# WHOLE SHIP DESIGN SYNTHESIS
# AND
# CONCURRENT ENGINEERING

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(Slide presentation edited by CACTS)

## INTRODUCTION

Who is Band Lavis & Associates? - Band, Lavis & Associates is a Naval Architect and Marine Engineering Firm that specialises in advanced technologies and innovative technical solutions to customer problems. The company was founded in 1977 and has, since its inception, been at the forefront of the development and application of Whole Ship Design Synthesis Models for use in early stage design.

## THE NAVAL ARCHITECT'S PROBLEM

The maritime market now presents numerous advanced hullforms (and hybrids) for potential use by craft operators. Advanced hullforms can be classified by hull shape,

- Monohull, Multihull
- Hard Chine, Round-Bilge

by vessel support,

- Displacement
- Planing or Semi-Planing
- Advanced means of Lift

### DISPLACEMENT HULLFORMS

Displacement hullforms describe vessels that are supported primarily by buoyancy. Most Vessels are still of displacement type. They use varying degrees of hydrodynamic lift (Semi-Planing hulls) and come in various shapes,

- Single Hull (Monohulls, Planing Monohulls)
- Twin hull (Catamarans, SWATH, Semi-SWATH)
- Triple hull (Trimarans)

Each of these is now described in terms of attributes and issues specific to their conformation

**Monohulls**

- Specific Attributes:
  - Technology is mature
  - Large hull volume for machinery integration
  - Large dead-weight capacity
- Specific Issues:
  - High power required
  - Limited by space and stability
  - Active Ride Control often required

**Catamarans**

- Specific Attributes:
  - Exceptional Stability
  - Large Deck space
  - Particularly suitable for Waterjets
  - Good Powering Performance (slender hulls)

- Specific Issues:
  - Wide Beam limits access to some Ports
  - High vertical accelerations in Head Seas
  - "Jerky" Roll motions in Beam Seas

**Small Waterplane Area Twin Hulls (SWATH)**

- Specific Attributes:
  - Excellent Seakeeping
  - Small Speed Loss in a Seaway
  - Large Usable Deck Space
- Specific Issues:
  - Machinery Installation (Narrow Struts)
  - Limited Top Speed (High Wetted Area)
  - Complexity of Active Fin Control
  - Large Draft

**Semi-Swath Vessels**

- Specific Attributes:
  - Seakeeping nearly as good as for SWATH
  - Easy Machinery Installation (including Waterjets)
  - Lower Resistance than SWATH
- Specific Issue:
  - Large draft

**ADVANCED MEANS OF LIFT**

This describes platforms using means of lift other than buoyancy or planing forces. Advanced Vessel support originate from water or air pressure, generated statically (by an internal power source), or dynamically through the vehicle speed. The Lift Pyramid (Figure 1) shows the three basic types, Hydrofoils, Air Cushion and Wing-in-Ground Effect, on the base, with displacement (Hydrostatic) at the apex. Hybrids that combine lift types, are illustrated by HYSWAS (Displacement + Hydrofoil) and by Surface Effect Ship (Catamaran + Air Cushion). Attributes and Issues for the various types follow.

**Hydrofoils**

- Specific Attributes:
  - Superior Seakeeping
  - High Speed Capability

- Specific Issues:
  - Limited Dead-weight
  - Cannot operate efficiently at Medium Speed
  - Complexity of Foil Control System
  - Expensive (Aerospace Technology)
  - Difficult to pilot (Airplane like)

**HYSWAS Vessels**

- Specific Attributes:
  - Excellent Seakeeping
  - Small Loss in Speed in a Seaway
  - Foils provide Lift and Active Control
- Specific Issues:
  - Machinery Installation
  - Stability dependent upon Foils which can lead to problems at low speed
  - Large Draft
  - Little Operational Experience

**Air Cushion Vehicles**

- Specific Attributes:
  - Amphibious Capability
  - High Speed Capability (40+kt)
- Specific Issues:
  - Air Propellers not very efficient, Noisy
  - Complexity of Lift System (fans+engines)
  - Expensive (Aerospace Technology)
  - Difficult to pilot (Airplane like)
  - "Cobblestone" like motions

**Surface Effect Ship (SES)**

- Specific Attributes:
  - Ship like Behaviour (stability, manoeuvring,...)
  - High Speed Capability (40+kts)
  - Efficient Propulsion (Marine)
- Specific Issues:
  - Loses Amphibious capability of ACVs
  - Complexity of Lift System (fans+engines)
  - "Cobblestone" like motions (active ride control often required

**TRENDS FOR HIGH PERFORMANCE VESSELS WORLDWIDE**

There is a fast growing market activity mostly in Europe, the Far East and Australia. Vessel sizes and speed are increasing. These trends are indicated by Figure 2 - Worlwide Fast Ferries Deliveries, Figure 3 - Speeds of Fast Ferries (1996), Figure 4 - Fast Ferries, Distribution by Types (1996). The growing sizes and speeds can be summarised by the following points:

- Car Ferries with up to 500 cars and 1500 passengers are now in service
- Cargo vessels with up to 8000 ton Dead-weight capacity are envisioned
- Higher speeds:
  - Most new Car-ferries can achieve 40 knot
  - Some are now offering 50+ knot

## OVERVIEW OF DESIGN SYNTHESIS

With all of the potential hullforms available, what type of hullform does the naval architect recommend to the customer for satisfying their specific requirements and how does the naval architect support the recommendation? The present tutorial objectives is to:

- Provide a suggested approach for answering the question: what hullform to recommend?
- Provide a suggested method for the naval architect to interactively work with the customer to establish a "preferred" set of requirements
- The process proposed is the " Whole Ship Design Synthesis", which is used to:
- Perform comparative analysis of competing hullforms
  - Compare commercial craft on the basis of passenger cost per nm travelled
  - Compare military and para-military craft of the basis of life-cycle cost
- Illustrate the impact on cost of changing customer requirements

**Whole-Ship Design Synthesis Models**

The synthesis process develops models which are used in order to:

- Provide rational basis for parametric investigations
- Ensure consistent design practices
- Resolve particularly well unconventional hullforms
- Use the power of modern computers to faster and more thoroughly iterate through the naval architect design spiral
- Operate through algorithms developed with emphasis on the use of first principle physics with empirical adjustments
- Naval architect know-how still required to make sense of large data base of results

Figure 5 shows the design spiral used in the synthesis model, Figure 6 shows its inputs and Figure 7 shows the calculation cycle.

**Capabilities/Benefits Of The Models**

- Quick evaluation of the characteristics of the optimum vessel
- Minimise cost, displacement or power for a given set of requirements
- Parametric investigations
- Subsystem trade-off and selection
- Hullform comparisons

Parametric analysis results obtained with the models are shown in Figures 8, 9 and 10. These illustrate ship's displacement, acquisition cost and life cycle cost obtained for various length and length to beam ratios.

Band, Lavis and Associates has whole ship design synthesis models for:

- Air Cushion Vehicles
- Surface Effect Ships
- Catamarans / Semi-Swath
- Trimarans
- Planing Monohulls
- Displacement/Semi-Displacement Monohulls

The BLA design synthesis models have been under continuous development at BLA since 1978 and have been continuously subjected to design verification.

- Key element in BLA synthesis models is the addition of cost calculations:
  - Predict operating costs which are an essential share of the global ownership cost
  - Predict ticket retail price to assess profitability at the earliest stage of design
- The previous process is only capable of addressing 2 dependent variables
  - If a third dependent variable is required, the previous process must currently be repeated
  - BLA is developing a new DSM that is capable handling 3 dependent variables at the same time

## EXAMPLES OF WHOLE SHIP DESIGN SYNTHESIS AND PARAMETRIC ANALYSIS

### CASE STUDY #1 - THE CASE OF A TOURIST BOAT

**Challenge**

- Owner/operator operated a conventional catamaran on an excursion route on the Chesapeake bay
- Characteristics of existing craft
  - Craft length : 48 ft
  - Craft beam: 18 ft
  - Design speed: 22 kt
  - Passenger capacity: 90 people
- Route characteristics:
  - Route length: 37 nm
  - Number of trips per day: 3
- Craft operator wanted a "faster" craft in order to expand the route length and/or increase the number of trips per day
- Operator expressed an interest in a 40 kt Catamaran

**Solution**

BLA proposed to the operator that a brief parametric study be made that examined the passenger cost/nm as a function of design speed. Specifically, both a Catamaran and an SES were evaluated, using the following procedure:

- The BLA Catamaran Design Synthesis Model (CDSM) and SES Design Synthesis Model (SDSM) were used to parametrically investigate the passenger cost per nm travelled for both a Catamaran and an SES.
- The parametric analysis varied length, beam and design speed
  - Design speed was held constant and the length and beam were parametrically varied
  - The length and beam combination that resulted in the least cost solution was selected
  - The design speed was incremented and the process was repeated
- Process of parametrically examining passenger cost/nm as a function of length and beam for fixed speeds was repeated for speeds of 25 kt, 30 kt, 35 kt and 40 kt for Catamarans and SES. Figures 11 and 12 show the parametric results for speeds of 25 and 35 knots.

**Results**

Overall results are given in Figure 13. They show that an SES is less expensive to operate than a Catamaran at speeds above 26 kt.

