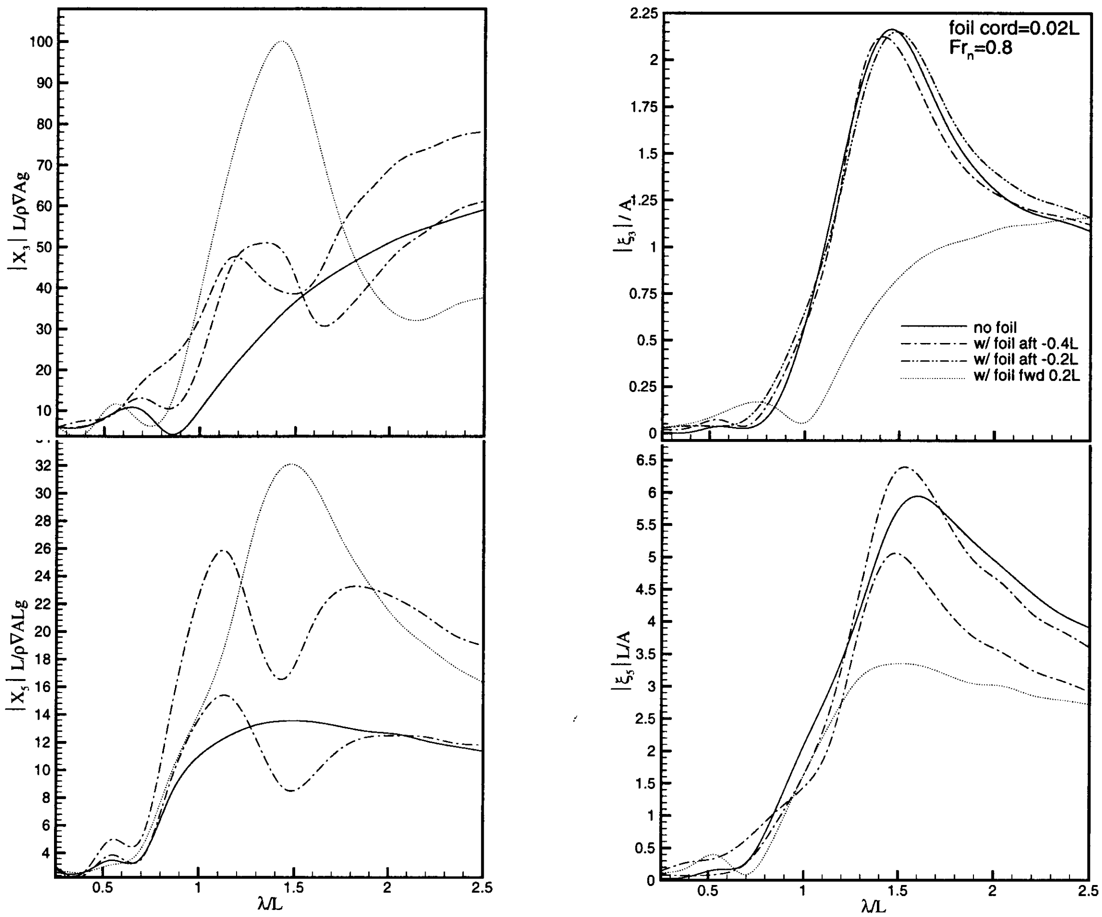


Figure 6.3.2-3: Corrected heave and pitch excitation forces and resulting heave and pitch RAOs for the "shallow transom" catamaran design (S/L=0.2) by using a foil mounted between the hulls for various longitudinal positions at Fr_n=0.8

For the purpose of solving the 2x2 system given by (6-4) in frequency domain, the hydrostatic coefficients were also corrected to include the foil/winglet effect. Equations (2-48) through (2-52) were used for that purpose. The heave restoring coefficient was assumed not to be affected appreciably by the presence of the foil/winglet due to the foil/winglet's small displacement compared with the displacement of the bare hull.

The foil/winglet added mass is proportional to their planform, S, area and is therefore negligible to that of the hull. However, the lift force is proportional to the square of the vessel's forward speed, U, and contributes an important correction to the damping and restoring coefficients and exciting forces.

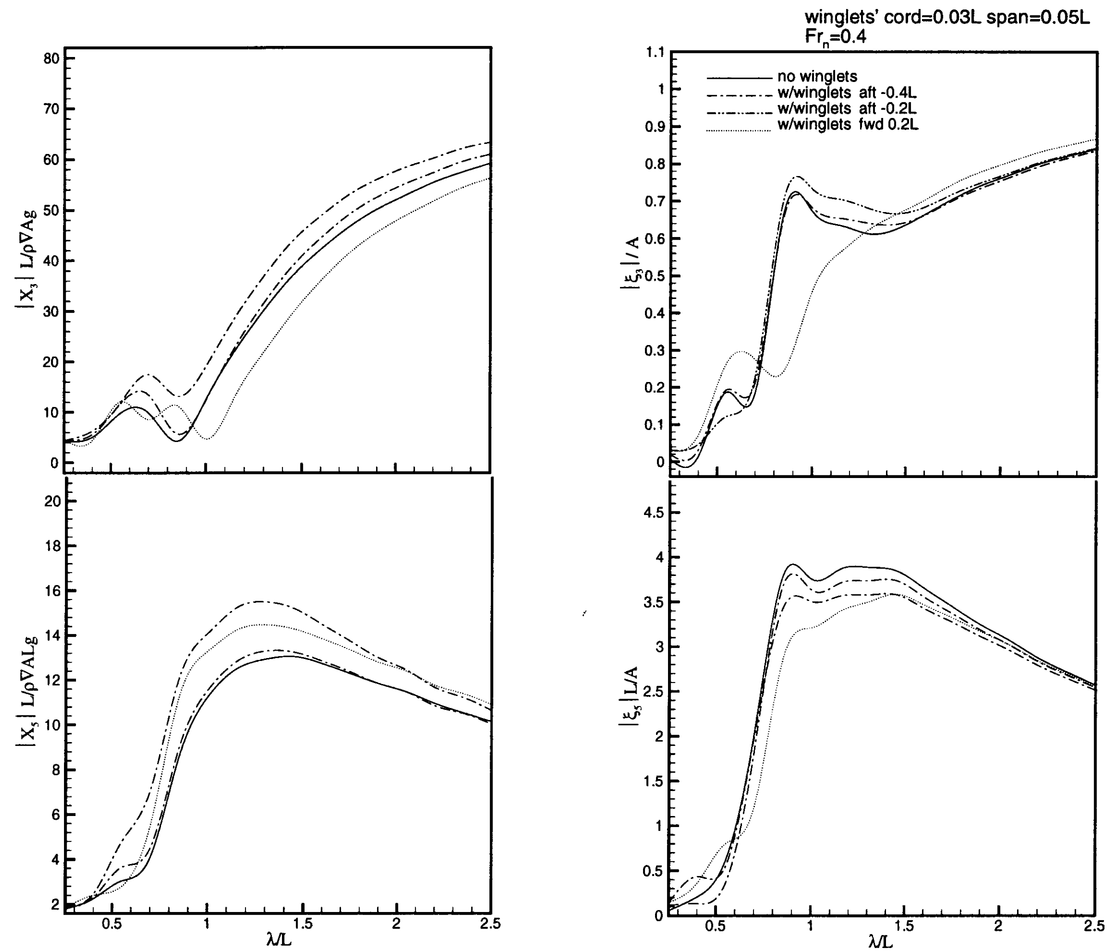


Figure 6.3.2-4: Corrected heave and pitch excitation forces and resulting heave and pitch RAOs for the "shallow transom" catamaran design (S/L=0.2) by using a pair of winglets mounted between the hulls for various longitudinal positions at Fr_n=0.4

Following the correction of all the coefficients, the solution of the (6-4) 2x2 system in frequency domain provides the resulting heave and pitch RAOs' amplitudes and phases as a function of ambient frequency or the normalized ambient wavelength (λ/L).

Figure 6.3.2-1 throughout Figure 6.3.2-6 illustrate the resulting heave and pitch RAO amplitudes for the case where a foil or a pair of winglets is mounted on the demi-hulls for various longitudinal locations, each one for different Froude number. Certain clear trends are evident which deserve discussion.

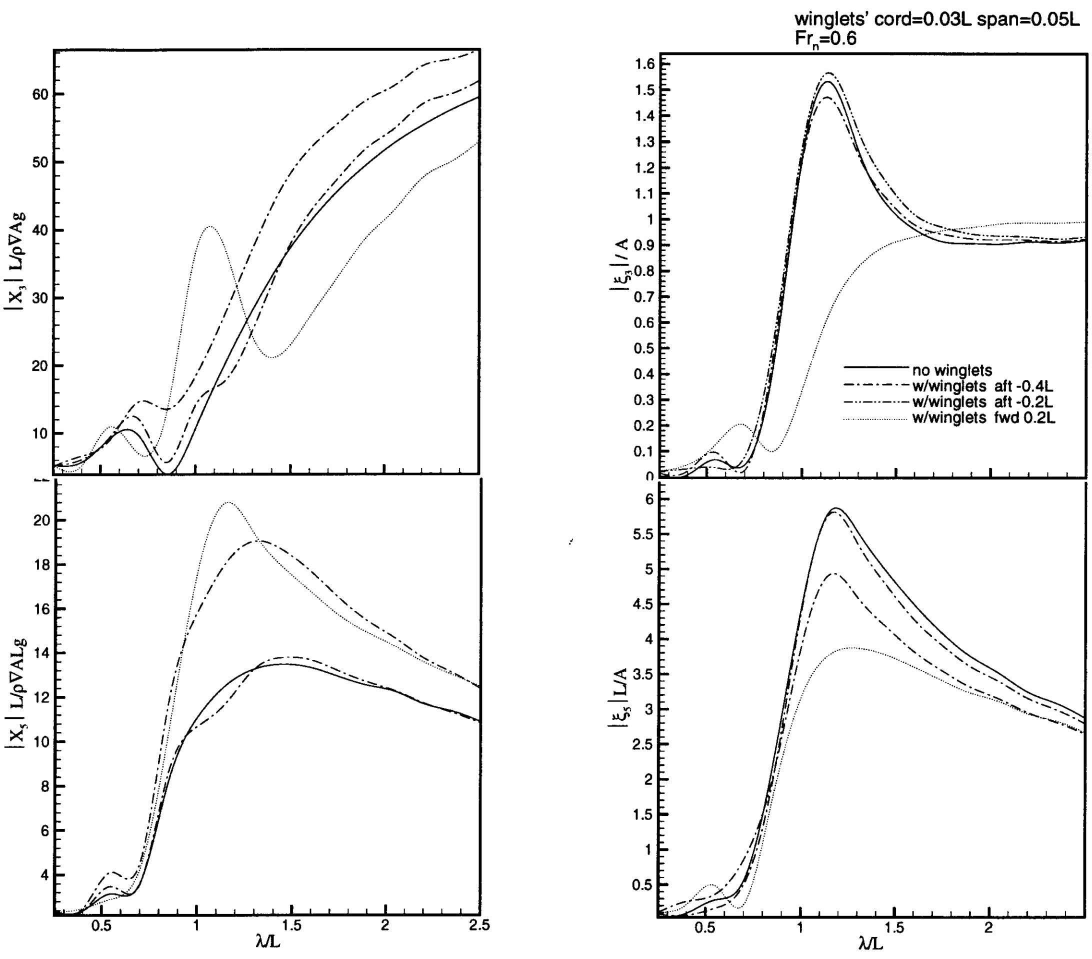


Figure 6.3.2-5: Corrected heave and pitch excitation forces and resulting heave and pitch RAOs for the "shallow transom" catamaran design (S/L=0.2) by using a pair of winglets mounted between the hulls for various longitudinal positions at Fr_n=0.6

The heave motion amplitudes are not effected appreciably, except when the foil or winglets are placed at forward positions. In this case, their presence is seen to shift, or altogether eliminate, the resonant peak towards longer waves, causing a drastic reduction of the heave motion in waves shorter than about 1.5 times the length of the ship and a slight increase in longer waves.

For the pitch motion the picture is quite different. The extreme after position of the foil or winglets is seen to decrease the pitch motion amplitude in all the range of wavelengths.

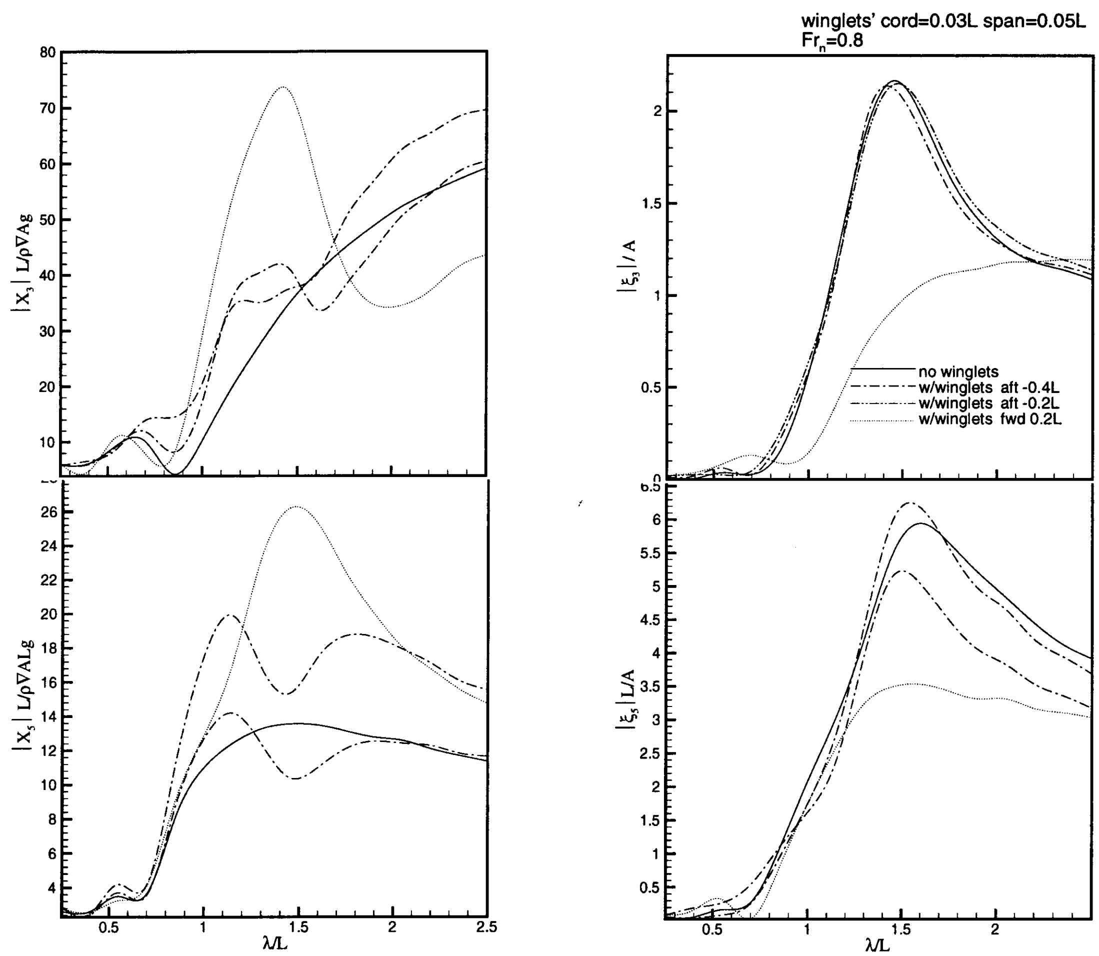


Figure 6.3.2-6: Corrected heave and pitch excitation forces and resulting heave and pitch RAOs for the "shallow transom" catamaran design (S/L=0.2) by using a pair of winglets mounted between the hulls for various longitudinal positions at Fr_n=0.8

However, the modest forward position of the foil/winglets of 0.2L is seen to have a larger positive effect on the pitch response amplitude in all the ambient frequencies. It interesting to note that the symmetric forward or after foil/winglets longitudinal location of 0.2L around the center of the hull gives totally different results in pitch response. In the case 0.2L after location the effects on the pitch response amplitude are very small. The aforementioned trends are consistent in all the Froude numbers examined. However, in higher Froude numbers the effects are seen to be larger.

6.4 Trimaran Design

The time-domain version of SWAN was used for the calculation of the inertia matrix, M, added mass matrix, A, damping coefficient matrix, B, and excitation forces vector, X for the trimaran design. The procedure of deriving the aforementioned coefficients is the same as described in the preceding paragraphs.

Because of the uniqueness of the trimaran hull geometry the high aspect ratio foils were mounted between the main hull and the side hulls. That restricts the possible longitudinal locations of the pair of foils, to only after locations. Note that, the geometric center of side hulls' waterline area is longitudinally located after, at a distance of 0.2L from midships. Given that the waterline length of the side hulls is 0.3L, the possible longitudinal locations of the pair of foils ranges from 0.05L after to 0.35L after. For the purpose of this study the foil cord was fixed to 2% of the waterline length of the main hull. Three different longitudinal locations of the pair of foils were considered. The foils longitudinal locations of -0.05L, -0.20L and –0.35L coincide with the longitudinal locations of the side hulls' bow, center and stern respectively. The transverse distance between the sailing lines of the main hull and the side hulls is 13% of the main hull waterline length. Finally, the foils' draft was considered fixed and equal to 1.5% of the waterline length of the main hull.

6.4.1 Foil corrected heave and pitch RAOs

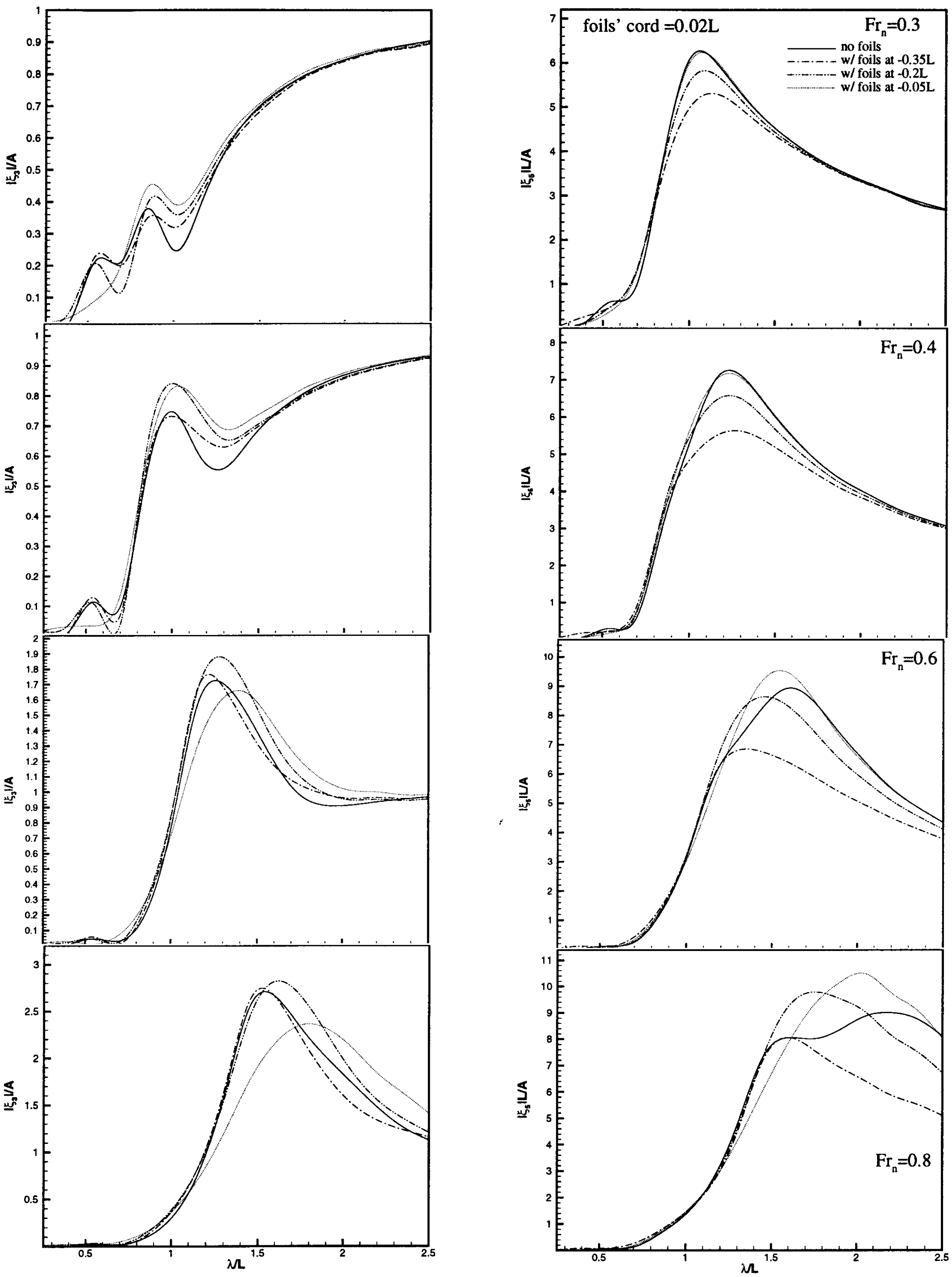


Figure 6.4.1-1: Heave and pitch RAOs for the trimaran design with foils mounted between the main hull and the side hulls for different locations at Froude numbers 0.3, 0.4, 0.6, and 0.8

Figure 6.4.1-1 includes the resulting heave and pitch RAOs amplitudes for the three aforementioned longitudinal locations of the pair of foils. Four different forward speeds, corresponding to Froude numbers of 0.3, 0.4, 0.6 and 0.8, were examined.

The results are seen to have the same effects on the heave and pitch motion as the ones discussed for the catamaran designs. The larger positive effects, especially in pitch, come from the extreme after location of the pair of foils, as expected.

Chapter 7

7 Market Review and benefits

7.1 General

In this chapter a methodology is presented on the estimation of the value, given by the shippers, on the characteristics of one mode of transportation relative to the other. Oceanic high-speed transportation opens an entirely new service quality option to shippers. It offers dramatically superior service at somewhat higher cost than its conventional maritime competition, while providing significantly lower cost with only marginal decrease in service quality compared to its air freight competition. These characteristics position the high-speed transportation between the existing air and ocean services.

High-speed transportation is not a new idea, especially among the passenger/vehicle ferries and containerships. In the trans-Atlantic route the idea of a high-speed monohull containership has already been explored, and seems to be very promising. The projected market share of such a service in US/Northern & Western Europe market is estimated to be 4.8% for 1998 and 7.4% for 2004 (Reference [25])

7.2 Total Logistic Cost Analysis

The total logistic cost analysis is based on the "total-cost concept", or evaluating the true total cost of transporting commodities, including a variety of other distribution costs in addition to direct transportation costs. The most important components include such elements as ordering costs, inventory carrying costs (for goods awaiting shipment, goods in transit, goods in cycle stock, and goods held as safety stock), warehousing costs, and perishability, damage, and other value-loss to goods in the supply chain.

These individual elements had been recognized many decades ago, but before 1950s were virtually always uncoordinated and under the management of separate corporate divisions. By 1965 it had been well recognized that it was necessary to focus on minimizing total logistic costs by examining these components together as a part of a single system. The literature on the total logistics costs analysis has further developed over the last 30 years, and this methodology serves as a consensus tool for determination of the true costs of transportation alternatives.

The total logistics cost methodology can be easily applied to high-speed transportation for the development of a Value Creation Model. This methodology is considered especially appropriate because it is by far the best means of evaluating the total direct impacts of changes in transportation service characteristics. It is extremely flexible in terms of readily providing alternative formulations and sensitivity analyses that confer great robustness to the generated results. The use of the total logistics cost model is also extremely effective because, once the model has been generated, it is possible to directly determine the commodity groups which would benefit from the service and thus should switch from existing modes to high-speed mode of transportation.

7.2.1 Value creation model for high-speed ocean transportation

This model utilizes the total logistics cost methodology and evaluates the net effect of the differences in rates balanced against the differences in inventory investment and inventory carrying costs among modal choices available to the shipper. There are a number of concepts in the total logistics cost model in which implicit or explicit assumptions must be made and there is an availability of alternative specifications. A brief introduction to the various key elements of the model is provided.

Inventory carrying charge. This element, usually expressed as an annual rate, and represents the capital carrying cost for the applicable commodity. The rate includes not only the interest cost of having capital tied up in inventory, but also incorporates such elements as insurance, security, warehousing, handling, administrative and other overhead costs.

Ordering cost. Represents the administrative burden of placing and processing each order with the carrier. In theory, smaller shipments impose greater costs on shippers and carriers. However, with improved communications, order costs had become virtually insignificant to all but the smallest shippers.

Origin and cycle inventory. Goods awaiting shipment at the origin and awaiting sale at the destination. These types of inventory, typically, assumed to be created and depleted at a linear rate, and thus to have an average quantity of half of the maximum size, or the shipment size.

Safety stock. Represents the quantity of inventory held at the destination in order to account for unreliability in arrival times and variability in demand for the good. Safety cost is held to minimize the cost of a stock out--running out of the inventory when there is demand, and thus missing a sale or having closed an assembly line. The input parameters must represent the travel time reliability, demand variability, the cost of a stock out, and the desired level of confidence that there will not be a stock out.

7.2.2 MIT Total Logistics Cost Model

The MIT total logistic cost model was developed by the Center for Transportation Studies and Flight Transportation Laboratory at MIT for *FastShip* Atlantic™[1]. It was originally designed for application on high-speed monohull containerships, but it can be readily used on any type of high-speed design like multi-hulls designs. The model is in fact a total logistic cost analysis of the benefits to given customers of using *FastShip* over ocean or airfreight services. A short description of the assumptions made and the formulas used in the model follows.

Inventory carrying charge. The model has followed the usual assumptions of including in the rate the interest of having capital tied up in the inventory, insurance, security, warehousing, handling and administrative costs. The model includes a value decay concept in order to attempt to account for commodity-specific variation in carrying charges and to allow a non-linear specification of non-carrying cost market losses due to perishability.

Ordering cost. Due to its small importance and the complete lack of data on the varying administrative costs to shippers, this element is incorporated into the inventory carrying charge along with the other administrative costs.

Origin and cycle inventory costs. Both inventories assumed to be created and depleted at a linear rate, and thus to have an average quantity of half the shipment size. The formulas used for the calculation of these two types of costs is given below:

(7-1) $$\text{Origin Cost/FEU} = \frac{i \cdot \frac{DP}{365} V \cdot \frac{x}{2}}{AS}$$

(7-2) $$\text{Cycle Cost/FEU} = \frac{i \cdot \frac{DP}{365} V \cdot \frac{x}{2}}{AS}$$

where i is the annual carrying charge, DP is the demand period in days, V in the value of the product per FEU , x is the average shipment size in FEU, and AS is the number of FEUs shipped annually .

In Transit Inventory Cost. During the time the goods are in transit they are in effect a moving inventory. To include the cost of holding the inventory during the transit time, the transit inventory cost parameter is used, and defined as follows:

$$(7\text{-}3) \qquad \textit{In-Transit Inventory Cost/FEU} = (V \cdot i) \cdot \left(\frac{DP}{365}\right) \cdot \left(\frac{T}{DP}\right)$$

where i is the annual carrying charge, V is the value of the product per FEU, DP is the demand period in days, and T is the days that the goods are in transit.

Origin Warehouse Cost. The cost incurred by having the cargo sit in a warehouse during shipment. The origin Warehouse cost can be calculated from the equation:

$$(7\text{-}4) \qquad \textit{Origin Warehouse Cost/FEU} = \frac{\frac{lbs.}{FEU} \cdot \frac{x}{2} \cdot WHC}{AS}$$

where WHC is the warehouse cost per pound, x is the average shipment size in FEU, and AS is the number of FEUs shipped annually.

Safety Stock Cost. As mentioned before, safety stock represents the quantity of inventory held at the destination in order to account for unreliability in arrival times and variability in demand for the good. To facilitate the calculation of safety stock cost, parameters representing the travel time reliability, demand variability, the cost of a stock-out, and the desired level of confidence that there will not be a stock out, must be used. In the model the following formula was used:

$$(7\text{-}5) \qquad \textit{Safety Stock Cost/FEU} = V \cdot \sigma_{SOC} \cdot \left(\frac{i}{AS}\right) \cdot \sqrt{T \cdot \sigma_{DS}^2 + DS^2 \cdot \sigma_{TT}}$$

where i is the annual carrying charge, V in the value of the product per FEU , σ_{SOC} is the stock out cost standard deviation, AS is the number of FEUs shipped annually, T is the transit time in days, σ_{TT} is the standard deviation of transit time, *DS* are the average daily sales, and σ_{DS} is the standard deviation of daily sales.

Perishability Cost. Commodities vary greatly in their ability to hold value over time. Some goods have short physical life (i.e. fresh flowers) and must be delivered to their destination quickly, or not at all. Other goods have their highest value early in the selling season (i.e. clothes) and are worth less as the season ends. Finally other products have life cycles that extend beyond a single season or even a year. Cost due to loss of product value is determined by the change in demand or product condition. The parameters, included in the expression for the perishable cost, are the salvage value at the end of the product's life, the value of good being shipped, the ratio of transit time to product's life, and a decay parameter. The last one determines the rate of decay in the value of the good being shipped. This parameter determines if the good loses its value at a constant rate daily (k=1.0), or at a small rate at the beginning of the product's life and a more dramatic rate near the end of the product's life (k>1.0). The perishable cost per FEU may be expressed as:

(7-6)

$$\textit{Perishability Cost/FEU} = (1-S)\cdot V\cdot\left(\frac{T}{SL}\right)^{k}$$

or

$$\textit{Perishability Cost/FEU} = (1-S)\cdot V$$

whichever is smaller

where S is the ratio of salvage value at the end of product life to the value at the beginning of product life, V in the value of the product per FEU , T is the transit time in days, SL is the self life of the product, and k is the decay parameter.

Transportation Cost. The cost of transportation is the price charged by the carrier for the movement of goods from origin to destination. In general, faster service and smaller cargo volumes are correlated with higher prices.

The formulation of the MIT total logistics cost model is extremely conservative. The conservatism of the model lies in several areas:

- Changes in manufacturing strategy, restructuring of supply chain and distribution strategies, smoothing of manufacturing and shipping operations, improved ability to fit planning cycles and ability to reduce non-transport replenishment time, are non-transport related elements that can potentially provide value. However, the model does not take into account these elements.
- For under value situations, the value of rapid access to the marketplace is high and well beyond what is reflected in the book value of the inventory. In this situation the model misses the potentially unusually high cost of a stock-out.

7.2.3 Supply Chain Management

The concept of Supply Chain management in not a new one. Nevertheless, it is an increasingly growing one among the shippers today. That concept not only can reduce total logistic cost by picking the optimal mode for distribution systems, but also can give additional benefits due to the reconstruction of manufacturing processes and supply chain network. A high-speed trans-Atlantic service provides an excellent opportunity for many shippers to re-engineer their supply chain to take advantage of this new service.

In business today, time management is on the cutting edge. The ways effective companies manage time, in production, new product development and distribution, represent the most powerful new source of competitive advantage. A leading concept in the use of time as a strategic weapon is the supply chain management.

If the product is delayed in marketing and distribution, the company will not gain a competitive advantage, no matter how fast a product is developed. The key points in the distribution channel are speed and reliability. The on-time meeting of product demand whenever it occurs is essential for the distribution channel. Electronic linkups between sales agents and customers can provide continuously sufficient supply and minimal over-ordering, as well as with access to information about product updates, price schedules, and availability. Distribution managers linked to both manufacturing facilities and the distribution centers can make sure that sufficient units of the product are in the manufacturing and supply chain for in-time delivery. A high-speed reliable tran-Atlantic service will provide many shippers with the opportunity to utilize the same rapid response techniques in the international trade as in their domestic market.

At the level of the individual firms, there is a trend of minimizing the number of distribution facilities, which places greater pressure for maintenance of customer service levels in the functions of inventory management, fast and reliable transportation, and information systems. A high-speed service will help shippers to reduce costs and increase responsiveness in their distribution networks. Specifically, with affordable, rapid, reliable trans-Atlantic trade, many shippers will be able to eliminate one or more layers in their distribution system, or to consolidate multiple facilities at a single, efficient site. That will result in reducing warehousing, transport, handling, and administrative costs, as well as in increased directness, consequently resulting in a competitive advantage in terms of quicker response in customers demands.

Following the decreasing number of distribution facilities, more attention must be directed to the location decision and to an analysis of the appropriate role of each facility and the associated transportation. By having independent partners holding more stock, like third party logistic providers and channel intermediates, the company commitment of operating its owned facilities can be reduced. This will place less emphasis on forecasting and more on responding to demand and managing distribution and inventory more effectively.

The time between the launch of a new product and when demand plunges or the product become obsolete is defined as product life cycle. It has been observed in recent years that commodities are experiencing increasingly short product life cycles, which are now measured in months instead of years. The proliferation of new products and product families are dramatically affecting the management and deployment of inventory in the supply chain to maintain competitive customer service levels. The cost of obsolescence and product non-availability can be very high in terms of lost sales, lost shelf space, and eroded goodwill. In addition, the risk and competitive costs of poor product introduction, and inadequate planning and execution in the supply chain have increased significantly. The aforementioned factors have forced the companies to attempt to integrate distribution with marketing and production, in order to manage delivery based on reliable velocity through the system. Decreasing product life and increasing differentiation and specialization mean efficient supply chains are becoming more critical to a wider range of goods.

A reliable high-speed trans-Atlantic service definitely adds substantial value to the supply chain management, by giving the shippers the opportunity of integrating into their trans-Atlantic supply chain system, elements such as high frequency, reliability, dedicated port facilities, high speed, sufficient capacity, utilization of standard containers, sophisticated third parties logistics, and elimination of intermediate carriers. It is clear that such a high-speed service creates value well beyond the total logistics savings measured by the MIT value creation model.

7.3 Latent and stimulated demand

The concept of *latent demand* is an important one in economics. It is defined as the demand that currently exists, but is presently unmet due to an insufficient supply or unfavorable conditions. A second important concept is *stimulated demand*, defined, as the existing demand that is poorly served by existing services, but will increase if served by more appropriate service. The differentiation, between which cargoes fall within the definition of latent demand and which represent existing but stimulated demand, is often difficult. However, both ideas are well developed in both theoretical and applied literature, and it is clear that a high-speed trans-Atlantic service will generate a substantial quantity of cargoes that were not previously shipped across Atlantic.

In the case of a high-speed trans-Atlantic transportation service, latent demand can be defined as the capture of shipments that, without the existence of that service, would otherwise not travel between North America and Europe. Shippers may desire to ship their products across the Atlantic, but without a high-speed ocean service neither conventional ocean nor air provides the service and the rate characteristics that they desire. This represents latent demand. A high-speed containership would provide a service that does not currently exist and is an improvement over existing services.

Stimulated demand, on the other hand, can be illustrated by a variety of commodities, which are currently barely competitive in trans-Atlantic markets, but occupy a small niche due to complex marketing issues of product differentiation and import substitution. These commodities are likely to find a greatly increased consumer market with reduced shipment costs, offered by the high-speed service, and thus lower prices for the customers.

Generation and capture of new demand, rather than fighting for market share, has been a mark of successful businesses. Numerous examples of latent and stimulated demand tied to improved transportation or communication services exist. For instance, fresh cut flowers, express package delivery, trans-continental rail container service, and cruise ship voyages all represent areas in which demand expanded enormously when a transportation innovation occurred allowing the expansion of supply.

The MIT total logistic cost model, originally created for the validation of *FastShip's* value creation model was applied to commodity-specific data for Northeast US trade with Northwest Europe for the estimation of latent and stimulated demand. The methodology used follows.

Commodities, for which latent or stimulated demand was likely, were identified by selecting goods for which a high-speed service would create very high total logistics cost savings relative to the product value. This was interpreted as a percentage decrease in delivered price by assuming that such cost savings were passed on to the product recipients. Based on this criterion, a set of parameters was derived that provided large percentage decreases in delivered prices. Among others, the key parameters were identified to be the high time sensitivity and the product value density. Applying product own-price elasticities and elasticities of import substitution to the percentage price decrease, stimulated demand for specific commodities could be estimated.

The commodities were next separated based on the average value density, and commodities following within the appropriate value density were retained. More commodities were eliminated based on consideration of time sensitivity. In particular, any good without changes in value based on seasonality or perishability was eliminated from consideration. From the remaining commodities a variety of illustrative commodities was selected for more detailed analysis. Since a range of values for each parameter is appropriate for each of the commodities that were analyzed, the spectrum of logistics cost savings possibilities could be equivalently covered by looking at different combinations of characteristics for a more limited number of commodities.

Own-price elasticity represents the percentage change in the consumption of a product due to a given percentage change in its own price. Traditionally, an elasticity of -1.0 is considered "normal" elasticity, meaning that one percent decrease in the commodity price will result in one percent increase in its consumption. Typical goods rarely have elasticities higher than 0.0 or less than about –2.5. However, these values represent aggregate long-term elasticities for the total sales of the commodity within a large market.

In addition to own-price elasticities, published estimates have been empirically generated for elasticities of import substitution for domestic production of consumer goods. These elasticities represent the percentage change in total imports given a percentage change in the price of imports, and are usually utilized in conjunction with changes in currency values or tariff policies. Values found in the literature ranged from –0.78 to –1.62. As with the own-price elasticities, this range again represents an extremely conservative estimate when utilized for specific commodities.

A single elasticity estimate was derived by averaging a "normal" elasticity of –1.0, a published commodity-specific own-price elasticity, and an import substitution elasticity of –1.62. Results for the stimulated demand were then obtained by multiplying the percentage decrease in the delivered price by the derived elasticity value. This methodology provides a conservative, lower bound estimate of the percentage increase in demand for the trans-Atlantic shipment stimulated by a high-speed ocean service.

In particular, results of the latent and stimulated demand analysis conducted for *FastShip* (Reference [26] and [28]) with use of this methodology showed widely varying results depending on the specific commodity characteristics. The commodities for which the largest relative benefits in the total logistics costs accrue have relatively low value densities (from $0.25 to $2.00 per pound) and are quite time sensitive, with a marketable shelf life of approximately two weeks, a low salvage value and a fairly high decay parameter. In addition, this quantitative analysis showed that most appropriate cargoes, such as seasonal apparel, certain time-sensitive publications and packages and certain fresh seafood, produce and prepared foods may increase their trans-Atlantic demand by from 20% to 100%. Historical examples of fresh cut flowers and small package express can trigger even greater percentage increases possible for commodities that are being shipped in limited quantities presently, but are enabled by a high-speed trans-Atlantic service to develop a broad new market.

Enormous possibilities for additional capture of latent demand can also be triggered by the strategic logistics management. Strategic logistics management involves the reformation of a company's corporate strategy to explicitly incorporate its distribution system, generating a competitive advantage. Just-in-time (JIT) manufacturing, is among the most common strategies encompassing consolidation or decentralization of production processes, quick response, built-to-order services and inter-company partnering.

Logistics-focused strategies demand rapid and reliable transportation services. Air transportation service can meet this need for only a limited number of high value commodities. So for trans-oceanic shipments a high-speed service will be the mode of choice for most corporations looking to implement their logistics strategies on a global basis. A substantial quantity of new cargoes, in addition to the stimulated demand from cost savings, is likely to be generated due to the strategic logistic benefits an oceanic high-speed service can provide.

7.4 Competitive Responses

A new oceanic high-speed service will, undoubtedly, attract cargoes from both the maritime and the air freight sectors, while they will also observe the generation and capture of unexploited demand. However, both sectors will hardly be affected, since, even at full utilization, the new service represents a small percentage of the total trans-Atlantic market size. Nonetheless, some operators maybe particularly impacted by the new service, and feel the need to respond to the competition posed by the high-speed service. The response might be either an attempt to move towards the high-speed service and compete directly for the intermediate market niche, or to move away from the high-speed service in an effort to restore market share from within the larger market segments.

The air-freight industry can be identified as one group of operators that might respond to the new service. Currently, it offers service in several forms, like on a space-available basis, on a reserved basis on dedicated air freighters, and as part of door-to-door delivery services.

Space-available cargo flies in the cargo holds of passenger aircraft, as condition permits. Since trans-Atlantic carriers generate over twice as much revenue per passenger than they do from a weight equivalent load of cargo, passengers always take priority and cargo is frequently refused, diverted, or delayed. The response might be expected from this kind of service, is a reduction of the profit margins to maintain existing market shares. However, since the cargo can only be carried when space and payload lift are available, this kind of service cannot be counted upon by shippers who need reliability or guaranteed space.

Standard air cargo services are carried on a dedicated cargo aircraft generally offering airport-to-airport service. Due to fixed high operating costs, these services cannot significantly lower rates and maintain adequate profitability for survival.

The door-to-door delivery services are based on the higher level of service. Thus, the carriers used for this service have significantly higher operating costs, and thus higher freight rates, than the standard air cargo services. To the extent that these services lower their rates and operating costs to compete with the oceanic high-speed service, they merely act as a standard air, and face the same economic constraints on lowering their charges below existing standard air rates.

Technologically, aviation has little feasibility of significantly reducing costs at current service levels within the foreseeable future. Because aircraft operate with substantially fixed cost, cargo volume is critical to airfreight operators, and prices will likely be lowered in the face of declining cargo. Such a reaction may force the least efficient dedicated air cargo carriers to withdraw from this service.

The second group of operators that might respond to the new service comes from the maritime industry. The maritime industry similarly faces economic and technological constraints to its potential competitive response. Standard ocean services are operating with rates close to costs, and rate decreases would be both non-sustainable, and largely ineffective in attracting a service-oriented market base. Maritime services could recapture a limited quantity of cargo from the high-speed service by improving service attributes like transit time, reliability and frequency.

Price-based competitive response will have virtually no impact since the inventory carrying costs are driving the advantage of the new service. A strong competitive response of service enhancement will permit a carrier to move only a short distance away from the pack and towards the high-speed service. In turn, similar competitive responses by the pack to such a move will likely draw the high service quality carrier back into the current lower cost and service quality equilibrium.

Chapter 8

8 Economic Viability of Catamaran Designs

8.1 Assumptions

In this chapter the economic viability of the catamaran designs is examined. For the economic evaluation of the catamaran variants, the MIT Total Logistics Cost model was used. The following is a list of the main assumptions and simplifications made in the model for the evaluation of the catamaran variants.

- The load capacity to displacement ratio was assumed to be the same for all the catamaran variants, equal with the one that *FastShip* exhibits. As a result, by scaling up all the catamaran variants to have the same displacement as *FastShip,* the load capacity of all the variants is equalized with the one of *FastShip,* which is 1416 TEU. Moreover, the same restriction of maximum weight per TEU (8 tons/TEU) was applied to both the monohull and catamaran variants, for the same displacement assumption to stand. Implicit in this assumption is that all the variants share the same construction weight.

- Due to the lack of information for the construction cost of catamaran vessels, all the variants were assumed to exhibit *FastShip's* construction cost. That assumption can be justified in part, by the same construction material weight assumption. By assuming that the construction cost is a function of the weight of the construction materials, and that this weight is the same for all the variants, leads to the same construction cost for all the variants.
- The *FastShip's* trans-Atlantic route from the European port of Cherbourg to the US port of Philadelphia was chosen for the economic evaluation of the catamaran variants and the direct comparison with the high-speed monohull design. All the variants were assumed to operate with the same speed strategy (service speed of 40 knots).
- The time budgeting was assumed to be the same for all the catamaran variants, equal to the one used for *FastShip.* Table 8-1 includes the time budget assumptions as well as some route characteristics for all the vessels.

Time budget assumptions for all variants	
European Port	Cherbourg
US Port	Philadelphia
Europian Land miles	325
Ocean miles	3372
US Land miles	769
Total miles	4466
European land days	0.3
European terminal days	0.5
Ocean days	3.97
US terminal days	1.17
US land days	1.42
Total days per shipment	7.36
Total days per round trip	9.61
Total shipments per week	3.00
Shipments per year	156.00
Days at sea needed for the shipments per year	619.3

Table 8-1: Time budget assumptions and route characteristics

- The advantage of *FastShip* over the conventional containerships in the trans-Atlantic route in terms of trip days saved per shipment was assumed to be 9.35 days. Consequently, the median ocean trip days per shipment was assumed to be 16.71 days.
- By assuming the same propulsion plant in all the variants (same engines, propulsors, etc.), a consistent fuel consumption per horsepower-hour can be assumed for all the ships. The specific fuel consumption, *sfc*, was assumed to be 0.32 lbs/hp-hr for all the ships.
- All the variants were fitted with water-jet propulsors. The pump efficiency and the jet efficiency were assumed to be 0.9 and 0.6 respectively. By using a 0.50 loss factor the overall propulsive coefficient, *PC,* for the water-jet propulsors was evaluated to be 0.54, for all the ships.
- Calm water resistance was used as the indicator of fuel savings benefits. No change was assumed in the fuel consumption due to the different loading conditions of the variants. For all the ships full load calm water resistance was assumed.
- The base year for the cost analysis was 1998.
- All the vessels were assumed to have 15 years of useful economic life.
- The cost of capital for the life cycle savings due to fuel savings was assumed to be 10%.
- The fuel oil price was assumed to be $ 250 per ton.
- The standard deviation of transit time in all the variants was assumed to be equal to that of *FastShip.*

8.2 Life cycle savings by using the Catamaran vessels

By using the assumptions described in the previous paragraph, calculations were made for the evaluation of life cycle savings. *FastShip* was used as baseline for the comparative calculations. For the calculation of the annual fuel consumption, *AFC,* the following formula was used:

$$AFC = \frac{sfc \cdot (EHP / PC) \cdot (TDAS \cdot 24)}{2{,}240} FP \tag{8-1}$$

where, *sfc,* is the specific fuel consumption in lbs/hp-hr, *PC,* is the propulsive coefficient for the water-jets, *FP* is the fuel price in $/ton, and *TDAS* are the total days at sea per year required for annual shipments. The following formula was used for the calculation of *TDAS:*

$$TDAS = (TD) \cdot (SPY) \tag{8-2}$$

where *TD* are the trip days required per shipment, and *SPY* is the shipments per year, directed by the service frequency of 3 shipments per week (156 shipments per year).

By using the *FastShips's* annual fuel cost as the baseline cost, the fuel savings for each catamaran variant were calculated. The following formula provides the annual fuel saving:

$$AS_{cat} = AFC_{cat} - AFC_{FastShip} \tag{8-3}$$

By using the 15 years of economic life of the vessels, cost of capital, *i*= 10%, and 1998 as the base year of the evaluation, the present value of the total fuel savings can be estimated by the following formula:

$$PV(AS) = AS \cdot \sum_{t=1}^{15} \frac{1}{(1+i)^t} \tag{8-4}$$

For the annual fuel saving to be used in the MIT total logistics cost model, it must be translated into terms of savings in the transportation cost per FEU. By using the service frequency assumption of 3 shipments per week and the load capacity (same for all the variants) 708 FEUs, the total annual load capacity, *TALC,* can be estimated from the following formula:

$$TALC(FEUs) = VLC(FEUs) \cdot SPY \tag{8-5}$$

where , VLC is the vessels' load capacity, and SPY are the shipments per year. The estimated total annual demand, *ETAD,* for *FastShip* (Reference [27]) is 279,539 FEUs. Thus, the fuel savings per FEU can be estimated by the following formula:

(8-6) $$FS(\$)/FEU = AS/\min(TALC, ETAD)$$

Finally, the fuel savings per FEU of each catamaran variant can be directly used to evaluate the cost of transportation per FEU for each catamaran variant, given the cost of transportation that is assumed for *FastShip,* by using the following formula:

(8-7) $$COT_{cat} = COT_{FastShip} - FS(\$)/FEU$$

Table 8-2 includes the results of the aforementioned calculations for the three catamaran variants.

Input parameters	
Fuel price ($/ton)	250
Specific fuel consumption (lb/(hr.hp)	0.32
Load capacity (FEU) per ship	708
Total annual load capacity (FEUs)	110,448
Total projected annual FEU demand (1998)*	279,539

* the total demand for *FastShip* as projected in phase II report

Fuel savings calculations	**FastShip (TGN770) baseline case**	**"Shallow transom" catamaran**	**"Deep transom" catamaran**	**"Asymmetric demi-hull" catamaran**
Speed (knots)	40	40	40	40
Resistance (kNts)	10,307	8,536	12,240	9,586
EHP	284,422	235,551	337,763	264,526
Propulsive coefficient	0.54	0.54	0.54	0.54
BHP	526,707	436,206	625,487	489,863
Power gain	0.00%	17.18%	-18.75%	7.00%
Annual Fuel cost	279,600,370	231,558,044	332,037,308	260,041,636
Annual Fuel savings	-	48,042,326	(52,436,938)	19,558,734
Vessel's economic life	15	15	15	15
Cost of Capital	10%	10%	10%	10%
PV of fuel savings	-	365,413,752	(398,839,516)	148,765,282
Fuel savings per FEU ($/FEU)	-	435	(475)	177
Cost of transportation/ FEU (using 94% premium)	3500	3,065	3,975	3,323

Table 8-2: Fuel savings calculations for the catamaran variants

By examining the results in the previous table, the potential benefits of using a high-speed catamaran design in the trans-Atlantic route is obvious. Both the "shallow transom" and the "asymmetric demi-hull" variant exhibit lower calm water resistance than the *FastShip,* resulting in the reduction of annual fuel expenses. However, the "deep transom" catamaran due to the higher calm water resistance, lacks the ability of providing fuel savings.

From all the catamaran variants the " shallow transom" designs is the most prominent. With power savings reaching 17% of the power needed for *FastShip* to achieve the servicing speed of 40 knots, it can easily provide annual fuel savings reaching $48 M/year. The resulting fuel saving per FEU, for the same design, are estimated to be $435/FEU. The savings will be seen directly in the transportation cost, which means $435 less cost of transportation per FEU.

The "asymmetric demi-hull" variant also provides fuel savings. The calm water resistance of this design is higher than the one of "shallow transom" variant, yet, less than the one of *FastShip*. The fuel savings reach the amount of $ 20M per year resulting in a $ 177/ FEU reduction in the transportation cost.

Table 8-3 includes the effects of using a different cost of capital in the calculation for the present value.

Cost of capital sensitivity analysis	FastShip (TGN770) baseline case	"Shallow transom" catamaran	"Deep transom" catamaran	"Asymmetric demi-hull" catamaran
Annual Fuel savings	-	48,042,326	(52,436,938)	19,558,734
Vessel's economic life	15	15	15	15
PV of fuel savings (i=5%)	-	498,662,916	(544,277,480)	203,012,966
PV of fuel savings (i=7.5%)	-	424,075,365	(462,867,127)	172,647,283
PV of fuel savings (i=10%)	-	365,413,752	(398,839,516)	148,765,282
PV of fuel savings (i=12.5%)	-	318,659,663	(347,808,655)	129,731,009
PV of fuel savings (i=15%)	-	280,921,261	(306,618,181)	114,367,154
PV of fuel savings (i=17.5%)	-	250,092,261	(272,969,136)	101,816,217
PV of fuel savings (i=20%)	-	224,620,581	(245,167,467)	91,446,324

Table 8-3: Cost of capital sensitivity analysis

The decision, whether an owner should proceed with the investment, is based on the Net Present Value, NPV, of the benefits. By assuming the same construction cost for the catamarans and the *FastShip,* the net benefits are the same as the present value of the annual fuel savings. However, this is not the case if higher construction cost is assumed for the catamarans. Then the differential construction cost must be subtracted from the present value of the fuel savings for the evaluation of the NPV of the benefits. This subtraction could lead to positive or negative NPV. The maximization of the benefits' NPV is one criterion that should trigger the choice of the appropriate variant.

8.3 Total Logistic Cost Analysis

8.3.1 Total Logistics cost model results

Table 8-2 includes the resulting fuel savings per FEU of the catamaran variants. The catamarans were considered to have a lower transportation cost due to these savings. For the *FastShip* the break-even rate of $ 3500/ FEU was assumed. The resulting break-even rates for the catamarans are also included in Table 8-2. The medium ocean cost of transportation as well as the break-even rates of the variants are also included in Figure 8.3.1-1 for comparison.

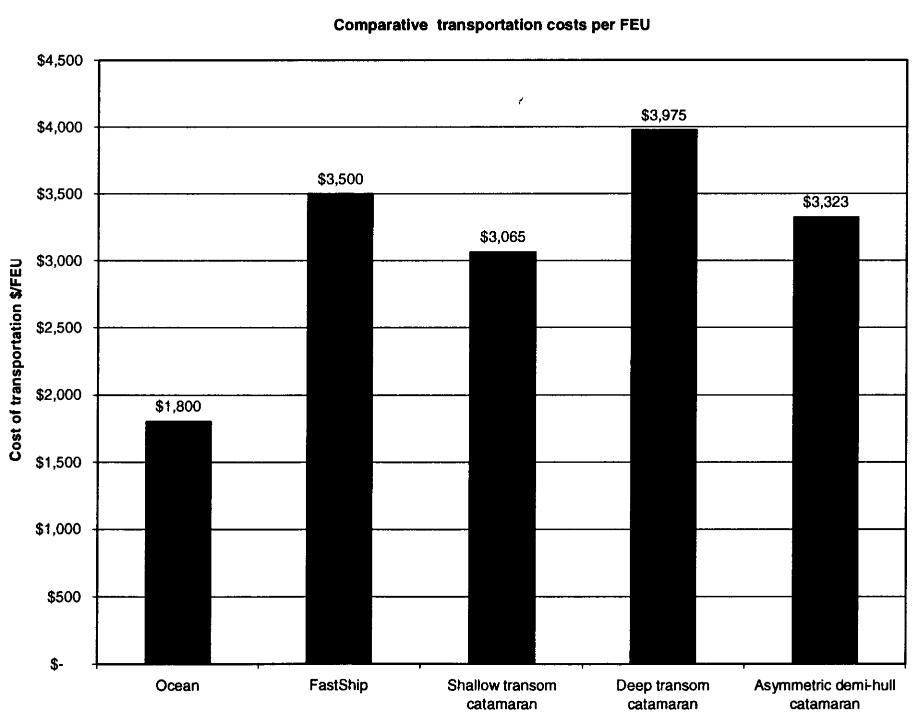


Figure 8.3.1-1: Transportation costs per FEU

The resulting transportation costs per FEU were used in the MIT total logistics model. The various logistics costs, which appear in the model, were described in the previous chapter. All of them, with the exception of cost of transportation, are functions of the ship's speed and the time budgeting assumptions. The same speeds and time budgeting assumptions for all the variants drive all the logistics costs of the catamaran variants to the same values that *Fastship* exhibits. However, the different transportation costs differentiate the resulting total logistics costs of the catamaran variants with respect the one of *FastShip*.

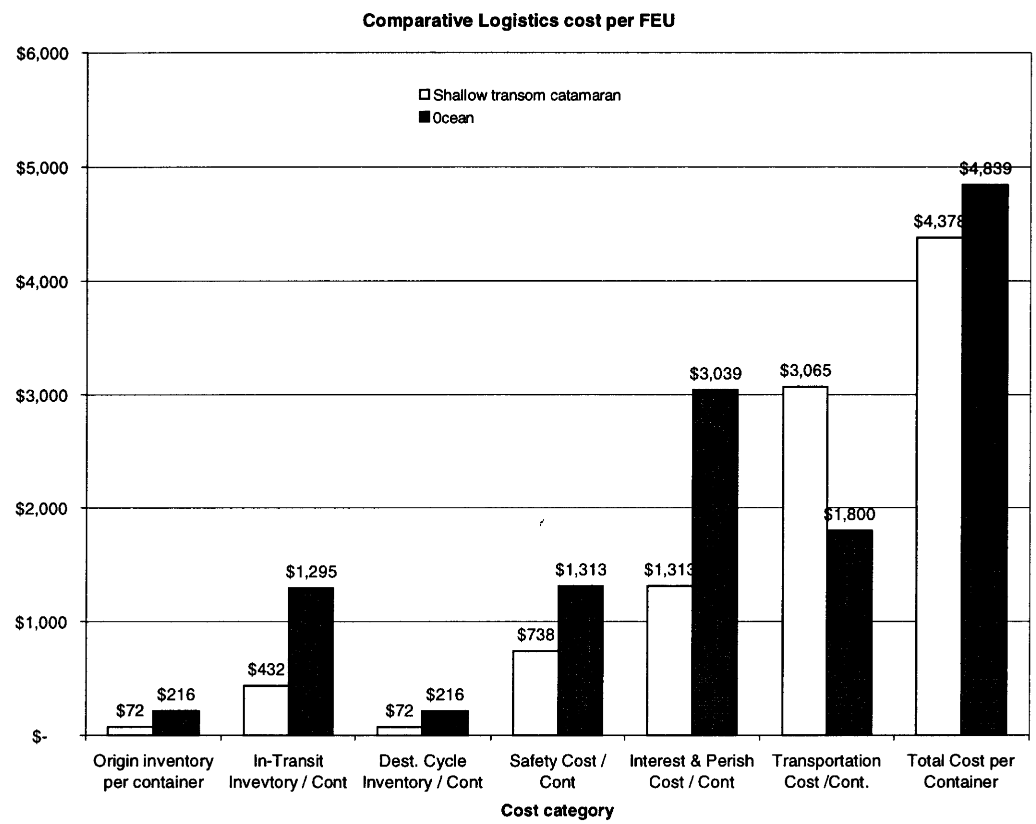


Figure 8.3.1-2: Comparative logistics costs per FEU for the "shallow transom" catamaran and the median Ocean freight

Using the MIT total logistics cost model, the total logistic cost was calculated for all the variants. Different commodities were used in the calculations, and for each commodity the different parameters were varied. Appendix 1 includes the total logistics model results for the *FastShip* and the three catamaran variants for a specific commodity, having a value per pound of $3.99/lb. The set of input parameters used in the calculations in Appendix 1 represents the base case for the following sensitivity analysis (Appendix 2).

Figure 8.3.1-2 includes the various resulting logistics costs for the best catamaran variant (shallow transom catamaran) and the median ocean freight. The higher fuel saving per FEU, for this catamaran variant, results in a lower total logistics cost. As expected the shallow transom catamaran's total logistics cost differs from the *FastShip's* cost by the amount of fuel savings. Nevertheless, as indicated in Appendix 1 calculations, the use of this design will maximize the savings per FEU with respect the median ocean freight.

8.3.2 Sensitivity analysis results

The MIT total logistics model was used to conduct sensitivity analyses in order to determine the effect of the various model input parameters on the total logistics cost savings. For the analyses only the best catamaran variant ("shallow transom" catamaran) and the baseline variant (*FastShip*) were used. For *FastShip* the break-even freight rate of 3500 $/FEU (with 94% premium over the median ocean rate of $ 1800/FEU) was used. The catamaran's freight rate was adjusted to reflect the fuel savings. For all the cases different sets of parameters were used and calculations were made for commodity value densities ranging from 1 to 50 $/lb. The graphical presentation of the resulting total logistics cost savings for the catamaran variant and *FastShip* are included in Appendix 2.

The parameters having the greatest impact on the model results are the commodity value density and the annual carrying charge. Product density, storability, travel reliability and travel time were also found to exert significant, however less important, effect on the model results. Product's time sensitivity (represented in the model by parameters such as shelf life, salvage value and decay parameter) also exhibits some significant effects when varied under certain combinations of commodity and service characteristics.

The fuel savings, exhibited by the catamaran variant, result in a consistently wider range of product value densities where savings could be seen, for all the possible combinations of the commodity input parameters. In addition, whenever the model results in savings for both variants, the catamaran variant, as expected, consistently indicates higher savings due to the fuel savings. The triangular shape of the resulting graphs indicates that the maximum saving exists for a particular product density value. However, this value changes as different sets of input parameters where used.

In the base case a non-time-sensitive product was used with density of 10.7 lb/cu.ft. The results indicate that maximum savings occur when the product value density is around $15/lb. In that case the catamaran design exhibits savings when the product value density ranged between $2 and $39/lb., and the *FastShip* when the same value ranged between $3.5 to $37/lb.

The annual carrying cost affects both the range of value densities where savings can occur, and the value density of maximum savings. Higher annual costs minimize the range of values where saving can occur and also shift the value density of maximum savings towards lower values. However, the value of maximum savings, whenever it occurs, remains independent of the variation of carrying cost. The higher product density and the higher storability generate similar effects. However, in the range that these two factors can be varied, the effects are less important on the model results.

Two seasonal commodities and six perishable commodities were tested in the model to address the product time sensitivity effects on the savings. In particular, the shelf life, salvage value and the decay parameter were varied under certain combinations of commodity and service characteristics. The results indicate noticeable effects on the range of product density values that produce savings when shelf life drops less than 20 days. Then the savings, if any, occurs only for low value density products. However, the value of maximum savings is increased as the product become more perishable. The higher value density products are all absorbed by airfreight which provides lower total logistics cost.

8.3.3 Latent and stimulated demand

The formulas and assumptions behind the latent and stimulated demand calculations were briefly presented in the previous chapter. *FastShip* and the three catamaran designs were evaluated in stimulation of demand. Five representative commodity groups were used in the calculations. The commodity parameters were adjusted accordingly to represent the commodity groups. A maximum container load of 59,000 lb./FEU was used in the calculations. The results for the four variants are included in Appendix 3.

The stimulated demand varies significantly for each specific commodity group. Again the "shallow transom" catamaran design is seen to have the highest savings compared with the other modes of transportation, due to the fuel savings. For this variant the total logistics cost savings for certain commodity group (bread, pastry, cakes, etc.) exceeded the 25.5% (w/o rate premium), and 20.7% (w/ 94% rate premium) of the commodity value. In the same case the stimulated demand reaches the high value of 33.5% over the exports in FEUs of that commodity. However, in the case of the perishable commodity groups of fresh cut flowers and fresh or chilled fishes, all the variants fail to generate savings due to the lower total logistics cost exhibited by the air freight. As a result the stimulation of demand fails for these commodity groups.

In general the high-speed ocean transportation is favored by commodities having relatively low value densities (from 0.25 to 2.0), shelf lives more than two weeks, and high salvage value and decay parameter. Groups of commodities like first class mail and newspapers, certain fresh bread, pastry etc., and data process machines etc., may increase their trans-Atlantic demand by from 1.0 to 26.4% for the case of the "shallow transom" catamaran design. In the best case (for fresh bread and pastries) the stimulation of demand by this catamaran variant exceeds by almost 2% the corresponding one exhibited by *FastShip*.

Chapter 9

9 Conclusions

A time-domain Rankine panel method code, SWAN-2, was utilized for the evaluation of calm water wave resistance and seakeeping performance of various multi-hull designs, such as catamarans and trimarans. A quick review of the steps followed in this study, is included:

- Design of the multi-hull variants. Three catamaran variants and one trimaran variant were designed to include geometrical complexities common in real-life designs (i.e. transom sterns). Geometrical differences between the catamaran variants were carefully selected in the design stage for the comparative examination to reveal the effects of such differences on variants performance.
- Appropriate computational models of the variants were generated for input into SWAN 2. This includes generation of free surface and hull grids, as well as, generation of appropriate input files.

- The calm water wave resistance of the variants was evaluated using linear potential flow calculations and including waterline terms and hydrostatic terms due to the dry transom in high Froude numbers.
- Heave and pitch RAOs were evaluated for the bare hull variants in head seas.
- Heave and pitch RAOs were re-evaluated in head seas for the case that winglets/foils were added as appendages in the multi-hull designs.

The data collected for the resistance and seakeeping performance of the variants with and without foils/winglets were compared with each other and with those of a monohull high-speed design (*TGN-770*). Some conclusions derived from the direct comparison. The effects of the transom geometry on the ship's resistance and seakeeping characteristics appear to be large. Big deep transoms have adverse effects on the calm water wave resistance, mainly due to the large hydrostatic force caused by the dry transom in high speeds. The effects on seakeeping performance are less; however, deep transoms usually cause the aggravation of the heave and pitch motions in head waves.

The advantage of the catamaran designs over the monohull designs with respect the high-speed calm water wave resistance was also revealed in this study. This advantage is a result of less wave generation,, exhibited by the multi-hull designs mainly due to the slenderness of the hulls. However, the larger wetted surface area of the same designs, definitely, creates the disadvantage of higher frictional resistance, which is dominant in lower speeds. From the comparison of heave and pitch RAOs in head seas of the monohull and catamaran designs, the resonance frequency of both motions appears to shift toward higher frequencies for the latter designs. That could be an advantage or disadvantage, depending on the most probable ambient wave frequency of the sea environment that the ship will sail. Usually, in large open seas like the Atlantic Ocean large low frequency wave are most common. So, catamarans, which resonate in higher frequencies, are likely to have a better heave and pitch performance in head seas.

Lower, but still significant, effects were caused by the separation between the demi-hulls in the catamaran designs in both the calm water resistance and seakeeping performance. In general, the magnitude of the interaction between the demi-hulls seems to have a small negative effect on the calm water resistance. However, for some Froude numbers positive effects were also witnessed. Moreover, the same interaction was observed to have positive effects in the seakeeping performance, especially on the pitch RAO.

By utilizing the data gathered for the calm water resistance for the catamaran designs and the available resistance experimental data for TGN770, a comparative logistics cost analysis was performed by using the MIT Total Logistics Cost Model. The trans-Atlantic route between the European port of Cherbourg and the U.S. port of Philadelphia was selected for the performance of the comparative analysis. The high-speed monohull variant (*FastShip*), originally designed for that route, was selected as baseline variant for the comparative analysis. The variants' calm water resistance differences with respect the baseline ship, were then translated to fuel savings which have a direct effect on the cost of transportation.

The total logistic cost analyses were performed in order to estimate how the trans-Atlantic shippers will value the characteristics of the high-speed ocean service relative to the currently existing ocean and air service. The logistics analyses revealed that the "shallow transom" catamaran variant with separation between hulls, S/L=0.2, generates higher savings and stimulates higher demand than *FastShip*, totally due to the fuel savings generated by the lower total calm water resistance of the design. Lower savings and stimulation of demand, yet higher than *FastShip,* were generated by the "asymmetric demi-hull" catamaran design. Finally, the last catamaran variant, namely the "deep transom" variant, fails to generate savings over *FastShip* due to the higher calm water resistance it exhibits. The analysis proved that a catamaran variant could easily increase the benefits in the trans-Atlantic high-speed oceanic service, by generating more benefits due to the fuel savings and by triggering more stimulated demand.

The calculations performed in both the hydrodynamic part and the logistic analysis part of this thesis are based on assumptions made mainly due to the lack of information. For the resistance and seakeeping performance evaluation of the variants a numerical code was utilized. However, tank testing is still required in the final stage of design to verify the numerical results.

The comparative total logistic cost analysis, performed in the last part of this thesis, was based on the assumptions stated in the first paragraph of Chapter 8. Some of these assumptions, like the equal construction weight, cost, and loading factor for the monohull and the catamaran designs, may not be applicable in reality. By changing the assumptions, the same calculations may give totally different results. For example, by assuming higher construction cost for the catamaran designs the difference of NPV between the monohull and catamaran projects decreases. Depending on the construction cost difference the monohull choice may become more attractive in terms of NPV. The differences in the construction weight and loading factor affect directly the displacement difference between the monohull and catamaran variants. That will directly affect the resistance calculations for the variants, thus, the fuel savings estimations.

For the reasons mentioned above, further investigation is needed for the adjustment of the assumptions. Furthermore, tank model testing in the final design stage is required before the selection of the more efficient variant.

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Appendix 1: Total Logistic Cost analysis Model

TOTAL LOGISTICS COST ANALYSIS MODEL

MODEL INPUTS

$ 3.99	Value per Pound
10.7	Density of Stowage (lb/cu.ft)
22.50%	Annual Carrying Charge
365	Demand Period (days)
4,563	Period Demand (tonnes)
365	Shelf Life (days)
100%	Per Cent Salvage Value
3	Perish / Decay parameter
94%	Fastship / Ocean Price Premium
$ -	Warehouse Cost / lb /year
300%	Coef. of Var. of Product Demand
85%	Container Space Used
40	Container Length (ft)
8	Container Width (ft)
9.5	Container Height (ft)

Ocean

1800	Transportation Cost per Container
16.71	Average Trip Time (days)
3.15	Std. Dev. of Trip Time (days)
3.00	Std. Deviations for Safety Stock
52	Shipments per Demand Period

Fastship

$ 3,500	Transportation Cost per Container
7.36	Average Trip Time (days)
0.17	Std. Dev. of Trip Time (days)
3	Std. Deviations for Safety Stock
156	Shipments per Demand Period

Summary Output:	Fast Ship	Ocean	Rate Premium		Savings:	w/prem.	without
Cost per container:	$ 5,815	$ 5,929	94%	$ 1,700		$ 114	$ 1,814

CALCULATED CONTAINER CHARACTERISTICS

943,160	Cubic ft. Annual Demand
2584	Cubic ft. used per Container
12.50	Cargo wt. per Cont. (tonnes)
1.00	Daily Sales
3.00	Std. Dev. of daily sales

365	Containers Demand in Period
$ 109,986.43	Value per container
$ 40,145,046	Period Value of Commodity

DETAILED MODEL OUTPUT - OCEAN

52	Shipments per Demand Period	7.0	Average Shipment Size (in Containers)
$ -	Perisable Cost / Cont.	$ -	Annual Perisable Costs
$ -	Origin Warehouse Cost / Cont.	$ -	Annual Origin Warehouse Costs
$ 238	Origin inventory per container	$ 86,852	Annual Origin Inventory Costs
$ 1,133	In-Transit Inventory / Cont.	$ 413,521	Annual In-Transit Inventory Costs
$ 238	Dest. Cycle Inventory / Cont.	$ 86,852	Annual Dest. Cycle inventory Costs
$ 2,520	Safety Cost / Cont.	$ 919,928	Annual Safety Stock Costs
$ 4,129	Interest & Perish Cost / Cont.	$ 1,507,154	Annual Interest & Perish Costs
$ 1,800	Transportation Cost /Cont.	$ 657,000	Annual Transportation Costs
$ 5,929	**Total Cost per Container**	$ 2,164,154	**Annual Total Logistics Cost**

DETAILED MODEL OUTPUT - FASTSHIP

156	Shipments per Demand Period	2.3	Average Shipment Size (in Containers)
$ -	Perisable Cost / Cont.	$ -	Annual Perisable Costs
$ -	Origin Warehouse Cost / Cont.	$ -	Annual Origin Warehouse Costs
$ 79	Origin inventory per container	$ 28,951	Annual Origin Inventory Costs
$ 499	In-Transit Inventory / Cont.	$ 182,138	Annual In-Transit Inventory Costs
$ 79	Dest. Cycle Inventory / Cont.	$ 28,951	Annual Dest. Cycle inventory Costs
$ 1,658	Safety Cost / Cont.	$ 605,006	Annual Safety Stock Costs
$ 2,315	Interest & Perish Cost / Cont.	$ 845,045	Annual Interest & Perish Costs
$ 3,500	Transportation Cost /Cont.	$ 1,277,500	Annual Transportation Costs
$ 5,815	**Total Cost per Container**	$ 2,122,545	**Annual Total Logistics Cost**

TOTAL LOGISTICS COST ANALYSIS MODEL

MODEL INPUTS

$ 3.99	Value per Pound		**Ocean**
10.7	Density of Stowage (lb/cu.ft)	1800	Transportation Cost per Container
22.50%	Annual Carrying Charge	16.71	Average Trip Time (days)
365	Demand Period (days)	3.15	Std. Dev. of Trip Time (days)
4,563	Period Demand (tonnes)	3.00	Std. Deviations for Safety Stock
365	Shelf Life (days)	52	Shipments per Demand Period
100%	Per Cent Salvage Value		
3	Perish / Decay parameter		**"Shallow Transom" Catamaran**
94%	Fastship / Ocean Price Premium	$ 3,065	Transportation Cost per Container
$ -	Warehouse Cost / lb /year	7.36	Average Trip Time (days)
300%	Coef. of Var. of Product Demand	0.17	Std. Dev. of Trip Time (days)
85%	Container Space Used	3	Std. Deviations for Safety Stock
40	Container Length (ft)	156	Shipments per Demand Period
8	Container Width (ft)	$ 435	Fuel savings/FEU
9.5	Container Height (ft)		

Summary Output:	Fast Ship	Ocean	Rate Premium		Savings:	w/prem.	without
Cost per container:	$ 5,380	$ 5,929	94%	$ 1,700		$ 549	$ 2,249

CALCULATED CONTAINER CHARACTERISTICS

943,160	Cubic ft. Annual Demand	365	Containers Demand in Period
2584	Cubic ft. used per Container	$ 109,986.43	Value per container
12.50	Cargo wt. per Cont. (tonnes)	$ 40,145,046	Period Value of Commodity
1.00	Daily Sales		
3.00	Std. Dev. of daily sales		

DETAILED MODEL OUTPUT - OCEAN

52	Shipments per Demand Period	7.0	Average Shipment Size (in Containers)
$ -	Perisable Cost / Cont.	$ -	Annual Perisable Costs
$ -	Origin Warehouse Cost / Cont.	$ -	Annual Origin Warehouse Costs
$ 238	Origin inventory per container	$ 86,852	Annual Origin Inventory Costs
$ 1,133	In-Transit Inventory / Cont.	$ 413,521	Annual In-Transit Inventory Costs
$ 238	Dest. Cycle Inventory / Cont.	$ 86,852	Annual Dest. Cycle inventory Costs
$ 2,520	Safety Cost / Cont.	$ 919,928	Annual Safety Stock Costs
$ 4,129	Interest & Perish Cost / Cont.	$ 1,507,154	Annual Interest & Perish Costs
$ 1,800	Transportation Cost /Cont.	$ 657,000	Annual Transportation Costs
$ 5,929	**Total Cost per Container**	$ 2,164,154	**Annual Total Logistics Cost**

DETAILED MODEL OUTPUT - SHALLOW TRANSOM CATAMARAN

156	Shipments per Demand Period	2.3	Average Shipment Size (in Containers)
$ -	Perisable Cost / Cont.	$ -	Annual Perisable Costs
$ -	Origin Warehouse Cost / Cont.	$ -	Annual Origin Warehouse Costs
$ 79	Origin inventory per container	$ 28,951	Annual Origin Inventory Costs
$ 499	In-Transit Inventory / Cont.	$ 182,138	Annual In-Transit Inventory Costs
$ 79	Dest. Cycle Inventory / Cont.	$ 28,951	Annual Dest. Cycle inventory Costs
$ 1,658	Safety Cost / Cont.	$ 605,006	Annual Safety Stock Costs
$ 2,315	Interest & Perish Cost / Cont.	$ 845,045	Annual Interest & Perish Costs
$ 3,065	Transportation Cost /Cont.	$ 1,118,725	Annual Transportation Costs
$ 5,380	**Total Cost per Container**	$ 1,963,770	**Annual Total Logistics Cost**

TOTAL LOGISTICS COST ANALYSIS MODEL

MODEL INPUTS

$ 3.99	Value per Pound
10.7	Density of Stowage (lb/cu.ft)
22.50%	Annual Carrying Charge
365	Demand Period (days)
4,563	Period Demand (tonnes)
365	Shelf Life (days)
100%	Per Cent Salvage Value
3	Perish / Decay parameter
94%	Fastship / Ocean Price Premium
$ -	Warehouse Cost / lb /year
300%	Coef. of Var. of Product Demand
85%	Container Space Used
40	Container Length (ft)
8	Container Width (ft)
9.5	Container Height (ft)

Ocean

1800	Transportation Cost per Container
16.71	Average Trip Time (days)
3.15	Std. Dev. of Trip Time (days)
3.00	Std. Deviations for Safety Stock
52	Shipments per Demand Period

"Deep Transom" Catamaran

$ 3,975	Transportation Cost per Container
7.36	Average Trip Time (days)
0.17	Std. Dev. of Trip Time (days)
3	Std. Deviations for Safety Stock
156	Shipments per Demand Period
$ (475)	Fuel savings/FEU

Summary Output:	Fast Ship	Ocean	Rate Premium		Savings:	w/prem.	without
Cost per container:	$ 6,290	$ 5,929	94%	$ 1,700		$ (361)	$ 1,339

CALCULATED CONTAINER CHARACTERISTICS

943,160	Cubic ft. Annual Demand
2584	Cubic ft. used per Container
12.50	Cargo wt. per Cont. (tonnes)
1.00	Daily Sales
3.00	Std. Dev. of daily sales

365	Containers Demand in Period
$ 109,986.43	Value per container
$ 40,145,046	Period Value of Commodity

DETAILED MODEL OUTPUT - OCEAN

52	Shipments per Demand Period	7.0	Average Shipment Size (in Containers)
$ -	Perisable Cost / Cont.	$ -	Annual Perisable Costs
$ -	Origin Warehouse Cost / Cont.	$ -	Annual Origin Warehouse Costs
$ 238	Origin inventory per container	$ 86,852	Annual Origin Inventory Costs
$ 1,133	In-Transit Inventory / Cont.	$ 413,521	Annual In-Transit Inventory Costs
$ 238	Dest. Cycle Inventory / Cont.	$ 86,852	Annual Dest. Cycle inventory Costs
$ 2,520	Safety Cost / Cont.	$ 919,928	Annual Safety Stock Costs
$ 4,129	Interest & Perish Cost / Cont.	$ 1,507,154	Annual Interest & Perish Costs
$ 1,800	Transportation Cost /Cont.	$ 657,000	Annual Transportation Costs
$ 5,929	**Total Cost per Container**	$ 2,164,154	**Annual Total Logistics Cost**

DETAILED MODEL OUTPUT - DEEP TRANSOM CATAMARAN

156	Shipments per Demand Period	2.3	Average Shipment Size (in Containers)
$ -	Perisable Cost / Cont.	$ -	Annual Perisable Costs
$ -	Origin Warehouse Cost / Cont.	$ -	Annual Origin Warehouse Costs
$ 79	Origin inventory per container	$ 28,951	Annual Origin Inventory Costs
$ 499	In-Transit Inventory / Cont.	$ 182,138	Annual In-Transit Inventory Costs
$ 79	Dest. Cycle Inventory / Cont.	$ 28,951	Annual Dest. Cycle inventory Costs
$ 1,658	Safety Cost / Cont.	$ 605,006	Annual Safety Stock Costs
$ 2,315	Interest & Perish Cost / Cont.	$ 845,045	Annual Interest & Perish Costs
$ 3,975	Transportation Cost /Cont.	$ 1,450,875	Annual Transportation Costs
$ 6,290	**Total Cost per Container**	$ 2,295,920	**Annual Total Logistics Cost**

TOTAL LOGISTICS COST ANALYSIS MODEL

MODEL INPUTS

$ 3.99	Value per Pound
10.7	Density of Stowage (lb/cu.ft)
22.50%	Annual Carrying Charge
365	Demand Period (days)
4,563	Period Demand (tonnes)
365	Shelf Life (days)
100%	Per Cent Salvage Value
3	Perish / Decay parameter
94%	Fastship / Ocean Price Premium
$ -	Warehouse Cost / lb /year
300%	Coef. of Var. of Product Demand
85%	Container Space Used
40	Container Length (ft)
8	Container Width (ft)
9.5	Container Height (ft)

Ocean

1800	Transportation Cost per Container
16.71	Average Trip Time (days)
3.15	Std. Dev. of Trip Time (days)
3.00	Std. Deviations for Safety Stock
52	Shipments per Demand Period

"Asymmetric demi-hull" Catamaran

$ 3,323	Transportation Cost per Container
7.36	Average Trip Time (days)
0.17	Std. Dev. of Trip Time (days)
3	Std. Deviations for Safety Stock
156	Shipments per Demand Period
$ 177	Fuel savings/FEU

Summary Output:	Fast Ship	Ocean	Rate Premium		Savings:	w/prem.	without
Cost per container:	$ 5,638	$ 5,929	94%	$ 1,700		$ 291	$ 1,991

CALCULATED CONTAINER CHARACTERISTICS

943,160	Cubic ft. Annual Demand
2584	Cubic ft. used per Container
12.50	Cargo wt. per Cont. (tonnes)
1.00	Daily Sales
3.00	Std. Dev. of daily sales

365	Containers Demand in Period
$ 109,986.43	Value per container
$ 40,145,046	Period Value of Commodity

DETAILED MODEL OUTPUT - OCEAN

52	Shipments per Demand Period	7.0	Average Shipment Size (in Containers)
$ -	Perisable Cost / Cont.	$ -	Annual Perisable Costs
$ -	Origin Warehouse Cost / Cont.	$ -	Annual Origin Warehouse Costs
$ 238	Origin inventory per container	$ 86,852	Annual Origin Inventory Costs
$ 1,133	In-Transit Inventory / Cont.	$ 413,521	Annual In-Transit Inventory Costs
$ 238	Dest. Cycle Inventory / Cont.	$ 86,852	Annual Dest. Cycle inventory Costs
$ 2,520	Safety Cost / Cont.	$ 919,928	Annual Safety Stock Costs
$ 4,129	Interest & Perish Cost / Cont.	$ 1,507,154	Annual Interest & Perish Costs
$ 1,800	Transportation Cost /Cont.	$ 657,000	Annual Transportation Costs
$ 5,929	**Total Cost per Container**	$ 2,164,154	**Annual Total Logistics Cost**

DETAILED MODEL OUTPUT - ASYMMETRIC DEMI-HULL CATAMARAN

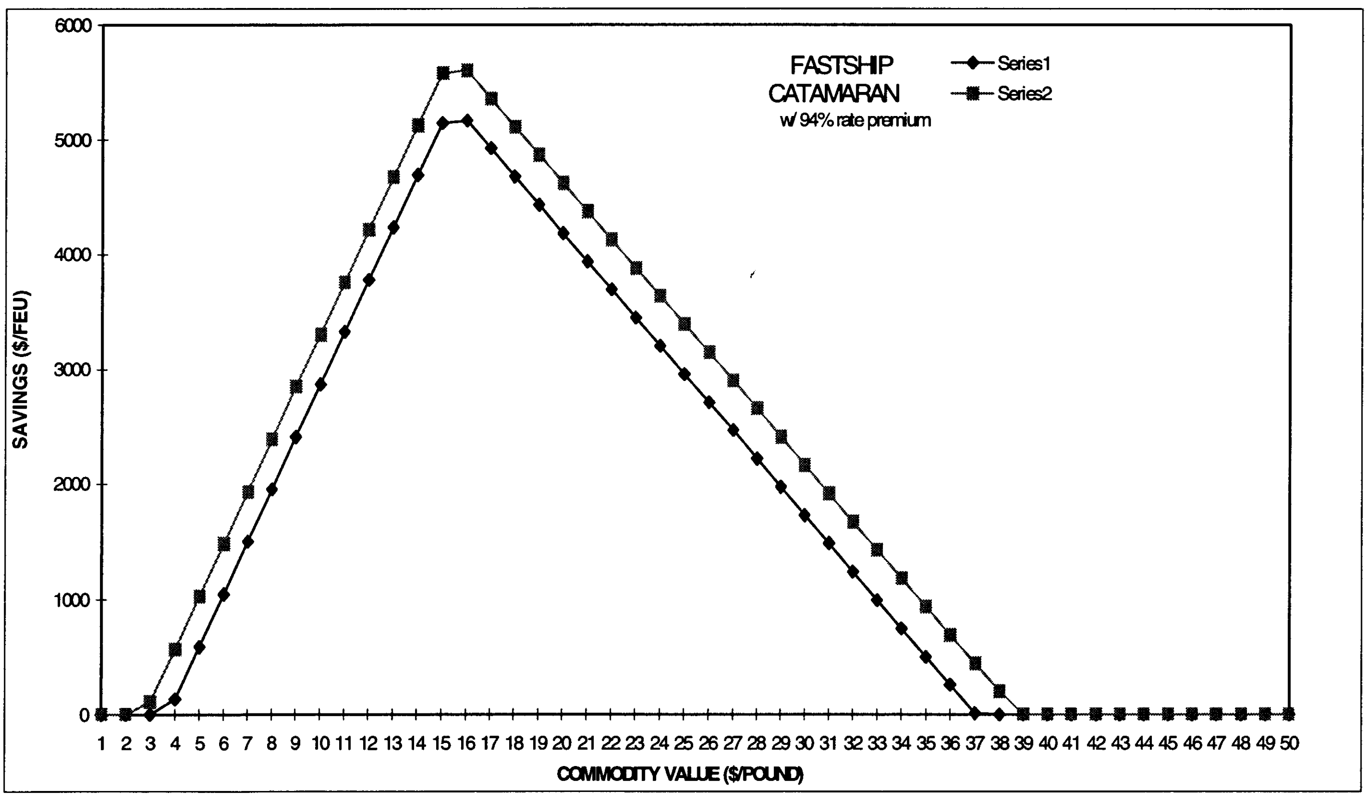
156	Shipments per Demand Period	2.3	Average Shipment Size (in Containers)
$ -	Perisable Cost / Cont.	$ -	Annual Perisable Costs
$ -	Origin Warehouse Cost / Cont.	$ -	Annual Origin Warehouse Costs
$ 79	Origin inventory per container	$ 28,951	Annual Origin Inventory Costs
$ 499	In-Transit Inventory / Cont.	$ 182,138	Annual In-Transit Inventory Costs
$ 79	Dest. Cycle Inventory / Cont.	$ 28,951	Annual Dest. Cycle inventory Costs
$ 1,658	Safety Cost / Cont.	$ 605,006	Annual Safety Stock Costs
$ 2,315	Interest & Perish Cost / Cont.	$ 845,045	Annual Interest & Perish Costs
$ 3,323	Transportation Cost /Cont.	$ 1,212,895	Annual Transportation Costs
$ 5,638	**Total Cost per Container**	$ 2,057,940	**Annual Total Logistics Cost**

Appendix 2: Sensitivity Analysis Results

TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
BASE CASE

FEUs Shipped Annually		365
Density(lb./Cu. Ft.)		10.7
Value Density ($/lb.)	$	3.99
Cubic Value ($/Cu.Ft.)	$	42.69
Tonnes per FEUs		12.54
Lbs. per FEU		27,649
Value per FEU	$	110,319
Annual Carrying Charge		22.5%
Demand Period		365
Shelf Life (Days)		365
Salvage Value		100%
Decay Parameter		3.0
Stock-out Cost (Stc. Devs. for Safety Stock)		3.00
Warehouse Cost ($/lb./year)	$	-
Daily Sales (FEU)		1.00
Coef. of Var. of Daily Sales		300%
Std. Dev of Daily Sales		3.00
Storability (FEU load factor)		85%

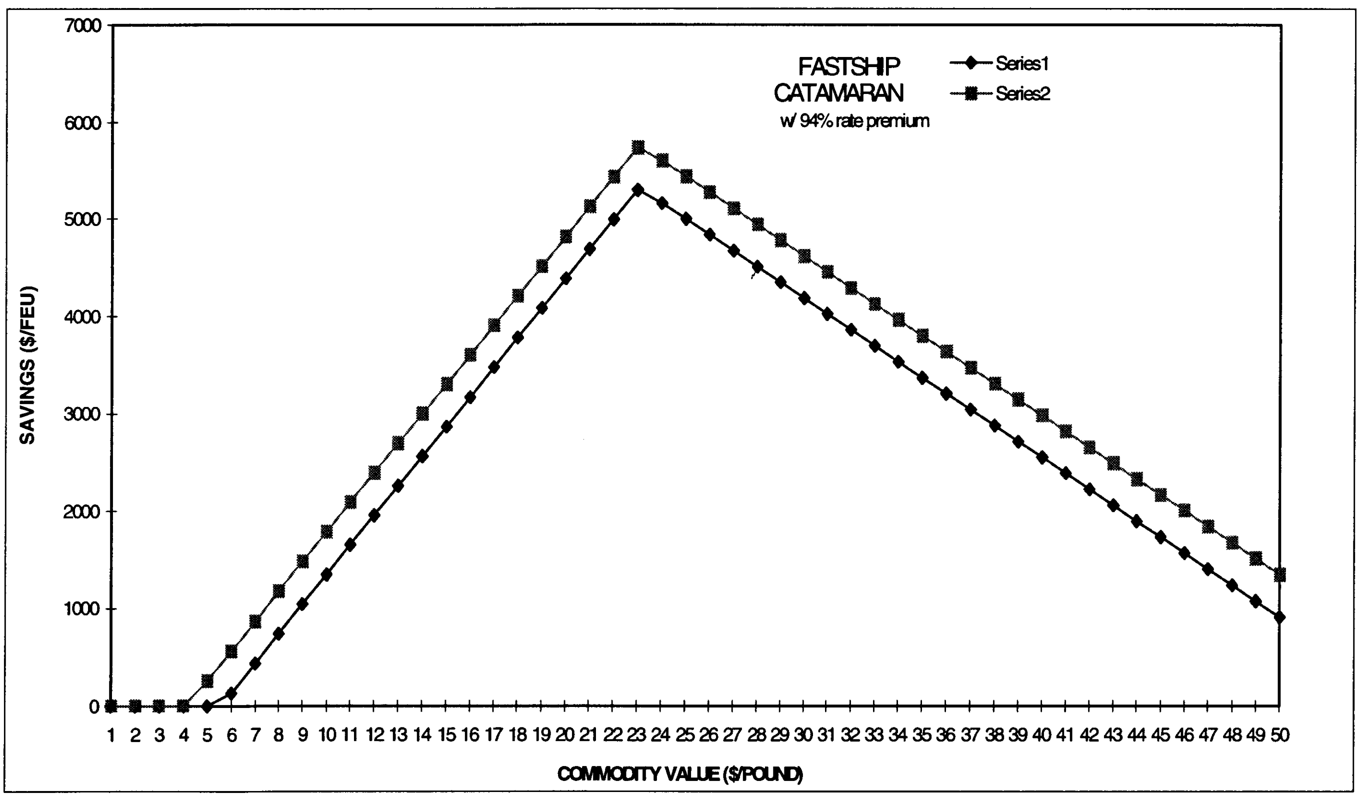
Standard Ocean	Freight Rate/ FEU	$	1,800
	Transit Time (days)		16.71
	Std. Dev. of Transit Time		3.15
	Service Freq. (Shipments per Demand Period)		52
	Avg. Shipment Size		7.0
Standard Air Freight	Freight Rate/ FEU	$	12,600
	Transit Time (days)		3.0
	Std. Dev. of Transit Time		0.5
	Service Freq. (Shipments per Demand Period)		365
	Avg. Shipment Size		1.0
FastShip	Freight Rate/ FEU	$	1,800
	Transit Time (days)		7.36
	Std. Dev. of Transit Time		0.17
	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3
"Shallow transom"	Freight Rate/ FEU	$	1,365
Catamaran	Transit Time (days)		7.36
Fuel savings/FEU	Std. Dev. of Transit Time		0.17
$ 435	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE: VERY LOW CARRYING COST

FEUs Shipped Annually	365
Density(lb./Cu. Ft.)	10.7
Value Density ($/lb.)	$ 3.99
Cubic Value ($/Cu.Ft.)	$ 42.69
Tonnes per FEUs	12.54
Lbs. per FEU	27,649
Value per FEU	$ 110,319
Annual Carrying Charge	15.0%
Demand Period	365
Shelf Life (Days)	365
Salvage Value	100%
Decay Parameter	3.0
Stock-out Cost (Stc. Devs. for Safety Stock)	3.00
Warehouse Cost ($/lb./year)	$ -
Daily Sales (FEU)	1.00
Coef. of Var. of Daily Sales	300%
Std. Dev of Daily Sales	3.00
Storability (FEU load factor)	85%

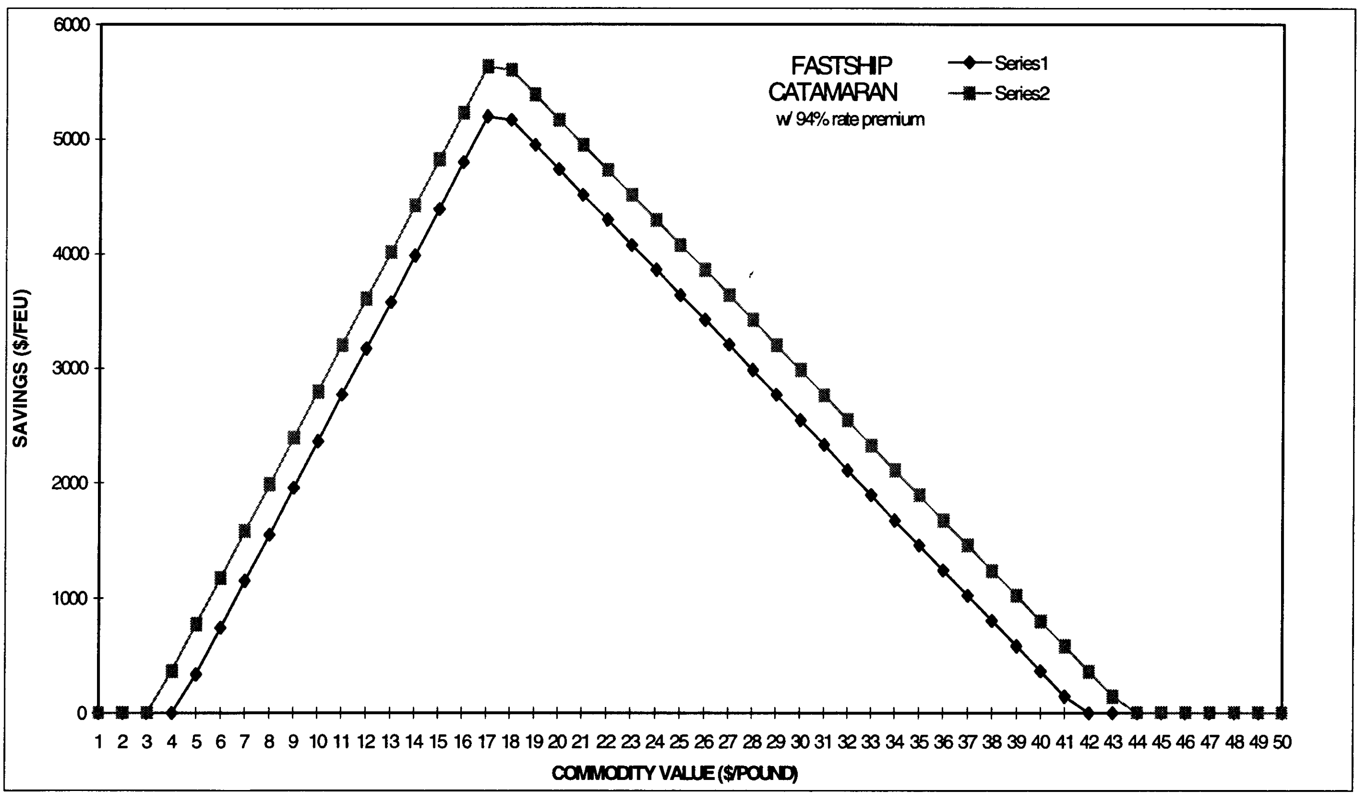
Standard Ocean	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	16.71
	Std. Dev. of Transit Time	3.15
	Service Freq. (Shipments per Demand Period)	52
	Avg. Shipment Size	7.0
Standard Air Freight	Freight Rate/ FEU	$ 12,600
	Transit Time (days)	3.0
	Std. Dev. of Transit Time	0.5
	Service Freq. (Shipments per Demand Period)	365
	Avg. Shipment Size	1.0
FastShip	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	7.36
	Std. Dev. of Transit Time	0.17
	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3
"Shallow transom" Catamaran	Freight Rate/ FEU	$ 1,365
	Transit Time (days)	7.36
Fuel savings/FEU	Std. Dev. of Transit Time	0.17
$ 435	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE: LOW CARRYING COST

FEUs Shipped Annually		365
Density(lb./Cu. Ft.)		10.7
Value Density ($/lb.)	$	3.99
Cubic Value ($/Cu.Ft.)	$	42.69
Tonnes per FEUs		12.54
Lbs. per FEU		27,649
Value per FEU	$	110,319
Annual Carrying Charge		20.0%
Demand Period		365
Shelf Life (Days)		365
Salvage Value		100%
Decay Parameter		3.0
Stock-out Cost (Stc. Devs. for Safety Stock)		3.00
Warehouse Cost ($/lb./year)	$	-
Daily Sales (FEU)		1.00
Coef. of Var. of Daily Sales		300%
Std. Dev of Daily Sales		3.00
Storability (FEU load factor)		85%

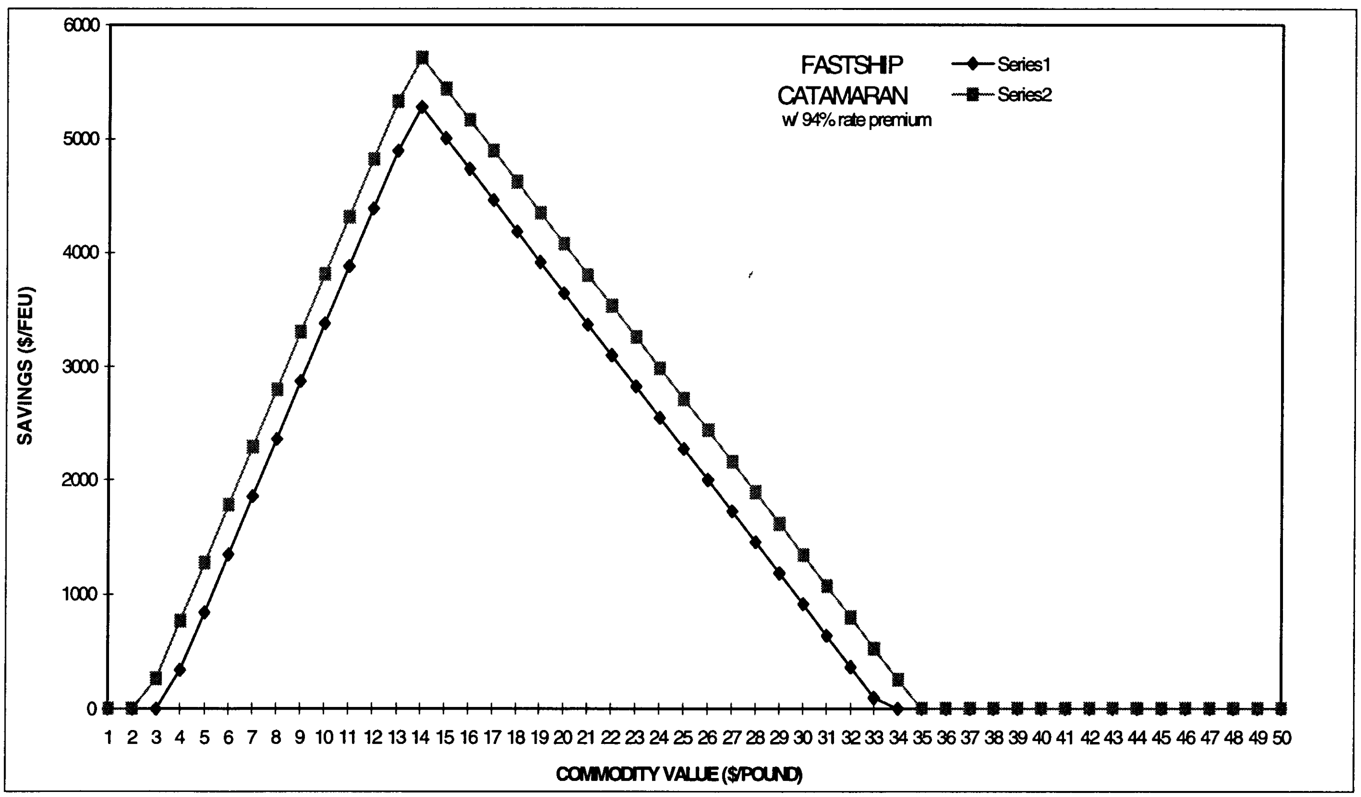
Standard Ocean	Freight Rate/ FEU	$	1,800
	Transit Time (days)		16.71
	Std. Dev. of Transit Time		3.15
	Service Freq. (Shipments per Demand Period)		52
	Avg. Shipment Size		7.0
Standard Air Freight	Freight Rate/ FEU	$	12,600
	Transit Time (days)		3.0
	Std. Dev. of Transit Time		0.5
	Service Freq. (Shipments per Demand Period)		365
	Avg. Shipment Size		1.0
FastShip	Freight Rate/ FEU	$	1,800
	Transit Time (days)		7.36
	Std. Dev. of Transit Time		0.17
	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3
"Shallow transom"	Freight Rate/ FEU	$	1,365
Catamaran	Transit Time (days)		7.36
Fuel savings/FEU	Std. Dev. of Transit Time		0.17
$ 435	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE: HIGH CARRYING COST A

FEUs Shipped Annually		365
Density(lb/Cu. Ft.)		10.7
Value Density ($/lb.)	$	3.99
Cubic Value ($/Cu.Ft.)	$	42.69
Tonnes per FEUs		12.54
Lbs. per FEU		27,649
Value per FEU	$	110,319
Annual Carrying Charge		25.0%
Demand Period		365
Shelf Life (Days)		365
Salvage Value		100%
Decay Parameter		3.0
Stock-out Cost (Stc. Devs. for Safety Stock)		3.00
Warehouse Cost ($/lb./year)	$	-
Daily Sales (FEU)		1.00
Coef. of Var. of Daily Sales		300%
Std. Dev of Daily Sales		3.00
Storability (FEU load factor)		85%

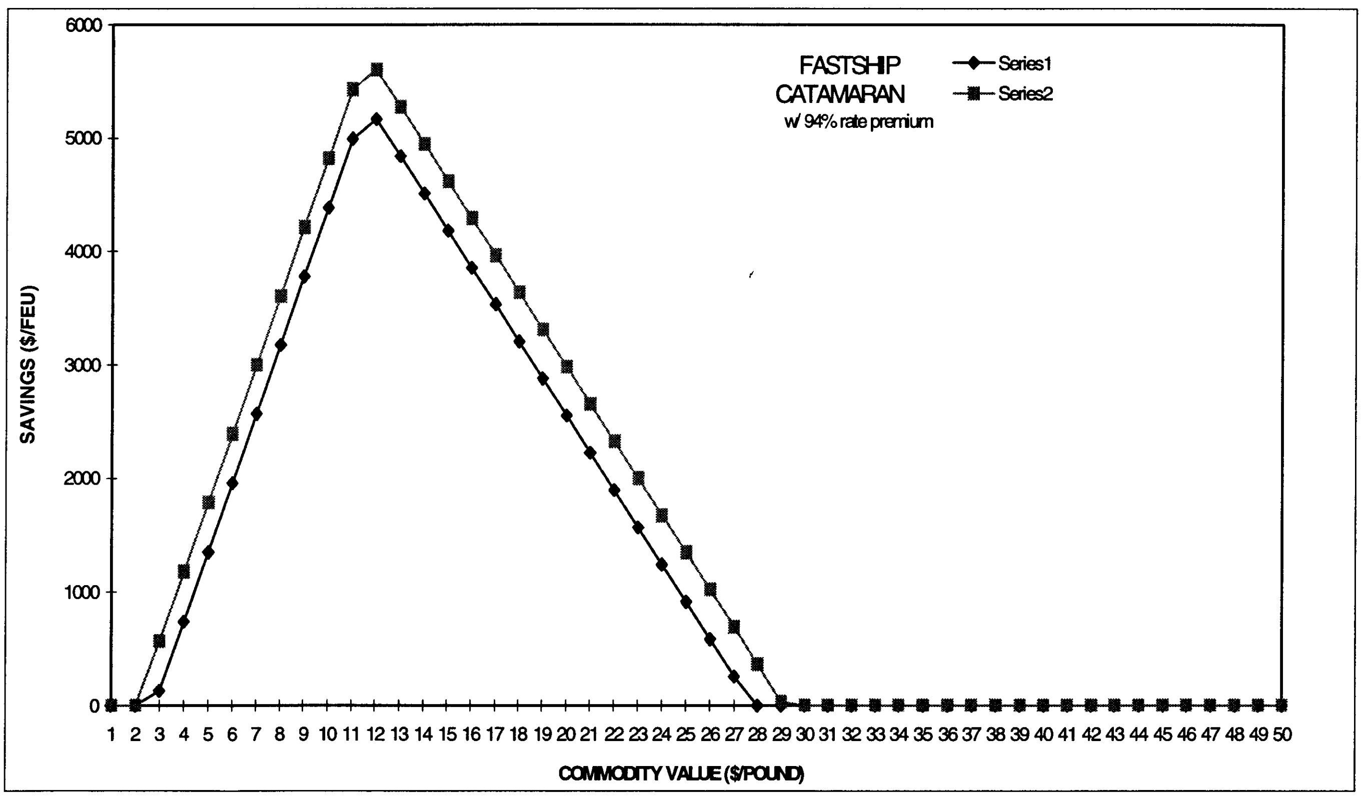
Standard Ocean	Freight Rate/ FEU	$	1,800
	Transit Time (days)		16.71
	Std. Dev. of Transit Time		3.15
	Service Freq. (Shipments per Demand Period)		52
	Avg. Shipment Size		7.0
Standard Air Freight	Freight Rate/ FEU	$	12,600
	Transit Time (days)		3.0
	Std. Dev. of Transit Time		0.5
	Service Freq. (Shipments per Demand Period)		365
	Avg. Shipment Size		1.0
FastShip	Freight Rate/ FEU	$	1,800
	Transit Time (days)		7.36
	Std. Dev. of Transit Time		0.17
	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3
"Shallow transom"	Freight Rate/ FEU	$	1,365
Catamaran	Transit Time (days)		7.36
Fuel savings/FEU	Std. Dev. of Transit Time		0.17
$ 435	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE : HIGH CARRYING COST B

FEUs Shipped Annually	365
Density(lb/Cu. Ft.)	10.7
Value Density ($/lb.)	$ 3.99
Cubic Value ($/Cu.Ft.)	$ 42.69
Tonnes per FEUs	12.54
Lbs. per FEU	27,649
Value per FEU	$ 110,319
Annual Carrying Charge	30.0%
Demand Period	365
Shelf Life (Days)	365
Salvage Value	100%
Decay Parameter	3.0
Stock-out Cost (Stc. Devs. for Safety Stock)	3.00
Warehouse Cost ($/lb./year)	$ -
Daily Sales (FEU)	1.00
Coef. of Var. of Daily Sales	300%
Std. Dev of Daily Sales	3.00
Storability (FEU load factor)	85%

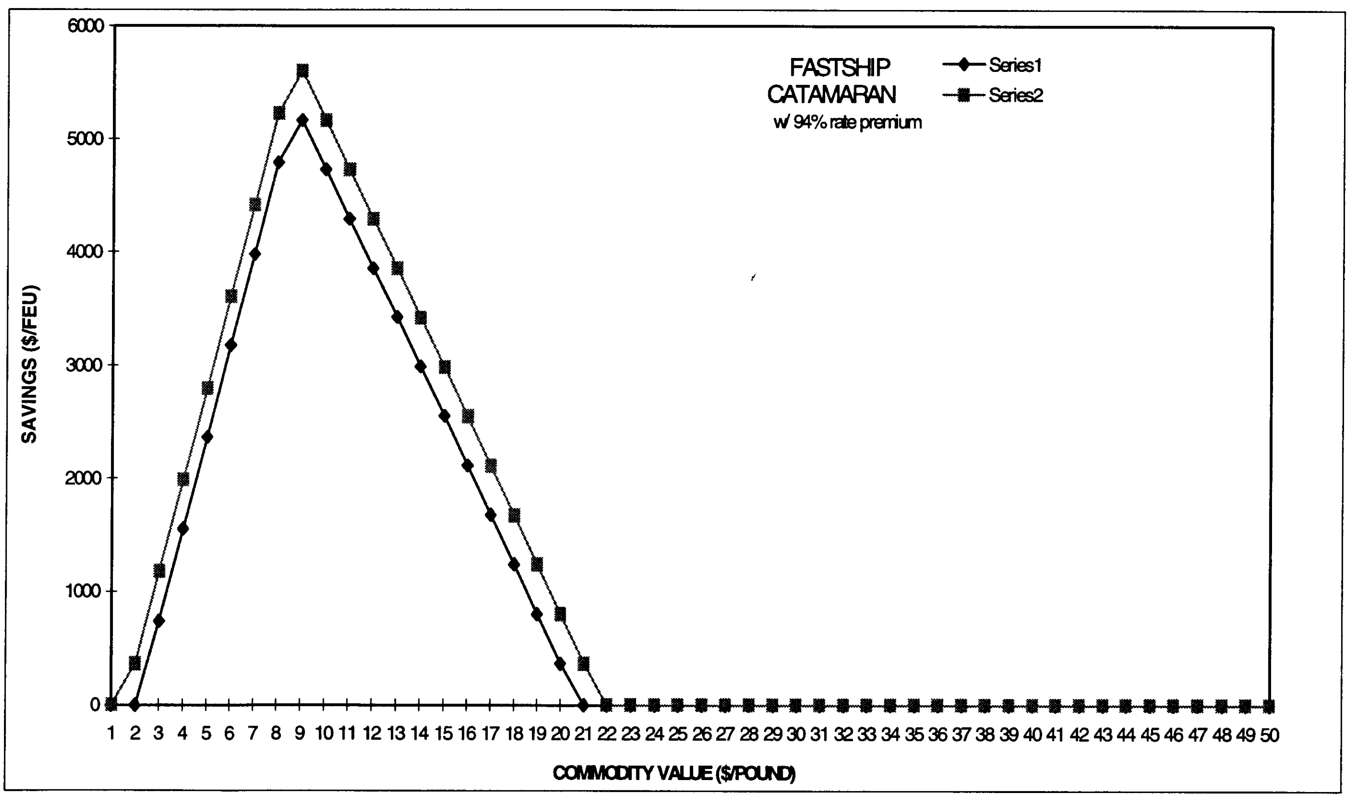
Standard Ocean	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	16.71
	Std. Dev. of Transit Time	3.15
	Service Freq. (Shipments per Demand Period)	52
	Avg. Shipment Size	7.0
Standard Air Freight	Freight Rate/ FEU	$ 12,600
	Transit Time (days)	3.0
	Std. Dev. of Transit Time	0.5
	Service Freq. (Shipments per Demand Period)	365
	Avg. Shipment Size	1.0
FastShip	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	7.36
	Std. Dev. of Transit Time	0.17
	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3
"Shallow transom" Catamaran	Freight Rate/ FEU	$ 1,365
	Transit Time (days)	7.36
Fuel savings/FEU	Std. Dev. of Transit Time	0.17
$ 435	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE : VERY HIGH CARRYING COST

FEUs Shipped Annually	365
Density(lb./Cu. Ft.)	10.7
Value Density ($/lb.)	$ 3.99
Cubic Value ($/Cu.Ft.)	$ 42.69
Tonnes per FEUs	12.54
Lbs. per FEU	27,649
Value per FEU	$ 110,319
Annual Carrying Charge	40.0%
Demand Period	365
Shelf Life (Days)	365
Salvage Value	100%
Decay Parameter	3.0
Stock-out Cost (Stc. Devs. for Safety Stock)	3.00
Warehouse Cost ($/lb./year)	$ -
Daily Sales (FEU)	1.00
Coef. of Var. of Daily Sales	300%
Std. Dev of Daily Sales	3.00
Storability (FEU load factor)	85%

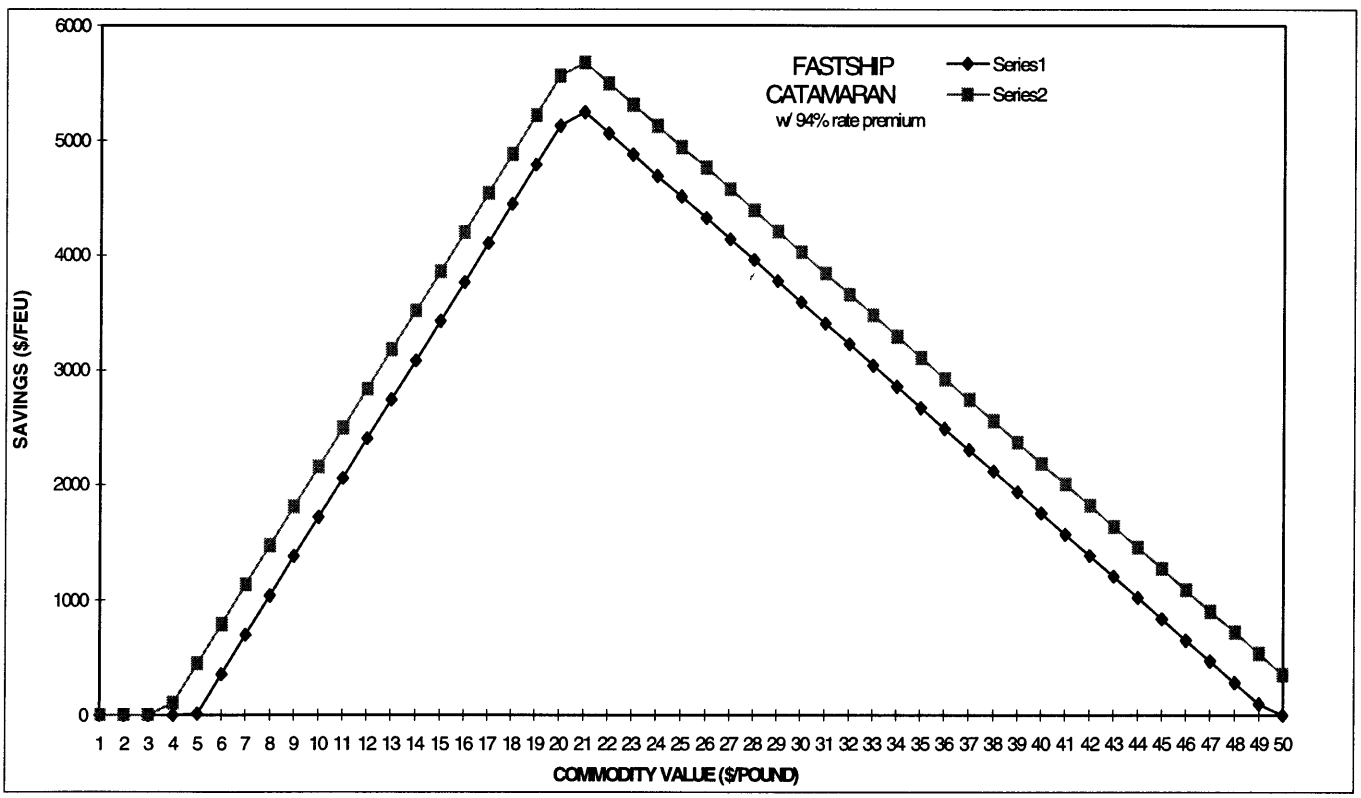
Standard Ocean	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	16.71
	Std. Dev. of Transit Time	3.15
	Service Freq. (Shipments per Demand Period)	52
	Avg. Shipment Size	7.0
Standard Air Freight	Freight Rate/ FEU	$ 12,600
	Transit Time (days)	3.0
	Std. Dev. of Transit Time	0.5
	Service Freq. (Shipments per Demand Period)	365
	Avg. Shipment Size	1.0
FastShip	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	7.36
	Std. Dev. of Transit Time	0.17
	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3
"Shallow transom"	Freight Rate/ FEU	$ 1,365
Catamaran	Transit Time (days)	7.36
Fuel savings/FEU	Std. Dev. of Transit Time	0.17
$ 435	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE: LOW DENSITY

FEUs Shipped Annually	365
Density(lb./Cu. Ft.)	8.0
Value Density ($/lb.)	$ 3.99
Cubic Value ($/Cu.Ft.)	$ 31.92
Tonnes per FEUs	9.38
Lbs. per FEU	20,672
Value per FEU	$ 82,481
Annual Carrying Charge	22.5%
Demand Period	365
Shelf Life (Days)	365
Salvage Value	100%
Decay Parameter	3.0
Stock-out Cost (Stc. Devs. for Safety Stock)	3.00
Warehouse Cost ($/lb./year)	$ -
Daily Sales (FEU)	1.00
Coef. of Var. of Daily Sales	300%
Std. Dev of Daily Sales	3.00
Storability (FEU load factor)	85%

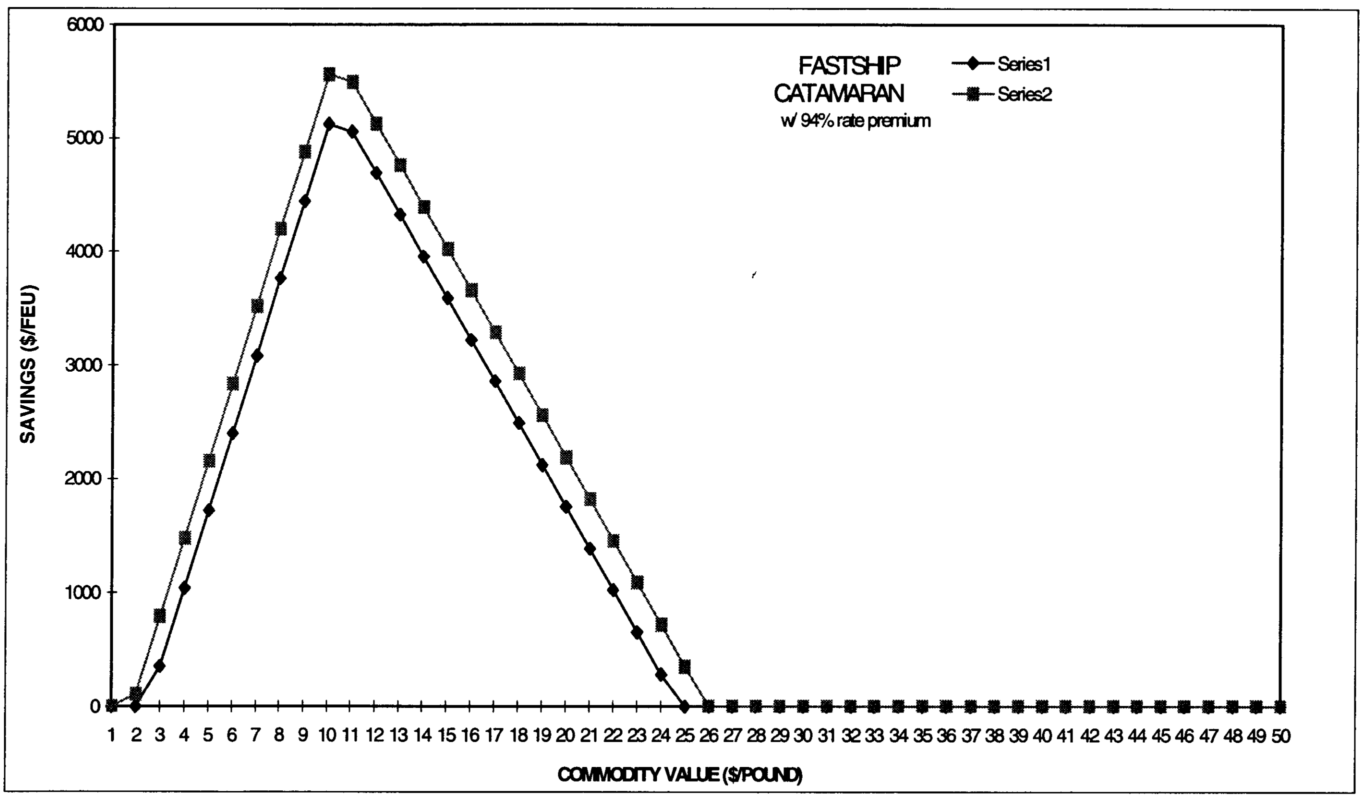
Standard Ocean	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	16.71
	Std. Dev. of Transit Time	3.15
	Service Freq. (Shipments per Demand Period)	52
	Avg. Shipment Size	7.0
Standard Air Freight	Freight Rate/ FEU	$ 12,600
	Transit Time (days)	3.0
	Std. Dev. of Transit Time	0.5
	Service Freq. (Shipments per Demand Period)	365
	Avg. Shipment Size	1.0
FastShip	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	7.36
	Std. Dev. of Transit Time	0.17
	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3
"Shallow transom"	Freight Rate/ FEU	$ 1,365
Catamaran	Transit Time (days)	7.36
Fuel savings/FEU	Std. Dev. of Transit Time	0.17
$ 435	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE: HIGH DENSITY

FEUs Shipped Annually	365
Density(lb./Cu. Ft.)	16.0
Value Density ($/lb.)	$ 3.99
Cubic Value ($/Cu.Ft.)	$ 63.84
Tonnes per FEUs	18.75
Lbs. per FEU	41,344
Value per FEU	$ 164,963
Annual Carrying Charge	22.5%
Demand Period	365
Shelf Life (Days)	365
Salvage Value	100%
Decay Parameter	3.0
Stock-out Cost (Stc. Devs. for Safety Stock)	3.00
Warehouse Cost ($/lb./year)	$ -
Daily Sales (FEU)	1.00
Coef. of Var. of Daily Sales	300%
Std. Dev of Daily Sales	3.00
Storability (FEU load factor)	85%

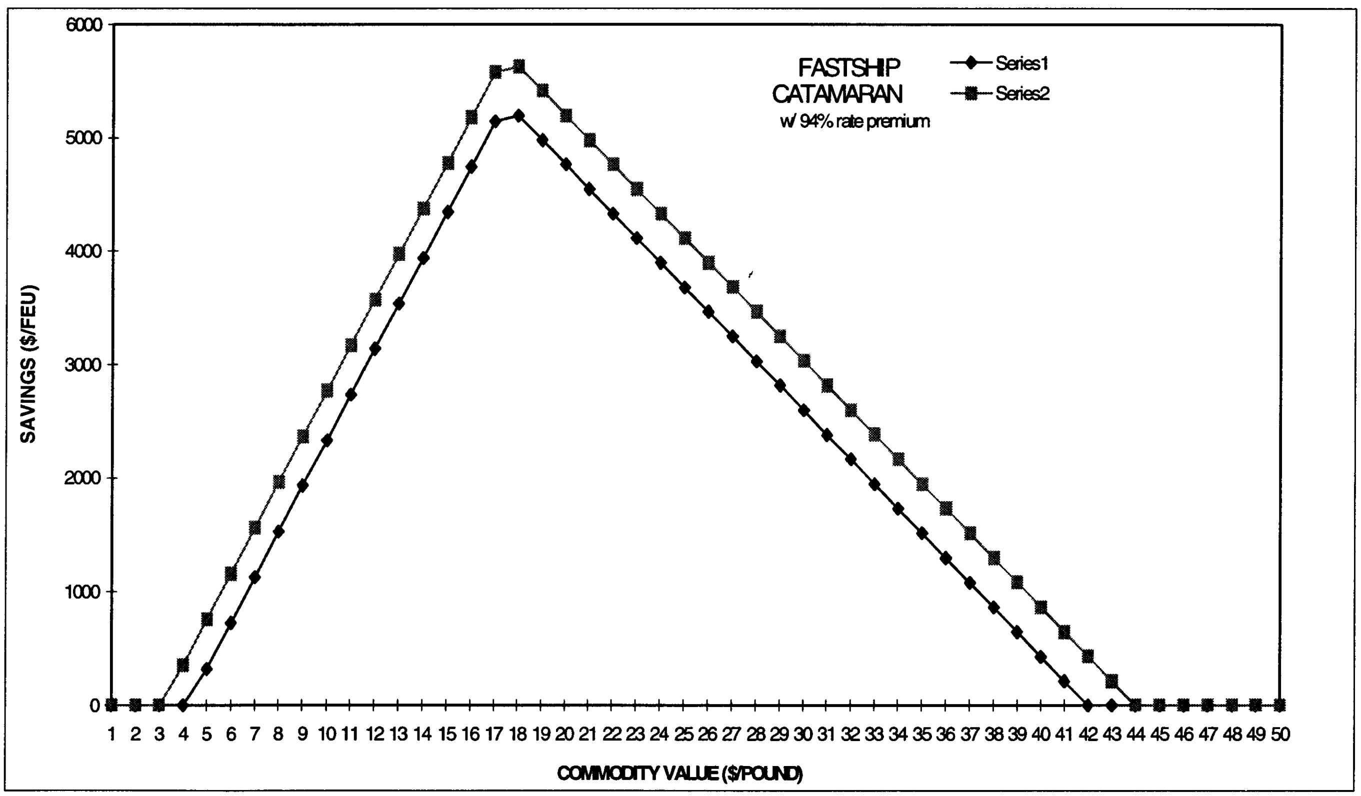
Standard Ocean	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	16.71
	Std. Dev. of Transit Time	3.15
	Service Freq. (Shipments per Demand Period)	52
	Avg. Shipment Size	7.0
Standard Air Freight	Freight Rate/ FEU	$ 12,600
	Transit Time (days)	3.0
	Std. Dev. of Transit Time	0.5
	Service Freq. (Shipments per Demand Period)	365
	Avg. Shipment Size	1.0
FastShip	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	7.36
	Std. Dev. of Transit Time	0.17
	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3
"Shallow transom"	Freight Rate/ FEU	$ 1,365
Catamaran	Transit Time (days)	7.36
Fuel savings/FEU	Std. Dev. of Transit Time	0.17
$ 435	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE: LOW STORABILITY

FEUs Shipped Annually		365
Density(lb/Cu. Ft.)		10.7
Value Density ($/lb.)	$	3.99
Cubic Value ($/Cu.Ft.)	$	42.69
Tonnes per FEUs		11.06
Lbs. per FEU		24,396
Value per FEU	$	97,340
Annual Carrying Charge		22.5%
Demand Period		365
Shelf Life (Days)		365
Salvage Value		100%
Decay Parameter		3.0
Stock-out Cost (Stc. Devs. for Safety Stock)		3.00
Warehouse Cost ($/lb./year)	$	-
Daily Sales (FEU)		1.00
Coef. of Var. of Daily Sales		300%
Std. Dev of Daily Sales		3.00
Storability (FEU load factor)		75%

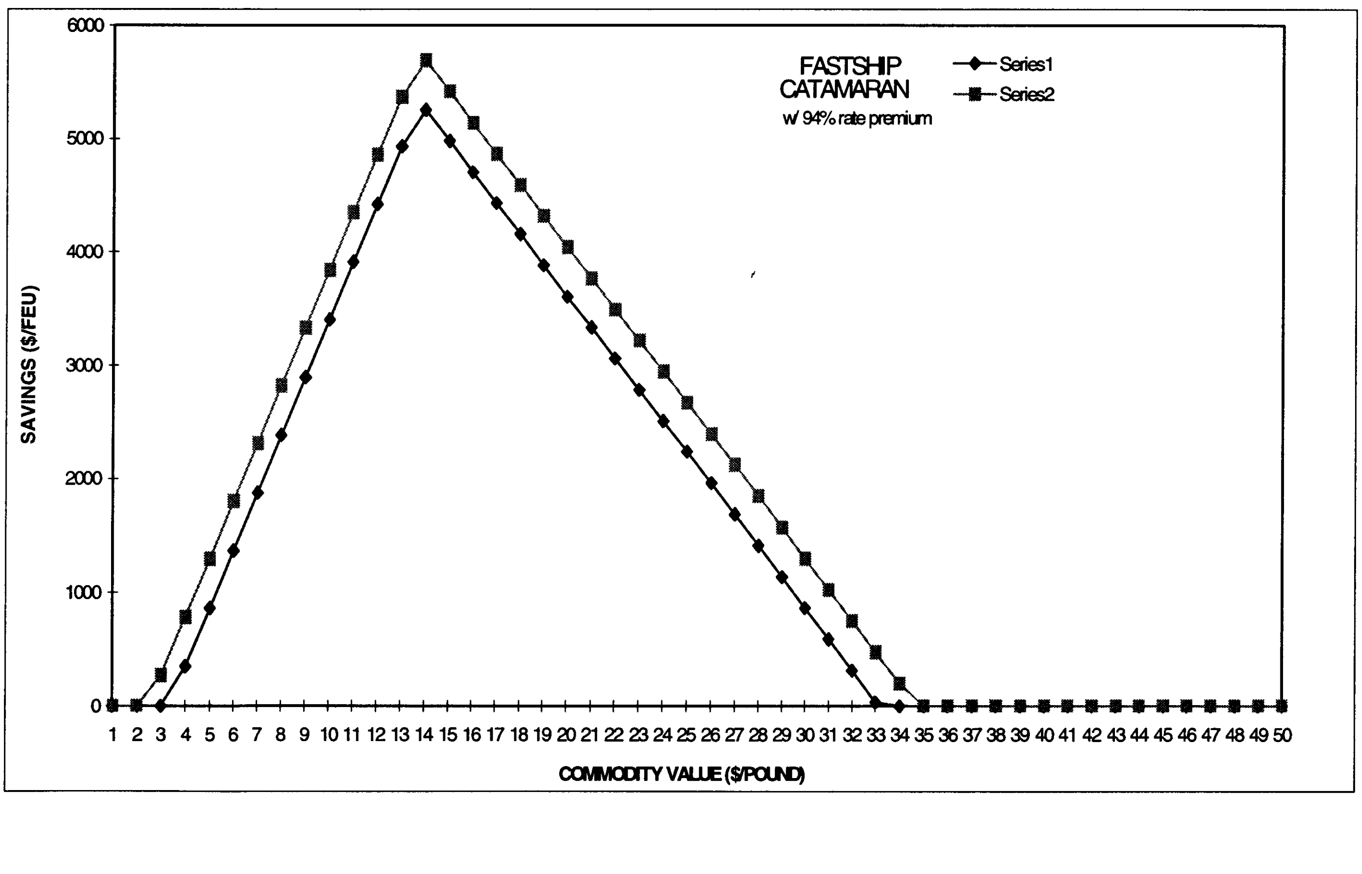
Standard Ocean	Freight Rate/ FEU	$	1,800
	Transit Time (days)		16.71
	Std. Dev. of Transit Time		3.15
	Service Freq. (Shipments per Demand Period)		52
	Avg. Shipment Size		7.0
Standard Air Freight	Freight Rate/ FEU	$	12,600
	Transit Time (days)		3.0
	Std. Dev. of Transit Time		0.5
	Service Freq. (Shipments per Demand Period)		365
	Avg. Shipment Size		1.0
FastShip	Freight Rate/ FEU	$	1,800
	Transit Time (days)		7.36
	Std. Dev. of Transit Time		0.17
	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3
"Shallow transom" Catamaran	Freight Rate/ FEU	$	1,365
	Transit Time (days)		7.36
Fuel savings/FEU	Std. Dev. of Transit Time		0.17
$ 435	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE: HIGH STORABILITY

FEUs Shipped Annually	365
Density(lb/Cu. Ft.)	10.7
Value Density ($/lb.)	$ 3.99
Cubic Value ($/Cu.Ft.)	$ 42.69
Tonnes per FEUs	14.01
Lbs. per FEU	30,902
Value per FEU	$ 123,297
Annual Carrying Charge	22.5%
Demand Period	365
Shelf Life (Days)	365
Salvage Value	100%
Decay Parameter	3.0
Stock-out Cost (Stc. Devs. for Safety Stock)	3.00
Warehouse Cost ($/lb./year)	$ -
Daily Sales (FEU)	1.00
Coef. of Var. of Daily Sales	300%
Std. Dev of Daily Sales	3.00
Storability (FEU load factor)	95%

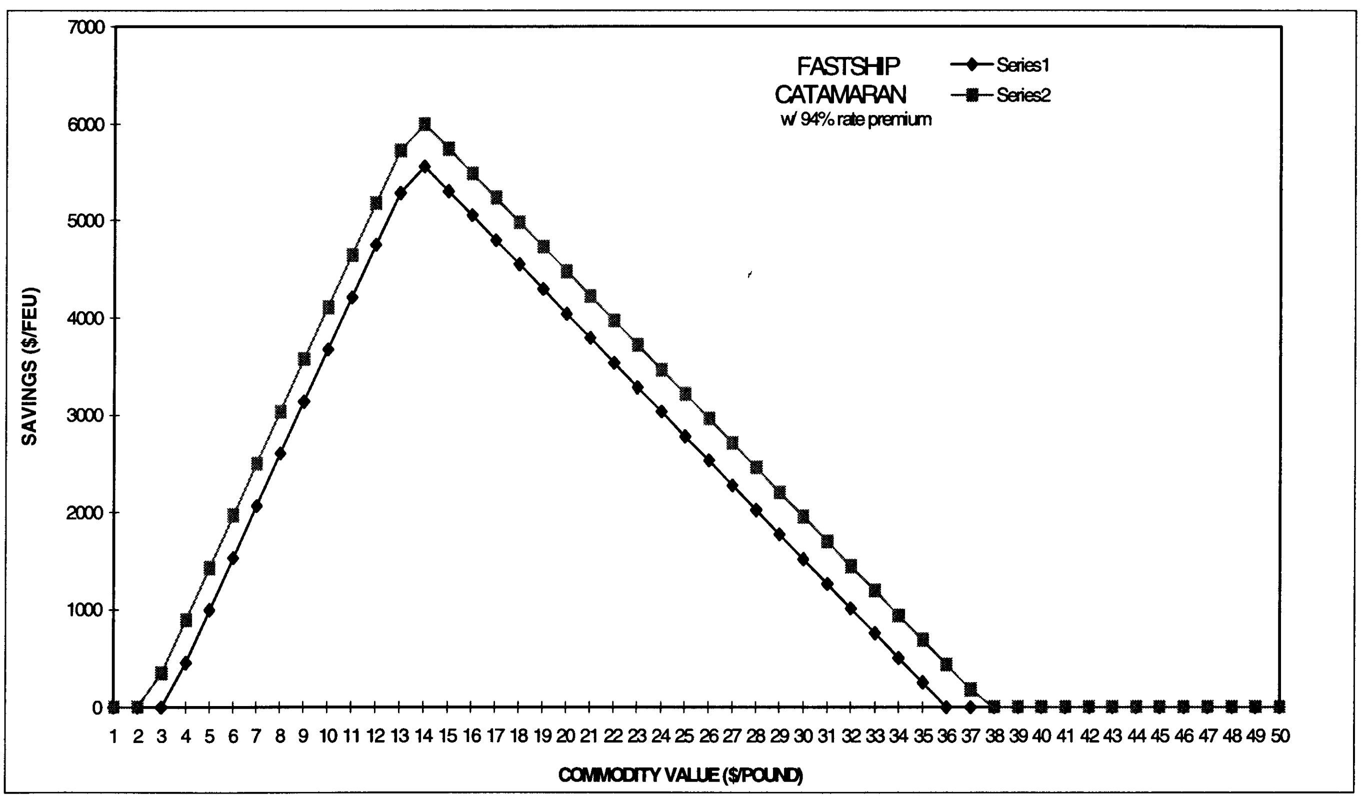
Standard Ocean	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	16.71
	Std. Dev. of Transit Time	3.15
	Service Freq. (Shipments per Demand Period)	52
	Avg. Shipment Size	7.0
Standard Air Freight	Freight Rate/ FEU	$ 12,600
	Transit Time (days)	3.0
	Std. Dev. of Transit Time	0.5
	Service Freq. (Shipments per Demand Period)	365
	Avg. Shipment Size	1.0
FastShip	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	7.36
	Std. Dev. of Transit Time	0.17
	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3
"Shallow transom"	Freight Rate/ FEU	$ 1,365
Catamaran	Transit Time (days)	7.36
Fuel savings/FEU	Std. Dev. of Transit Time	0.17
$ 435	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE: SEASONAL COMMODITY A

FEUs Shipped Annually		365
Density(lb/Cu. Ft.)		10.7
Value Density ($/lb.)	$	3.99
Cubic Value ($/Cu.Ft.)	$	42.69
Tonnes per FEUs		12.54
Lbs. per FEU		27,649
Value per FEU	$	110,319
Annual Carrying Charge		22.5%
Demand Period		365
Shelf Life (Days)		90
Salvage Value		50%
Decay Parameter		3.0
Stock-out Cost (Stc. Devs. for Safety Stock)		3.00
Warehouse Cost ($/lb./year)	$	-
Daily Sales (FEU)		1.00
Coef. of Var. of Daily Sales		300%
Std. Dev of Daily Sales		3.00
Storability (FEU load factor)		85%

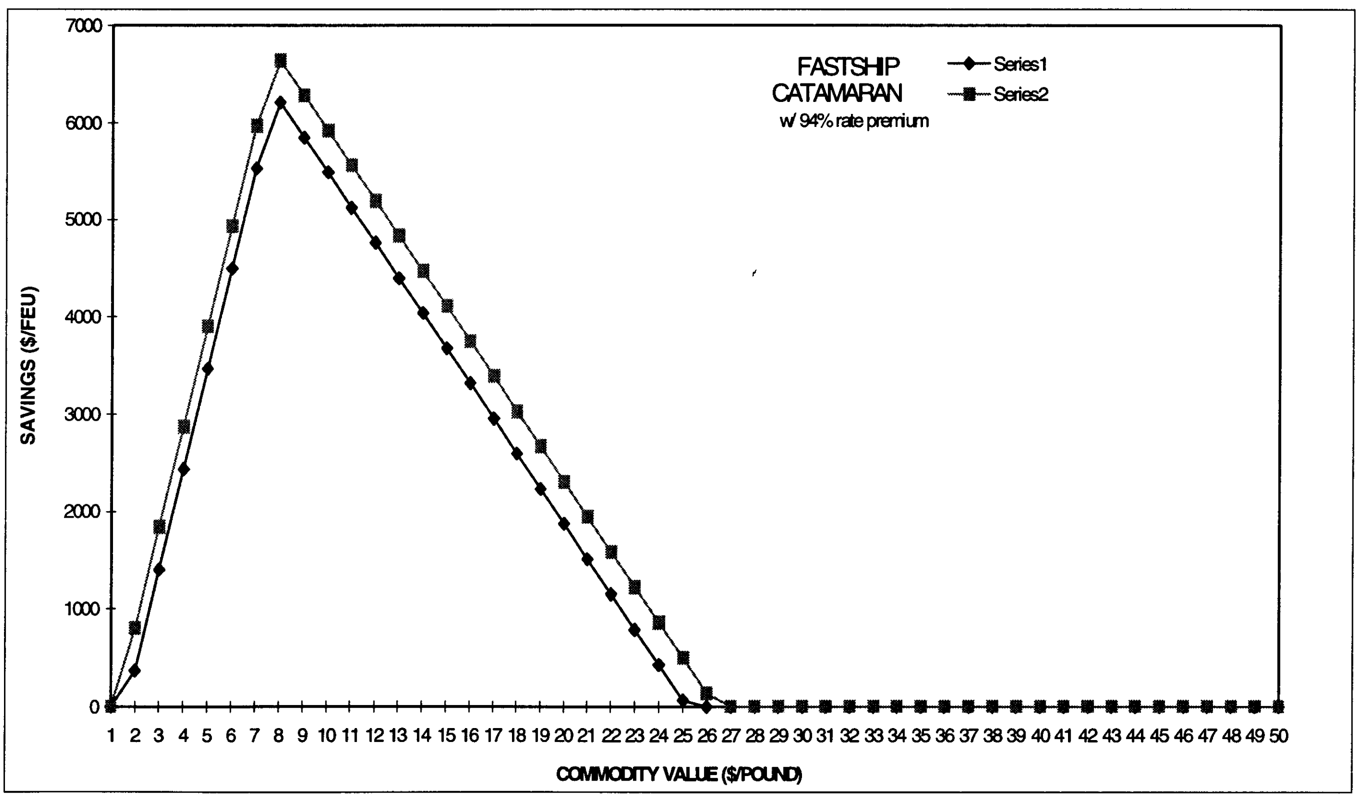
Standard Ocean	Freight Rate/ FEU	$	1,800
	Transit Time (days)		16.71
	Std. Dev. of Transit Time		3.15
	Service Freq. (Shipments per Demand Period)		52
	Avg. Shipment Size		7.0
Standard Air Freight	Freight Rate/ FEU	$	12,600
	Transit Time (days)		3.0
	Std. Dev. of Transit Time		0.5
	Service Freq. (Shipments per Demand Period)		365
	Avg. Shipment Size		1.0
FastShip	Freight Rate/ FEU	$	1,800
	Transit Time (days)		7.36
	Std. Dev. of Transit Time		0.17
	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3
"Shallow transom"	Freight Rate/ FEU	$	1,365
Catamaran	Transit Time (days)		7.36
Fuel savings/FEU	Std. Dev. of Transit Time		0.17
$ 435	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE: SEASONAL COMMODITY B

FEUs Shipped Annually		365
Density(lb./Cu. Ft.)		10.7
Value Density ($/lb.)	$	3.99
Cubic Value ($/Cu.Ft.)	$	42.69
Tonnes per FEUs		12.54
Lbs. per FEU		27,649
Value per FEU	$	110,319
Annual Carrying Charge		22.5%
Demand Period		365
Shelf Life (Days)		90
Salvage Value		25%
Decay Parameter		2.0
Stock-out Cost (Stc. Devs. for Safety Stock)		3.00
Warehouse Cost ($/lb./year)	$	-
Daily Sales (FEU)		1.00
Coef. of Var. of Daily Sales		300%
Std. Dev of Daily Sales		3.00
Storability (FEU load factor)		85%

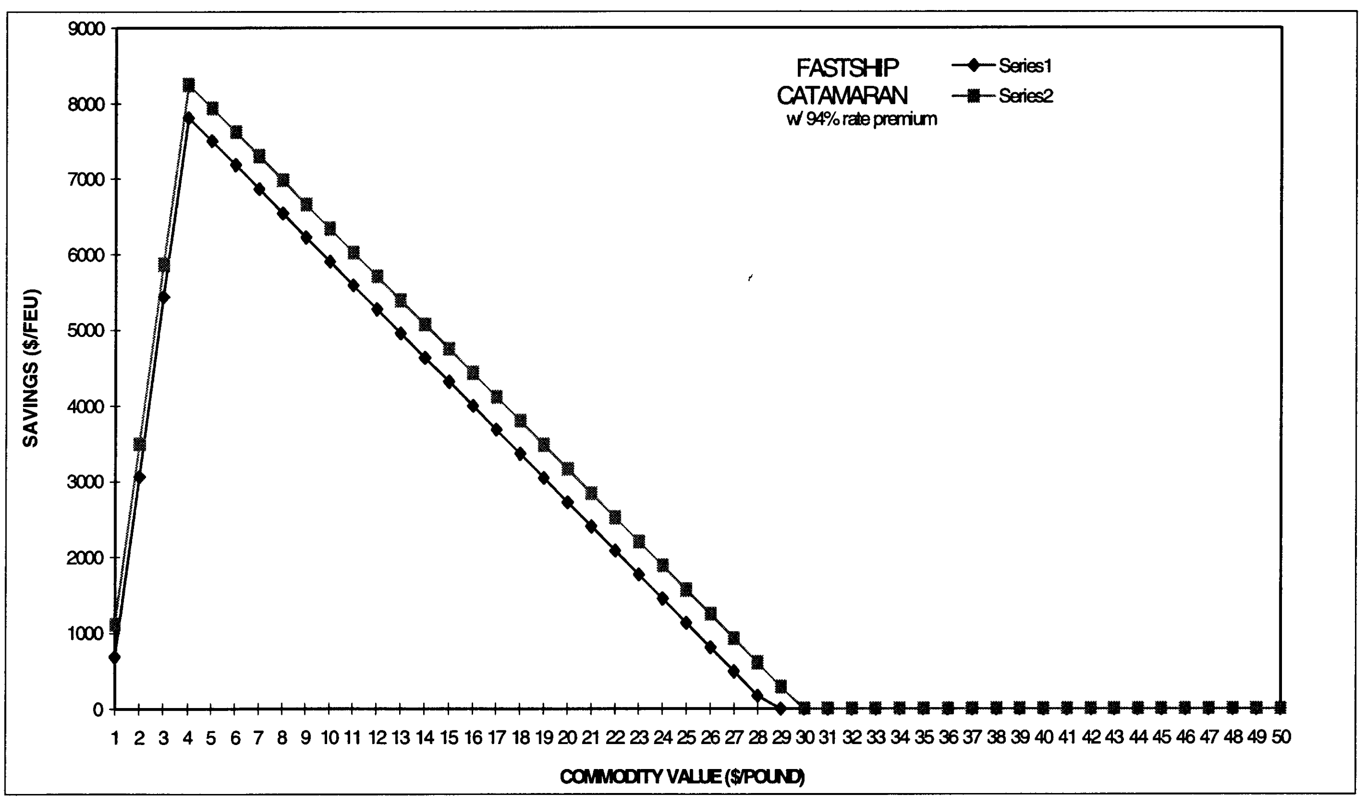
Standard Ocean	Freight Rate/ FEU	$	1,800
	Transit Time (days)		16.71
	Std. Dev. of Transit Time		3.15
	Service Freq. (Shipments per Demand Period)		52
	Avg. Shipment Size		7.0
Standard Air Freight	Freight Rate/ FEU	$	12,600
	Transit Time (days)		3.0
	Std. Dev. of Transit Time		0.5
	Service Freq. (Shipments per Demand Period)		365
	Avg. Shipment Size		1.0
FastShip	Freight Rate/ FEU	$	1,800
	Transit Time (days)		7.36
	Std. Dev. of Transit Time		0.17
	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3
"Shallow transom" Catamaran	Freight Rate/ FEU	$	1,365
	Transit Time (days)		7.36
Fuel savings/FEU	Std. Dev. of Transit Time		0.17
$ 435	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE : PERISHABLE COMMODITY A

FEUs Shipped Annually	365
Density(lb./Cu. Ft.)	10.7
Value Density ($/lb.)	$ 3.99
Cubic Value ($/Cu.Ft.)	$ 42.69
Tonnes per FEUs	12.54
Lbs. per FEU	27,649
Value per FEU	$ 110,319
Annual Carrying Charge	22.5%
Demand Period	365
Shelf Life (Days)	30
Salvage Value	25%
Decay Parameter	4.0
Stock-out Cost (Stc. Devs. for Safety Stock)	3.00
Warehouse Cost ($/lb./year)	$ -
Daily Sales (FEU)	1.00
Coef. of Var. of Daily Sales	300%
Std. Dev of Daily Sales	3.00
Storability (FEU load factor)	85%

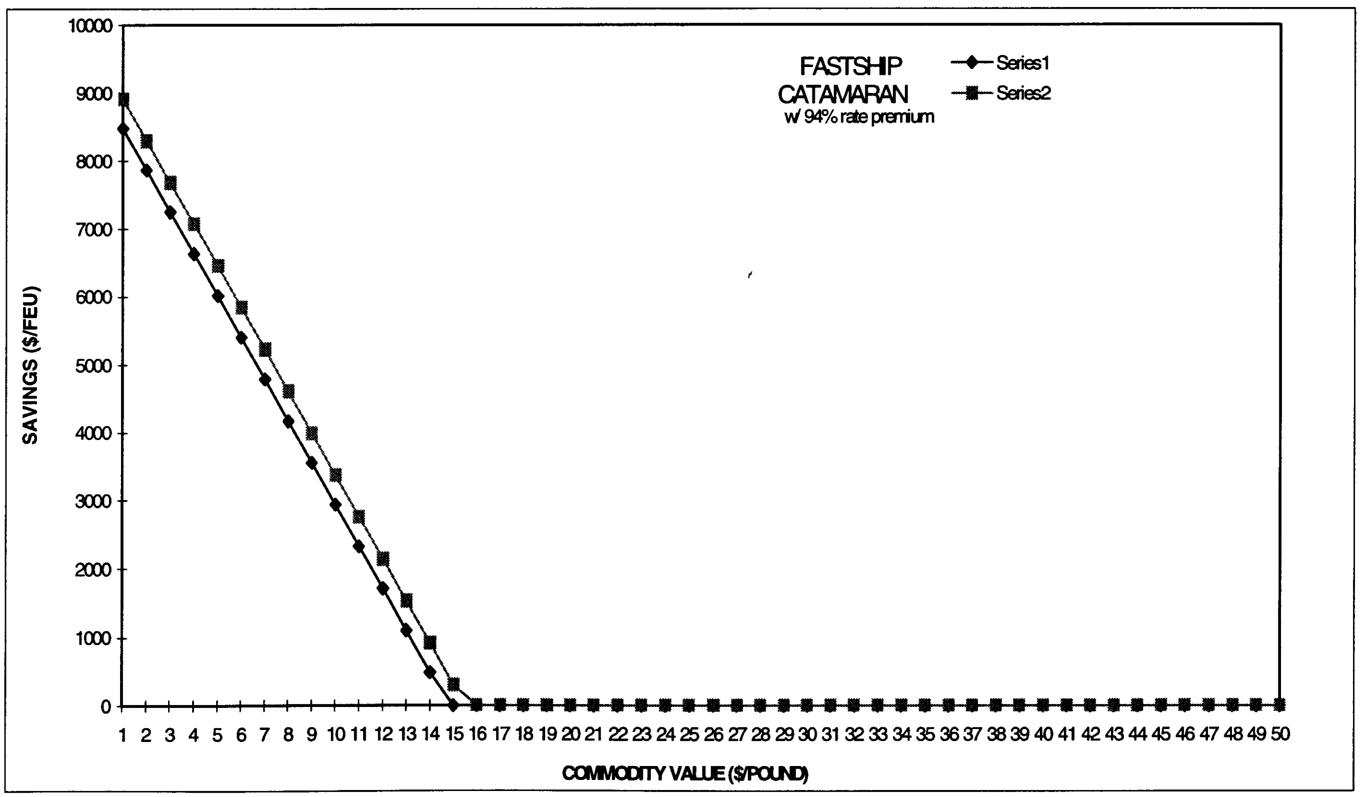
Standard Ocean	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	16.71
	Std. Dev. of Transit Time	3.15
	Service Freq. (Shipments per Demand Period)	52
	Avg. Shipment Size	7.0
Standard Air Freight	Freight Rate/ FEU	$ 12,600
	Transit Time (days)	3.0
	Std. Dev. of Transit Time	0.5
	Service Freq. (Shipments per Demand Period)	365
	Avg. Shipment Size	1.0
FastShip	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	7.36
	Std. Dev. of Transit Time	0.17
	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3
"Shallow transom"	Freight Rate/ FEU	$ 1,365
Catamaran	Transit Time (days)	7.36
Fuel savings/FEU	Std. Dev. of Transit Time	0.17
$ 435	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE : PERISHABLE COMMODITY B

FEUs Shipped Annually		365
Density(lb./Cu. Ft.)		10.7
Value Density ($/lb.)	$	3.99
Cubic Value ($/Cu.Ft.)	$	42.69
Tonnes per FEUs		12.54
Lbs. per FEU		27,649
Value per FEU	$	110,319
Annual Carrying Charge		22.5%
Demand Period		365
Shelf Life (Days)		20
Salvage Value		25%
Decay Parameter		4.0
Stock-out Cost (Stc. Devs. for Safety Stock)		3.00
Warehouse Cost ($/lb./year)	$	-
Daily Sales (FEU)		1.00
Coef. of Var. of Daily Sales		300%
Std. Dev of Daily Sales		3.00
Storability (FEU load factor)		85%

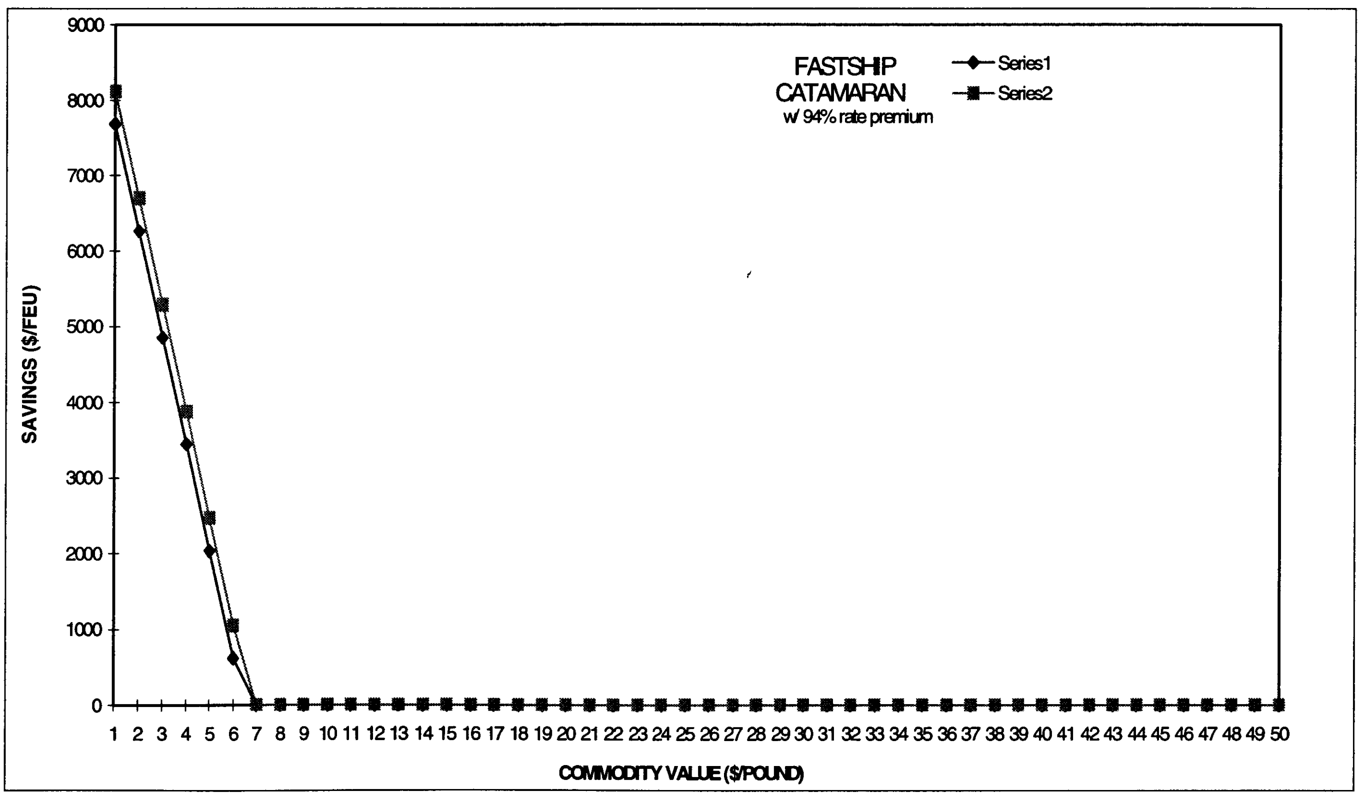
Standard Ocean	Freight Rate/ FEU	$	1,800
	Transit Time (days)		16.71
	Std. Dev. of Transit Time		3.15
	Service Freq. (Shipments per Demand Period)		52
	Avg. Shipment Size		7.0
Standard Air Freight	Freight Rate/ FEU	$	12,600
	Transit Time (days)		3.0
	Std. Dev. of Transit Time		0.5
	Service Freq. (Shipments per Demand Period)		365
	Avg. Shipment Size		1.0
FastShip	Freight Rate/ FEU	$	1,800
	Transit Time (days)		7.36
	Std. Dev. of Transit Time		0.17
	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3
"Shallow transom"	Freight Rate/ FEU	$	1,365
Catamaran	Transit Time (days)		7.36
Fuel savings/FEU	Std. Dev. of Transit Time		0.17
$ 435	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE : PERISHABLE COMMODITY C

FEUs Shipped Annually	365
Density(lb/Cu. Ft.)	10.7
Value Density ($/lb.)	$ 3.99
Cubic Value ($/Cu.Ft.)	$ 42.69
Tonnes per FEUs	12.54
Lbs. per FEU	27,649
Value per FEU	$ 110,319
Annual Carrying Charge	22.5%
Demand Period	365
Shelf Life (Days)	15
Salvage Value	25%
Decay Parameter	4.0
Stock-out Cost (Stc. Devs. for Safety Stock)	3.00
Warehouse Cost ($/lb./year)	$ -
Daily Sales (FEU)	1.00
Coef. of Var. of Daily Sales	300%
Std. Dev of Daily Sales	3.00
Storability (FEU load factor)	85%

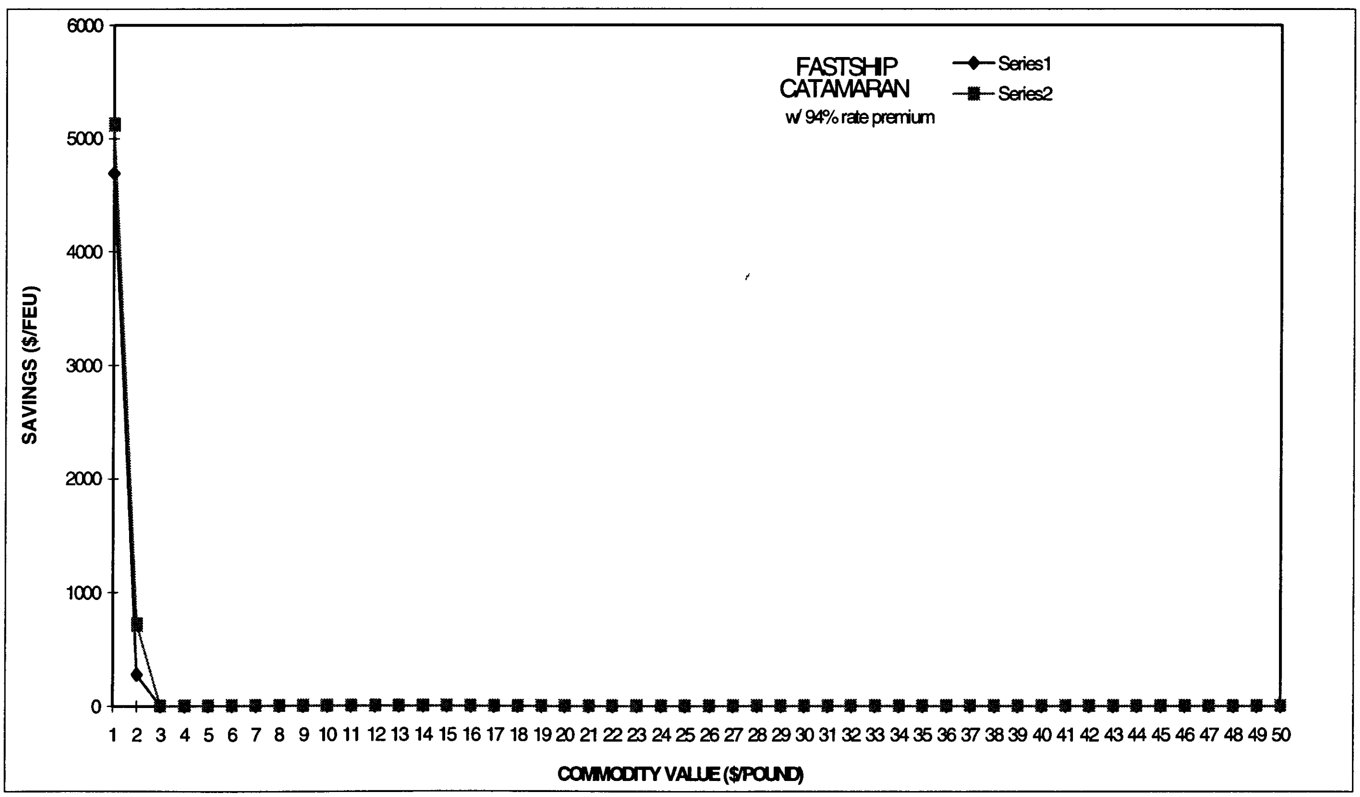
Standard Ocean		Freight Rate/ FEU	$ 1,800
		Transit Time (days)	16.71
		Std. Dev. of Transit Time	3.15
		Service Freq. (Shipments per Demand Period)	52
		Avg. Shipment Size	7.0
Standard Air Freight		Freight Rate/ FEU	$ 12,600
		Transit Time (days)	3.0
		Std. Dev. of Transit Time	0.5
		Service Freq. (Shipments per Demand Period)	365
		Avg. Shipment Size	1.0
FastShip		Freight Rate/ FEU	$ 1,800
		Transit Time (days)	7.36
		Std. Dev. of Transit Time	0.17
		Service Freq. (Shipments per Demand Period)	156
		Avg. Shipment Size	2.3
"Shallow transom"		Freight Rate/ FEU	$ 1,365
Catamaran		Transit Time (days)	7.36
Fuel savings/FEU		Std. Dev. of Transit Time	0.17
$	435	Service Freq. (Shipments per Demand Period)	156
		Avg. Shipment Size	2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE: PERISHABLE COMMODITY D

FEUs Shipped Annually		365
Density(lb/Cu. Ft.)		10.7
Value Density ($/lb.)	$	3.99
Cubic Value ($/Cu.Ft.)	$	42.69
Tonnes per FEUs		12.54
Lbs. per FEU		27,649
Value per FEU	$	110,319
Annual Carrying Charge		22.5%
Demand Period		365
Shelf Life (Days)		15
Salvage Value		25%
Decay Parameter		2.0
Stock-out Cost (Stc. Devs. for Safety Stock)		3.00
Warehouse Cost ($/lb./year)	$	-
Daily Sales (FEU)		1.00
Coef. of Var. of Daily Sales		300%
Std. Dev of Daily Sales		3.00
Storability (FEU load factor)		85%

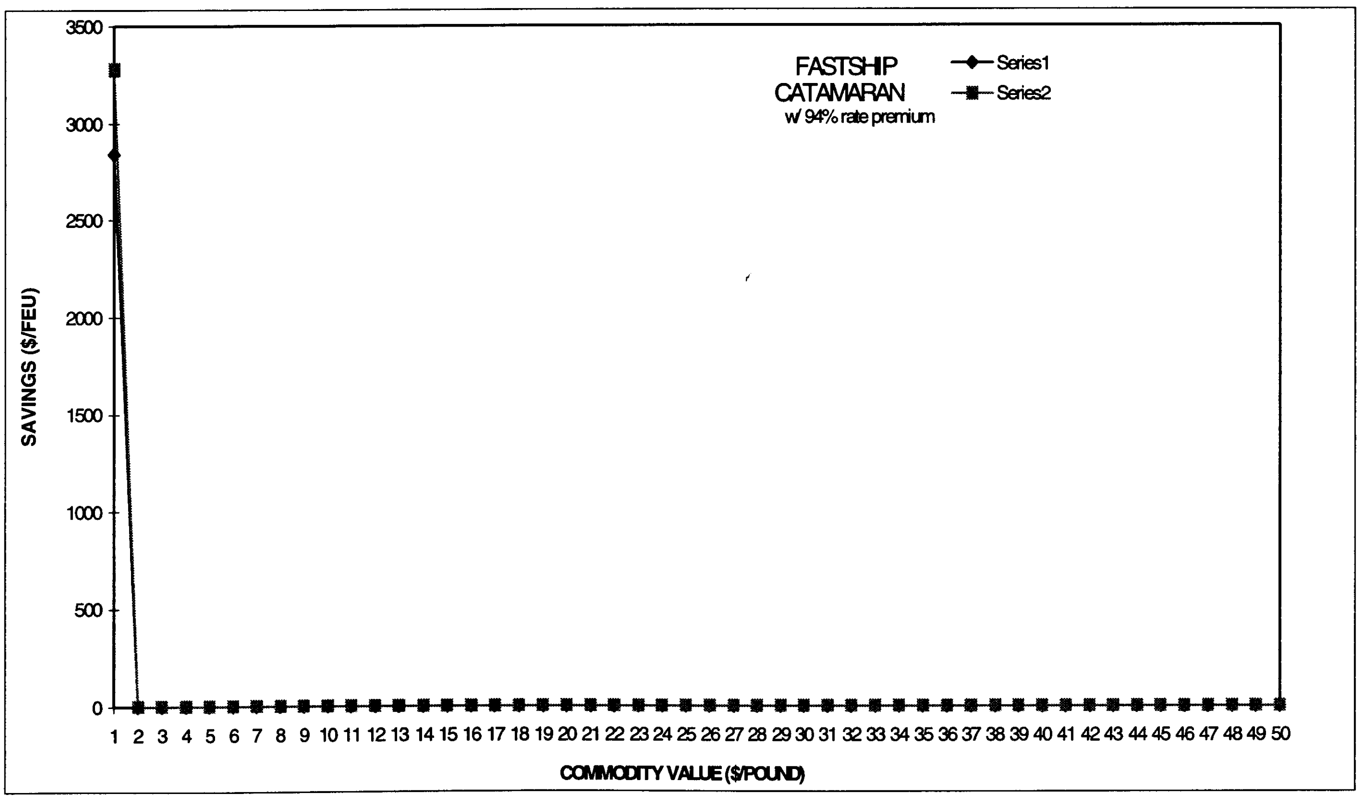
Standard Ocean	Freight Rate/ FEU	$	1,800
	Transit Time (days)		16.71
	Std. Dev. of Transit Time		3.15
	Service Freq. (Shipments per Demand Period)		52
	Avg. Shipment Size		7.0
Standard Air Freight	Freight Rate/ FEU	$	12,600
	Transit Time (days)		3.0
	Std. Dev. of Transit Time		0.5
	Service Freq. (Shipments per Demand Period)		365
	Avg. Shipment Size		1.0
FastShip	Freight Rate/ FEU	$	1,800
	Transit Time (days)		7.36
	Std. Dev. of Transit Time		0.17
	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3
"Shallow transom"	Freight Rate/ FEU	$	1,365
Catamaran	Transit Time (days)		7.36
Fuel savings/FEU	Std. Dev. of Transit Time		0.17
$ 435	Service Freq. (Shipments per Demand Period)		156
	Avg. Shipment Size		2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE : PERISHABLE COMMODITY E

FEUs Shipped Annually	365
Density(lb/Cu. Ft.)	10.7
Value Density ($/lb.)	$ 3.99
Cubic Value ($/Cu.Ft.)	$ 42.69
Tonnes per FEUs	12.54
Lbs. per FEU	27,649
Value per FEU	$ 110,319
Annual Carrying Charge	22.5%
Demand Period	365
Shelf Life (Days)	9
Salvage Value	50%
Decay Parameter	4.0
Stock-out Cost (Stc. Devs. for Safety Stock)	3.00
Warehouse Cost ($/lb./year)	$ -
Daily Sales (FEU)	1.00
Coef. of Var. of Daily Sales	300%
Std. Dev of Daily Sales	3.00
Storability (FEU load factor)	85%

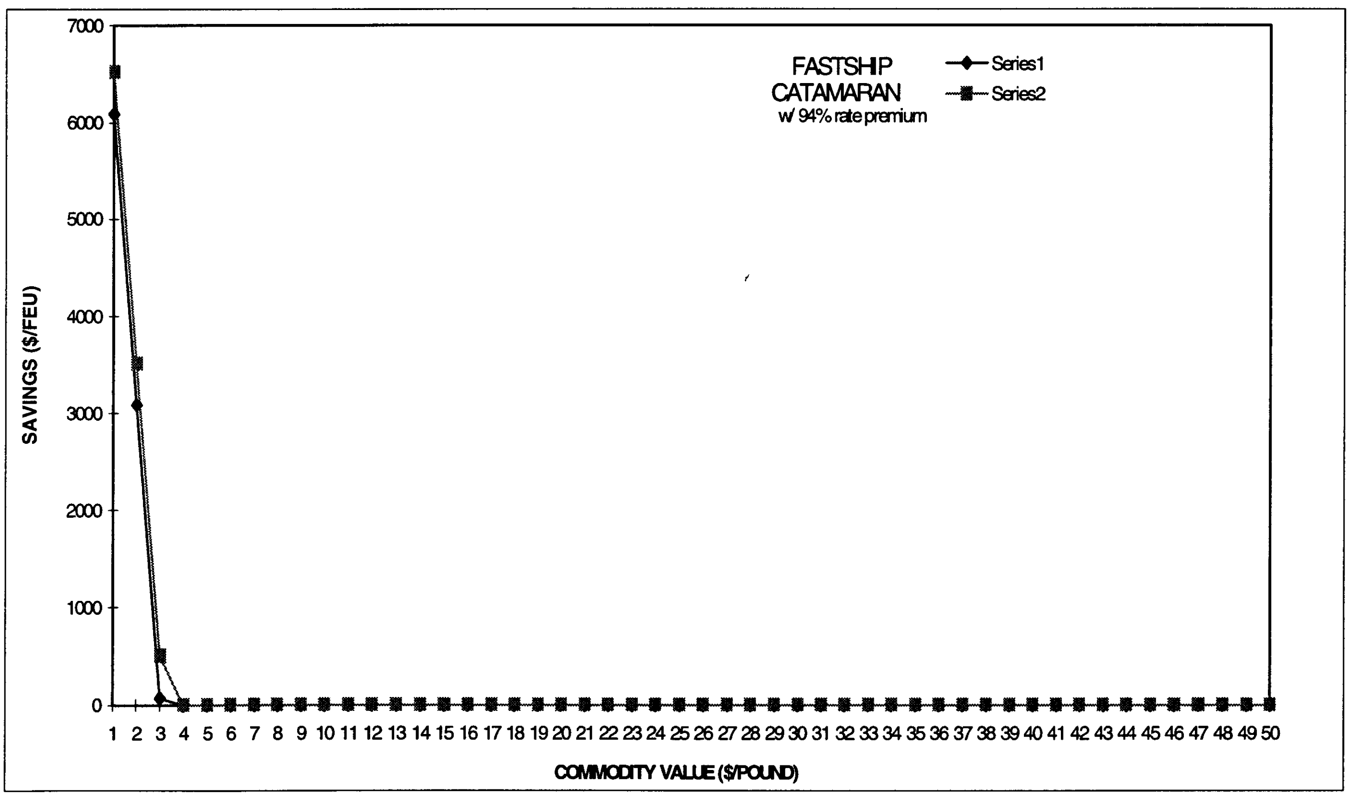
Standard Ocean	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	16.71
	Std. Dev. of Transit Time	3.15
	Service Freq. (Shipments per Demand Period)	52
	Avg. Shipment Size	7.0
Standard Air Freight	Freight Rate/ FEU	$ 12,600
	Transit Time (days)	3.0
	Std. Dev. of Transit Time	0.5
	Service Freq. (Shipments per Demand Period)	365
	Avg. Shipment Size	1.0
FastShip	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	7.36
	Std. Dev. of Transit Time	0.17
	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3
"Shallow transom"	Freight Rate/ FEU	$ 1,365
Catamaran	Transit Time (days)	7.36
Fuel savings/FEU	Std. Dev. of Transit Time	0.17
$ 435	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3



TOTAL LOGISTIC COST MODEL: SENSITIVITY ANALYSIS
CASE : PERISHABLE COMMODITY F

FEUs Shipped Annually	365
Density(lb./Cu. Ft.)	10.7
Value Density ($/lb.)	$ 3.99
Cubic Value ($/Cu.Ft.)	$ 42.69
Tonnes per FEUs	12.54
Lbs. per FEU	27,649
Value per FEU	$ 110,319
Annual Carrying Charge	22.5%
Demand Period	365
Shelf Life (Days)	9
Salvage Value	50%
Decay Parameter	8.0
Stock-out Cost (Stc. Devs. for Safety Stock)	3.00
Warehouse Cost ($/lb./year)	$ -
Daily Sales (FEU)	1.00
Coef. of Var. of Daily Sales	300%
Std. Dev of Daily Sales	3.00
Storability (FEU load factor)	85%

Standard Ocean	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	16.71
	Std. Dev. of Transit Time	3.15
	Service Freq. (Shipments per Demand Period)	52
	Avg. Shipment Size	7.0
Standard Air Freight	Freight Rate/ FEU	$ 12,600
	Transit Time (days)	3.0
	Std. Dev. of Transit Time	0.5
	Service Freq. (Shipments per Demand Period)	365
	Avg. Shipment Size	1.0
FastShip	Freight Rate/ FEU	$ 1,800
	Transit Time (days)	7.36
	Std. Dev. of Transit Time	0.17
	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3
"Shallow transom"	Freight Rate/ FEU	$ 1,365
Catamaran	Transit Time (days)	7.36
Fuel savings/FEU	Std. Dev. of Transit Time	0.17
$ 435	Service Freq. (Shipments per Demand Period)	156
	Avg. Shipment Size	2.3



Appendix 3: Latent and stimulated demand results

MODEL INPUT CONSTANTS AND PARAMETERS

	3040 cu.ft./high cube FEU		2205 LB./tonne	MAX LOAD 59000 lb./FEU			
	1992 DATA: CONTAINERIZED COMMODITIES, PORT OF NEW YORK						
DESCRIPTION	Data Source	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E
	Commodity Description	DATA PROCESS MACHINES ; MAGN. READER,ETC.	SWEATERS, PULLOVERS,VESTS, ETC. KNIT OR CROCHETED	BREAD, PASTRY, CAKES, ETC; FRESH	FISH FRESH OR CHILLED (NO FILLETS)	CUT FLOWERS FRESH	FIRST CLASS MAIL, NEWS-PAPERS
COMMODITY ATTRIBUTES	FEUs Shipped Annually	7,843	112	134	57	14	86
	Density(lb./Cu. Ft.)	20.0	12.0	14.0	31.0	5.0	33.0
	Value Density ($/lb.)	$ 10.82	$ 6.37	$ 0.96	$ 1.55	$ 5.46	$ 2.09
	Cubic Value ($/Cu.Ft.)	$ 216.40	$ 76.44	$ 13.44	$ 48.05	$ 27.30	$ 68.97
	Tonnes per FEUs	23.44	14.89	16.41	26.76	5.86	26.76
	Lbs. per FEU	51,680	32,832	36,176	59,000	12,920	59,000
	Value per FEU	$ 559,178	$ 209,140	$ 34,729	$ 91,450	$ 70,543	$ 123,310
	Annual Carrying Charge	22.5%	22.5%	22.5%	22.5%	22.5%	22.5%
	Demand Period	365	365	365	365	365	365
	Shelf Life (Days)	365	90	21	14	7	30
	Salvage Value	75%	50%	40%	25%	0%	40%
	Decay Parameter	2.0	3.0	4.0	3.0	2.5	2.0
	Stock-out Cost (Stc. Devs. for Safety Stock)	3.00	3.00	3.00	3.00	1.64	1.64
	Warehouse Cost ($/lb./year)	$ -	$ -	$ -	$ -	$ -	$ -
	Daily Sales (FEU)	21.49	0.31	0.37	0.16	0.04	0.24
	Coef. of Var. of Daily Sales	300%	200%	100%	150%	300%	100%
	Std. Dev of Daily Sales	64.46	0.61	0.37	0.23	0.12	0.24
	Storability (FEU load factor)	85%	90%	85%	90%	85%	90%
MODAL CHARACTERISTICS OCEAN FREIGHT	Freight Rate/ FEU	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800
	Transit Time (days)	16.71	16.71	16.71	16.71	16.71	16.71
	Std. Dev. of Transit Time	3.15	3.15	3.15	3.15	3.15	3.15
	Servive Freq. (Shipments per Demand Period)	52	52	52	52	52	52
	Avg. Shipment Size	150.8	2.2	2.6	1.1	0.3	1.7
MODAL CHARACTERISTICS AIR FREIGHT	Freight Rate/ FEU	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600
	Transit Time (days)	3.0	3.0	3.0	3.0	3.0	3.0
	Std. Dev. of Transit Time	0.5	0.5	0.5	0.5	0.5	0.5
	Servive Freq. (Shipments per Demand Period)	365	365	365	365	365	365
	Avg. Shipment Size	21.5	0.3	0.4	0.2	0.0	0.2
MODAL CHARACTERISTICS FASTSHIP	Freight Rate/ FEU	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800
	Transit Time (days)	7.36	7.36	7.36	7.36	7.36	7.36
	Std. Dev. of Transit Time	0.17	0.17	0.17	0.17	0.17	0.17
	Servive Freq. (Shipments per Demand Period)	156	156	156	156	156	156
	Avg. Shipment Size	50.3	0.7	0.9	0.4	0.1	0.6
MODEL RESULTS: OCEAN FREIGHT	Perishable Cost/FEU	$ 292.99	$ 669.28	$ 8,353.56	$ 68,587.50	$ 70,543.20	$ 22,954.08
	Origin Inventory / FEU	$ 1,209.76	$ 452.47	$ 75.13	$ 197.85	$ 152.62	$ 266.78
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 5,759.91	$ 2,154.28	$ 357.73	$ 942.00	$ 726.64	$ 1,270.18
	Cycle Inventory / FEU	$ 1,209.76	$ 452.47	$ 75.13	$ 197.85	$ 152.62	$ 266.78
	Safety Cost /FEU	$ 12,813.6	$ 3,235.7	$ 286.2	$ 1,079.6	$ 883.7	$ 555.5
	Freight Rate/ FEU	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800
	Total Logistic Cost /FEU	$ 23,086.03	$ 8,764.18	$ 10,947.78	$ 72,804.75	$ 74,258.77	$ 27,113.36
MODEL RESULTS: AIR FREIGHT	Perishable Cost/FEU	$ 9.44	$ 3.87	$ 8.68	$ 674.88	$ 8,482.29	$ 739.86
	Origin Inventory / FEU	$ 172.35	$ 64.46	$ 10.70	$ 28.19	$ 21.74	$ 38.01
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 1,034.10	$ 386.77	$ 64.22	$ 169.12	$ 130.46	$ 228.04
	Cycle Inventory / FEU	$ 172.35	$ 64.46	$ 10.70	$ 28.19	$ 21.74	$ 38.01
	Safety Cost /FEU	$ 5,422.8	$ 1,367.4	$ 120.2	$ 455.4	$ 374.0	$ 233.2
	Freight Rate/ FEU	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600
	Total Logistic Cost /FEU	$ 19,411.08	$ 14,486.98	$ 12,814.47	$ 13,955.74	$ 21,630.22	$ 13,877.13
MODEL RESULTS: FASTSHIP	Perishable Cost/FEU	$ 56.84	$ 57.19	$ 314.40	$ 9,965.39	$ 70,543.20	$ 4,453.10
	Origin Inventory / FEU	$ 403.25	$ 150.82	$ 25.04	$ 65.95	$ 50.87	$ 88.93
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 2,536.98	$ 948.86	$ 157.56	$ 414.91	$ 320.05	$ 559.46
	Cycle Inventory / FEU	$ 403.25	$ 150.82	$ 25.04	$ 65.95	$ 50.87	$ 88.93
	Safety Cost /FEU	$ 8,427.1	$ 2,104.6	$ 176.2	$ 691.7	$ 581.2	$ 342.1
	Freight Rate/ FEU	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800
	Total Logistic Cost /FEU	$ 13,627.41	$ 5,212.28	$ 2,498.29	$ 13,003.94	$ 73,346.17	$ 7,332.49
MODEL RESULTS: SUMMURY	Logistics Cost Savings/FEU	$ 5,783.67	$ 3,551.89	$ 8,449.49	$ 951.80	$ (51,715.95)	$ 6,544.64
	w / 94% rate premium	$ 4,083.67	$ 1,859.89	$ 6,757.49	$ (740.20)	$ (53,407.95)	$ 4,852.64
	w / 100% rate premium	$ 3,983.67	$ 1,751.89	$ 6,649.49	$ (848.20)	$ (53,515.95)	$ 4,744.64
	Value created / Value	1.03%	1.70%	24.33%	1.04%	-73.31%	5.31%
	w / 94% rate premium	0.73%	0.89%	19.46%	-0.81%	-75.71%	3.94%
	w / 100% rate premium	0.71%	0.84%	19.15%	-0.93%	-75.86%	3.85%
LATEND DEMAND CHARACTERISTICS	Base Elasticity	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
	Own Price Elasticity	-1.24	-0.94	-1.20	-1.06	-1.84	-0.20
	Import Elasticity	-1.62	-1.62	-1.62	-1.62	-1.62	-1.62
	Applied Elasticity	-1.29	-1.19	-1.27	-1.23	-1.49	-0.94
	Stimulated Demand (%)	0.94%	1.06%	24.78%	0.00%	0.00%	3.70%
	Exports (FEU)	7,842.90	111.96	134.24	56.60	14.22	86.39
	Stimulated Demand (FEU)	73.70	1.18	33.26	0.00	0.00	3.20

MODEL INPUT CONSTANTS AND PARAMETERS

3040 cu.ft./high cube FEU — 2205 LB./tonne — MAX LOAD 59000 lb./FEU

1992 DATA: CONTAINERIZED COMMODITIES, PORT OF NEW YORK

DESCRIPTION							
	Data Source	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E
	Commodity Description	DATA PROCESS MACHINES ; MAGN. READER,ETC.	SWEATERS, PULLOVERS,VESTS, ETC. KNIT OR CROCHETED	BREAD, PASTRY, CAKES, ETC; FRESH	FISH FRESH OR CHILLED (NO FILLETS)	CUT FLOWERS FRESH	FIRST CLASS MAIL, NEWS-PAPERS
COMMODITY ATTRIBUTES	FEUs Shipped Annually	7,843	112	134	57	14	86
	Density(lb./Cu. Ft.)	20.0	12.0	14.0	31.0	5.0	33.0
	Value Density ($/lb.)	$ 10.82	$ 6.37	$ 0.96	$ 1.55	$ 5.46	$ 2.09
	Cubic Value ($/Cu.Ft.)	$ 216.40	$ 76.44	$ 13.44	$ 48.05	$ 27.30	$ 68.97
	Tonnes per FEUs	23.44	14.89	16.41	26.76	5.86	26.76
	Lbs. per FEU	51,680	32,832	36,176	59,000	12,920	59,000
	Value per FEU	$ 559,178	$ 209,140	$ 34,729	$ 91,450	$ 70,543	$ 123,310
	Annual Carrying Charge	22.5%	22.5%	22.5%	22.5%	22.5%	22.5%
	Demand Period	365	365	365	365	365	365
	Shelf Life (Days)	365	90	21	14	7	30
	Salvage Value	75%	50%	40%	25%	0%	40%
	Decay Parameter	2.0	3.0	4.0	3.0	2.5	2.0
	Stock-out Cost (Stc. Devs. for Safety Stock)	3.00	3.00	3.00	3.00	1.64	1.64
	Warehouse Cost ($/lb./year)	$ -	$ -	$ -	$ -	$ -	$ -
	Daily Sales (FEU)	21.49	0.31	0.37	0.16	0.04	0.24
	Coef. of Var. of Daily Sales	300%	200%	100%	150%	300%	100%
	Std. Dev of Daily Sales	64.46	0.61	0.37	0.23	0.12	0.24
	Storability (FEU load factor)	85%	90%	85%	90%	85%	90%
MODAL CHARACTERISTICS OCEAN FREIGHT	Freight Rate/ FEU	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800
	Transit Time (days)	16.71	16.71	16.71	16.71	16.71	16.71
	Std. Dev. of Transit Time	3.15	3.15	3.15	3.15	3.15	3.15
	Servive Freq. (Shipments per Demand Period)	52	52	52	52	52	52
	Avg. Shipment Size	150.8	2.2	2.6	1.1	0.3	1.7
MODAL CHARACTERISTICS AIR FREIGHT	Freight Rate/ FEU	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600
	Transit Time (days)	3.0	3.0	3.0	3.0	3.0	3.0
	Std. Dev. of Transit Time	0.5	0.5	0.5	0.5	0.5	0.5
	Servive Freq. (Shipments per Demand Period)	365	365	365	365	365	365
	Avg. Shipment Size	21.5	0.3	0.4	0.2	0.0	0.2
MODAL CHARACTERISTICS SH. TR. CATAMARAN	Freight Rate/ FEU	$ 1,365	$ 1,365	$ 1,365	$ 1,365	$ 1,365	$ 1,365
	Transit Time (days)	7.36	7.36	7.36	7.36	7.36	7.36
	Std. Dev. of Transit Time	0.17	0.17	0.17	0.17	0.17	0.17
	Servive Freq. (Shipments per Demand Period)	156	156	156	156	156	156
	Avg. Shipment Size	50.3	0.7	0.9	0.4	0.1	0.6
MODEL RESULTS: OCEAN FREIGHT	Perishable Cost/FEU	$ 292.99	$ 669.28	$ 8,353.56	$ 68,587.50	$ 70,543.20	$ 22,954.08
	Origin Inventory / FEU	$ 1,209.76	$ 452.47	$ 75.13	$ 197.85	$ 152.62	$ 266.78
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 5,759.91	$ 2,154.28	$ 357.73	$ 942.00	$ 726.64	$ 1,270.18
	Cycle Inventory / FEU	$ 1,209.76	$ 452.47	$ 75.13	$ 197.85	$ 152.62	$ 266.78
	Safety Cost /FEU	$ 12,813.6	$ 3,235.7	$ 286.2	$ 1,079.6	$ 883.7	$ 555.5
	Freight Rate/ FEU	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800
	Total Logistic Cost /FEU	$ 23,086.03	$ 8,764.18	$ 10,947.78	$ 72,804.75	$ 74,258.77	$ 27,113.36
MODEL RESULTS: AIR FREIGHT	Perishable Cost/FEU	$ 9.44	$ 3.87	$ 8.68	$ 674.88	$ 8,482.29	$ 739.86
	Origin Inventory / FEU	$ 172.35	$ 64.46	$ 10.70	$ 28.19	$ 21.74	$ 38.01
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 1,034.10	$ 386.77	$ 64.22	$ 169.12	$ 130.46	$ 228.04
	Cycle Inventory / FEU	$ 172.35	$ 64.46	$ 10.70	$ 28.19	$ 21.74	$ 38.01
	Safety Cost /FEU	$ 5,422.8	$ 1,367.4	$ 120.2	$ 455.4	$ 374.0	$ 233.2
	Freight Rate/ FEU	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600
	Total Logistic Cost /FEU	$ 19,411.08	$ 14,486.98	$ 12,814.47	$ 13,955.74	$ 21,630.22	$ 13,877.13
MODEL RESULTS: SHALLOW TRANSOM CATAMARAN	Perishable Cost/FEU	$ 56.84	$ 57.19	$ 314.40	$ 9,965.39	$ 70,543.20	$ 4,453.10
	Origin Inventory / FEU	$ 403.25	$ 150.82	$ 25.04	$ 65.95	$ 50.87	$ 88.93
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 2,536.98	$ 948.86	$ 157.56	$ 414.91	$ 320.05	$ 559.46
	Cycle Inventory / FEU	$ 403.25	$ 150.82	$ 25.04	$ 65.95	$ 50.87	$ 88.93
	Safety Cost /FEU	$ 8,427.1	$ 2,104.6	$ 176.2	$ 691.7	$ 581.2	$ 342.1
	Freight Rate/ FEU	$ 1,365	$ 1,365	$ 1,365	$ 1,365	$ 1,365	$ 1,365
	Total Logistic Cost /FEU	$ 13,192.41	$ 4,777.28	$ 2,063.29	$ 12,568.94	$ 72,911.17	$ 6,897.49
MODEL RESULTS: SUMMURY	Logistics Cost Savings/FEU	$ 6,218.67	$ 3,986.89	$ 8,884.49	$ 1,386.80	$ (51,280.95)	$ 6,979.64
	w / 94% rate premium	$ 4,518.67	$ 2,294.89	$ 7,192.49	$ (305.20)	$ (52,972.95)	$ 5,287.64
	w / 100% rate premium	$ 4,418.67	$ 2,186.89	$ 7,084.49	$ (413.20)	$ (53,080.95)	$ 5,179.64
	Value created / Value	1.11%	1.91%	25.58%	1.52%	-72.69%	5.66%
	w / 94% rate premium	0.81%	1.10%	20.71%	-0.33%	-75.09%	4.29%
	w / 100% rate premium	0.79%	1.05%	20.40%	-0.45%	-75.25%	4.20%
LATEND DEMAND CHARACTERISTICS	Base Elasticity	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
	Own Price Elasticity	-1.24	-0.94	-1.20	-1.06	-1.84	-0.20
	Import Elasticity	-1.62	-1.62	-1.62	-1.62	-1.62	-1.62
	Applied Elasticity	-1.29	-1.19	-1.27	-1.23	-1.49	-0.94
	Stimulated Demand (%)	1.04%	1.30%	26.37%	0.00%	0.00%	4.03%
	Exports (FEU)	7,842.90	111.96	134.24	56.60	14.22	86.39
	Stimulated Demand (FEU)	81.55	1.46	35.40	0.00	0.00	3.48

MODEL INPUT CONSTANTS AND PARAMETERS

3040 cu.ft./high cube FEU	2205 LB./tonne	**MAX LOAD** 59000 lb./FEU

1992 DATA: CONTAINERIZED COMMODITIES, PORT OF NEW YORK

DESCRIPTION							
	Data Source	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E
	Commodity Description	DATA PROCESS MACHINES ; MAGN. READER,ETC.	SWEATERS, PULLOVERS,VESTS, ETC. KNIT OR CROCHETED	BREAD, PASTRY, CAKES, ETC; FRESH	FISH FRESH OR CHILLED (NO FILLETS)	CUT FLOWERS FRESH	FIRST CLASS MAIL, NEWS-PAPERS
COMMODITY ATTRIBUTES	FEUs Shipped Annually	7,843	112	134	57	14	86
	Density(lb./Cu. Ft.)	20.0	12.0	14.0	31.0	5.0	33.0
	Value Density ($/lb.)	$ 10.82	$ 6.37	$ 0.96	$ 1.55	$ 5.46	$ 2.09
	Cubic Value ($/Cu.Ft.)	$ 216.40	$ 76.44	$ 13.44	$ 48.05	$ 27.30	$ 68.97
	Tonnes per FEUs	23.44	14.89	16.41	26.76	5.86	26.76
	Lbs. per FEU	51,680	32,832	36,176	59,000	12,920	59,000
	Value per FEU	$ 559,178	$ 209,140	$ 34,729	$ 91,450	$ 70,543	$ 123,310
	Annual Carrying Charge	22.5%	22.5%	22.5%	22.5%	22.5%	22.5%
	Demand Period	365	365	365	365	365	365
	Shelf Life (Days)	365	90	21	14	7	30
	Salvage Value	75%	50%	40%	25%	0%	40%
	Decay Parameter	2.0	3.0	4.0	3.0	2.5	2.0
	Stock-out Cost (Stc. Devs. for Safety Stock)	3.00	3.00	3.00	3.00	1.64	1.64
	Warehouse Cost ($/lb./year)	$ -	$ -	$ -	$ -	$ -	$ -
	Daily Sales (FEU)	21.49	0.31	0.37	0.16	0.04	0.24
	Coef. of Var. of Daily Sales	300%	200%	100%	150%	300%	100%
	Std. Dev of Daily Sales	64.46	0.61	0.37	0.23	0.12	0.24
	Storability (FEU load factor)	85%	90%	85%	90%	85%	90%
MODAL CHARACTERISTICS OCEAN FREIGHT	Freight Rate/ FEU	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800
	Transit Time (days)	16.71	16.71	16.71	16.71	16.71	16.71
	Std. Dev. of Transit Time	3.15	3.15	3.15	3.15	3.15	3.15
	Servive Freq. (Shipments per Demand Period)	52	52	52	52	52	52
	Avg. Shipment Size	150.8	2.2	2.6	1.1	0.3	1.7
MODAL CHARACTERISTICS AIR FREIGHT	Freight Rate/ FEU	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600
	Transit Time (days)	3.0	3.0	3.0	3.0	3.0	3.0
	Std. Dev. of Transit Time	0.5	0.5	0.5	0.5	0.5	0.5
	Servive Freq. (Shipments per Demand Period)	365	365	365	365	365	365
	Avg. Shipment Size	21.5	0.3	0.4	0.2	0.0	0.2
MODAL CHARACTERISTICS DP. TR. CATAMARAN	Freight Rate/ FEU	$ 2,101	$ 2,101	$ 2,101	$ 2,101	$ 2,101	$ 2,101
	Transit Time (days)	7.36	7.36	7.36	7.36	7.36	7.36
	Std. Dev. of Transit Time	0.17	0.17	0.17	0.17	0.17	0.17
	Servive Freq. (Shipments per Demand Period)	156	156	156	156	156	156
	Avg. Shipment Size	50.3	0.7	0.9	0.4	0.1	0.6
MODEL RESULTS: OCEAN FREIGHT	Perishable Cost/FEU	$ 292.99	$ 669.28	$ 8,353.56	$ 68,587.50	$ 70,543.20	$ 22,954.08
	Origin Inventory / FEU	$ 1,209.76	$ 452.47	$ 75.13	$ 197.85	$ 152.62	$ 266.78
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 5,759.91	$ 2,154.28	$ 357.73	$ 942.00	$ 726.64	$ 1,270.18
	Cycle Inventory / FEU	$ 1,209.76	$ 452.47	$ 75.13	$ 197.85	$ 152.62	$ 266.78
	Safety Cost /FEU	$ 12,813.6	$ 3,235.7	$ 286.2	$ 1,079.6	$ 883.7	$ 555.5
	Freight Rate/ FEU	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800
	Total Logistic Cost /FEU	$ 23,086.03	$ 8,764.18	$ 10,947.78	$ 72,804.75	$ 74,258.77	$ 27,113.36
MODEL RESULTS: AIR FREIGHT	Perishable Cost/FEU	$ 9.44	$ 3.87	$ 8.68	$ 674.88	$ 8,482.29	$ 739.86
	Origin Inventory / FEU	$ 172.35	$ 64.46	$ 10.70	$ 28.19	$ 21.74	$ 38.01
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 1,034.10	$ 386.77	$ 64.22	$ 169.12	$ 130.46	$ 228.04
	Cycle Inventory / FEU	$ 172.35	$ 64.46	$ 10.70	$ 28.19	$ 21.74	$ 38.01
	Safety Cost /FEU	$ 5,422.8	$ 1,367.4	$ 120.2	$ 455.4	$ 374.0	$ 233.2
	Freight Rate/ FEU	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600
	Total Logistic Cost /FEU	$ 19,411.08	$ 14,486.98	$ 12,814.47	$ 13,955.74	$ 21,630.22	$ 13,877.13
MODEL RESULTS: DEEP TRANSOM CATAMARAN	Perishable Cost/FEU	$ 56.84	$ 57.19	$ 314.40	$ 9,965.39	$ 70,543.20	$ 4,453.10
	Origin Inventory / FEU	$ 403.25	$ 150.82	$ 25.04	$ 65.95	$ 50.87	$ 88.93
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 2,536.98	$ 948.86	$ 157.56	$ 414.91	$ 320.05	$ 559.46
	Cycle Inventory / FEU	$ 403.25	$ 150.82	$ 25.04	$ 65.95	$ 50.87	$ 88.93
	Safety Cost /FEU	$ 8,427.1	$ 2,104.6	$ 176.2	$ 691.7	$ 581.2	$ 342.1
	Freight Rate/ FEU	$ 2,101	$ 2,101	$ 2,101	$ 2,101	$ 2,101	$ 2,101
	Total Logistic Cost /FEU	$ 13,928.41	$ 5,513.28	$ 2,799.29	$ 13,304.94	$ 73,647.17	$ 7,633.49
MODEL RESULTS: SUMMURY	Logistics Cost Savings/FEU	$ 5,482.67	$ 3,250.89	$ 8,148.49	$ 650.80	$ (52,016.95)	$ 6,243.64
	w / 94% rate premium	$ 3,782.67	$ 1,558.89	$ 6,456.49	$ (1,041.20)	$ (53,708.95)	$ 4,551.64
	w / 100% rate premium	$ 3,682.67	$ 1,450.89	$ 6,348.49	$ (1,149.20)	$ (53,816.95)	$ 4,443.64
	Value created / Value	0.98%	1.55%	23.46%	0.71%	-73.74%	5.06%
	w / 94% rate premium	0.68%	0.75%	18.59%	-1.14%	-76.14%	3.69%
	w / 100% rate premium	0.66%	0.69%	18.28%	-1.26%	-76.29%	3.60%
LATEND DEMAND CHARACTERISTICS	Base Elasticity	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
	Own Price Elasticity	-1.24	-0.94	-1.20	-1.06	-1.84	-0.20
	Import Elasticity	-1.62	-1.62	-1.62	-1.62	-1.62	-1.62
	Applied Elasticity	-1.29	-1.19	-1.27	-1.23	-1.49	-0.94
	Stimulated Demand (%)	0.87%	0.88%	23.67%	0.00%	0.00%	3.47%
	Exports (FEU)	7,842.90	111.96	134.24	56.60	14.22	86.39
	Stimulated Demand (FEU)	68.26	0.99	31.78	0.00	0.00	3.00

MODEL INPUT CONSTANTS AND PARAMETERS

3040 cu.ft./high cube FEU	2205 LB./tonne	MAX LOAD 59000 lb./FEU

1992 DATA: CONTAINERIZED COMMODITIES, PORT OF NEW YORK

DESCRIPTION	Data Source	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E	Marad NY_E
	Commodity Description	DATA PROCESS MACHINES ; MAGN. READER,ETC.	SWEATERS, PULLOVERS,VESTS, ETC. KNIT OR CROCHETED	BREAD, PASTRY, CAKES, ETC; FRESH	FISH FRESH OR CHILLED (NO FILLETS)	CUT FLOWERS FRESH	FIRST CLASS MAIL, NEWS-PAPERS
COMMODITY ATTRIBUTES	FEUs Shipped Annually	7,843	112	134	57	14	86
	Density(lb./Cu. Ft.)	20.0	12.0	14.0	31.0	5.0	33.0
	Value Density ($/lb.)	$ 10.82	$ 6.37	$ 0.96	$ 1.55	$ 5.46	$ 2.09
	Cubic Value ($/Cu.Ft.)	$ 216.40	$ 76.44	$ 13.44	$ 48.05	$ 27.30	$ 68.97
	Tonnes per FEUs	23.44	14.89	16.41	26.76	5.86	26.76
	Lbs. per FEU	51,680	32,832	36,176	59,000	12,920	59,000
	Value per FEU	$ 559,178	$ 209,140	$ 34,729	$ 91,450	$ 70,543	$ 123,310
	Annual Carrying Charge	22.5%	22.5%	22.5%	22.5%	22.5%	22.5%
	Demand Period	365	365	365	365	365	365
	Shelf Life (Days)	365	90	21	14	7	30
	Salvage Value	75%	50%	40%	25%	0%	40%
	Decay Parameter	2.0	3.0	4.0	3.0	2.5	2.0
	Stock-out Cost (Stc. Devs. for Safety Stock)	3.00	3.00	3.00	3.00	1.64	1.64
	Warehouse Cost ($/lb./year)	$ -	$ -	$ -	$ -	$ -	$ -
	Daily Sales (FEU)	21.49	0.31	0.37	0.16	0.04	0.24
	Coef. of Var. of Daily Sales	300%	200%	100%	150%	300%	100%
	Std. Dev of Daily Sales	64.46	0.61	0.37	0.23	0.12	0.24
	Storability (FEU load factor)	85%	90%	85%	90%	85%	90%
MODAL CHARACTERISTICS OCEAN FREIGHT	Freight Rate/ FEU	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800
	Transit Time (days)	16.71	16.71	16.71	16.71	16.71	16.71
	Std. Dev. of Transit Time	3.15	3.15	3.15	3.15	3.15	3.15
	Servive Freq. (Shipments per Demand Period)	52	52	52	52	52	52
	Avg. Shipment Size	150.8	2.2	2.6	1.1	0.3	1.7
MODAL CHARACTERISTICS AIR FREIGHT	Freight Rate/ FEU	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600
	Transit Time (days)	3.0	3.0	3.0	3.0	3.0	3.0
	Std. Dev. of Transit Time	0.5	0.5	0.5	0.5	0.5	0.5
	Servive Freq. (Shipments per Demand Period)	365	365	365	365	365	365
	Avg. Shipment Size	21.5	0.3	0.4	0.2	0.0	0.2
MODAL CHARACTERISTICS ASYM. CATAMARAN	Freight Rate/ FEU	$ 1,688	$ 1,688	$ 1,688	$ 1,688	$ 1,688	$ 1,688
	Transit Time (days)	7.36	7.36	7.36	7.36	7.36	7.36
	Std. Dev. of Transit Time	0.17	0.17	0.17	0.17	0.17	0.17
	Servive Freq. (Shipments per Demand Period)	156	156	156	156	156	156
	Avg. Shipment Size	50.3	0.7	0.9	0.4	0.1	0.6
MODEL RESULTS: OCEAN FREIGHT	Perishable Cost/FEU	$ 292.99	$ 669.28	$ 8,353.56	$ 68,587.50	$ 70,543.20	$ 22,954.08
	Origin Inventory / FEU	$ 1,209.76	$ 452.47	$ 75.13	$ 197.85	$ 152.62	$ 266.78
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 5,759.91	$ 2,154.28	$ 357.73	$ 942.00	$ 726.64	$ 1,270.18
	Cycle Inventory / FEU	$ 1,209.76	$ 452.47	$ 75.13	$ 197.85	$ 152.62	$ 266.78
	Safety Cost /FEU	$ 12,813.6	$ 3,235.7	$ 286.2	$ 1,079.6	$ 883.7	$ 555.5
	Freight Rate/ FEU	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800	$ 1,800
	Total Logistic Cost /FEU	$ 23,086.03	$ 8,764.18	$ 10,947.78	$ 72,804.75	$ 74,258.77	$ 27,113.36
MODEL RESULTS: AIR FREIGHT	Perishable Cost/FEU	$ 9.44	$ 3.87	$ 8.68	$ 674.88	$ 8,482.29	$ 739.86
	Origin Inventory / FEU	$ 172.35	$ 64.46	$ 10.70	$ 28.19	$ 21.74	$ 38.01
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 1,034.10	$ 386.77	$ 64.22	$ 169.12	$ 130.46	$ 228.04
	Cycle Inventory / FEU	$ 172.35	$ 64.46	$ 10.70	$ 28.19	$ 21.74	$ 38.01
	Safety Cost /FEU	$ 5,422.8	$ 1,367.4	$ 120.2	$ 455.4	$ 374.0	$ 233.2
	Freight Rate/ FEU	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600	$ 12,600
	Total Logistic Cost /FEU	$ 19,411.08	$ 14,486.98	$ 12,814.47	$ 13,955.74	$ 21,630.22	$ 13,877.13
MODEL RESULTS: ASYM. DEMI-HULL CATAMARAN	Perishable Cost/FEU	$ 56.84	$ 57.19	$ 314.40	$ 9,965.39	$ 70,543.20	$ 4,453.10
	Origin Inventory / FEU	$ 403.25	$ 150.82	$ 25.04	$ 65.95	$ 50.87	$ 88.93
	Origin Warehouse Cost / FEU	$ -	$ -	$ -	$ -	$ -	$ -
	In-Transit Inventory Cost /FEU	$ 2,536.98	$ 948.86	$ 157.56	$ 414.91	$ 320.05	$ 559.46
	Cycle Inventory / FEU	$ 403.25	$ 150.82	$ 25.04	$ 65.95	$ 50.87	$ 88.93
	Safety Cost /FEU	$ 8,427.1	$ 2,104.6	$ 176.2	$ 691.7	$ 581.2	$ 342.1
	Freight Rate/ FEU	$ 1,688	$ 1,688	$ 1,688	$ 1,688	$ 1,688	$ 1,688
	Total Logistic Cost /FEU	$ 13,515.41	$ 5,100.28	$ 2,386.29	$ 12,891.94	$ 73,234.17	$ 7,220.49
MODEL RESULTS: SUMMURY	Logistics Cost Savings/FEU	$ 5,895.67	$ 3,663.89	$ 8,561.49	$ 1,063.80	$ (51,603.95)	$ 6,656.64
	w / 94% rate premium	$ 4,195.67	$ 1,971.89	$ 6,869.49	$ (628.20)	$ (53,295.95)	$ 4,964.64
	w / 100% rate premium	$ 4,095.67	$ 1,863.89	$ 6,761.49	$ (736.20)	$ (53,403.95)	$ 4,856.64
	Value created / Value	1.05%	1.75%	24.65%	1.16%	-73.15%	5.40%
	w / 94% rate premium	0.75%	0.94%	19.78%	-0.69%	-75.55%	4.03%
	w / 100% rate premium	0.73%	0.89%	19.47%	-0.81%	-75.70%	3.94%
LATEND DEMAND CHARACTERISTICS	Base Elasticity	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
	Own Price Elasticity	-1.24	-0.94	-1.20	-1.06	-1.84	-0.20
	Import Elasticity	-1.62	-1.62	-1.62	-1.62	-1.62	-1.62
	Applied Elasticity	-1.29	-1.19	-1.27	-1.23	-1.49	-0.94
	Stimulated Demand (%)	0.97%	1.12%	25.19%	0.00%	0.00%	3.78%
	Exports (FEU)	7,842.90	111.96	134.24	56.60	14.22	86.39
	Stimulated Demand (FEU)	75.72	1.25	33.81	0.00	0.00	3.27