- Operator subsequently discontinued service before new craft was acquired

## CASE STUDY #2 - COST OF MACHINERY AND SPEED

**Challenge**

- Examine the effect that the type of propulsion engine has on the passenger cost for a mixed traffic SES
  - Limit diesel power to 9 500 shp (limit of medium speed diesel)
  - Limit gas turbine power to 18 000 shp (limit of Lycoming LM1600)
- Examine impact of speed requirement

**Characteristics of service**

- Mixed traffic ferry
  - 400 passengers
  - 60 cars
- Range: 200 nm
- Route length: 32 nm
- Number of trips per day: 6
- Year round operation
- 50 % passenger load factor
- 65% load factor for cars
- 10% design margin
- 20% fuel margin
- 20% power margin

**Solution**

Use SDSM to select optimum combination of length and beam for constant values of calm-water speed

- Stop parametric analysis when limit of engine power is reached

**Results**

Figures 14 and 15 compare parametric analysis of passenger unit cost for Diesel and Gas Turbine powered SES at 30 kt; Figures 16 and 17, at 40 kt. Figure 18 shows unit cost against speed for both type of power source. The following points summarise the results:

- Maximum calm water speed with 4 x 9500 shp max. rating Diesel engine is **52 kt**
- Maximum calm water speed with 2 x 18,000 shp max. rating Gas Turbine engine is **53 kt**
- For speeds below 40 kt, the Diesel engine has a 10% advantage in passenger cost per nm
- At speeds of **47 kt** and above, the Gas Turbine engine is the most cost effective
- The cost of calm water speed is approximately **0.015 $/nm/pass**.

## CASE STUDY #3 - HULLFORM SELECTION

**Challenge**

The SR.N4 MK III craft have exceeded their design life and we wish to propose a replacement craft. We will examine Wavepiercing Catamaran, SES and ACV craft with calm water speed capability from 30 kt to 70 kt

**Requirements to be examined**

- Route description
  - Range: 200 nm
  - Route length: 32 nm
  - Calm water
  - Speed: 40 kt - to - 70 kt
  - Number of passengers: 400, at 200 lb/pass.
  - Number of cars: 60, at 2000 lb/car
- 12.5% design margin
- 20% fuel margin
- 20% power margin
- 8% profit
- 2 craft
- Operate 12 months per year
- 10 year operation
- 1500 operating hr/year
- 6 trips per day
- 7days per week

**Solution**

- Use CDSM to design Catamaran
  - Examine Diesel and GT engines
- Use SDSM to design SES
  - Examine Diesel and GT engines
- Use ADSM to design ACV
  - Look at GT only
- Propulsion machinery
  - Waterjet propulsors for Catamaran and SES
  - Airscrew for ACV
  - Max Diesel power 9500 shp
  - Max GT power 18,000 shp

**Limits**

- Catamaran, Max L/B = 18
- SES, Max L/B = 5
  - Not to exceed Pc/Lc limit
- ACV, Max L/B = 2.5

**Results**

Figure 19 shows the unit cost comparison between the three hullforms examined. Main points are that:

- Diesel Catamaran preferred for speeds between **30 kt** and **40 kt**
- Gas Turbine powered Catamaran preferred between **40 kt** and **52 kt**
- ACV is by far the best hullform for speeds above **52 kt**

# LIFT PYRAMID

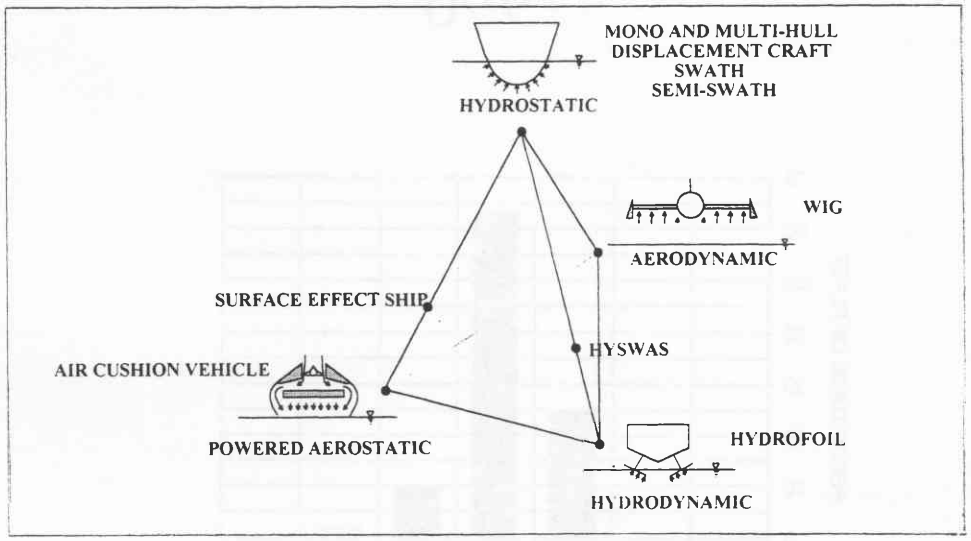



Figure 1

# WORLDWIDE FAST FERRIES DELIVERIES

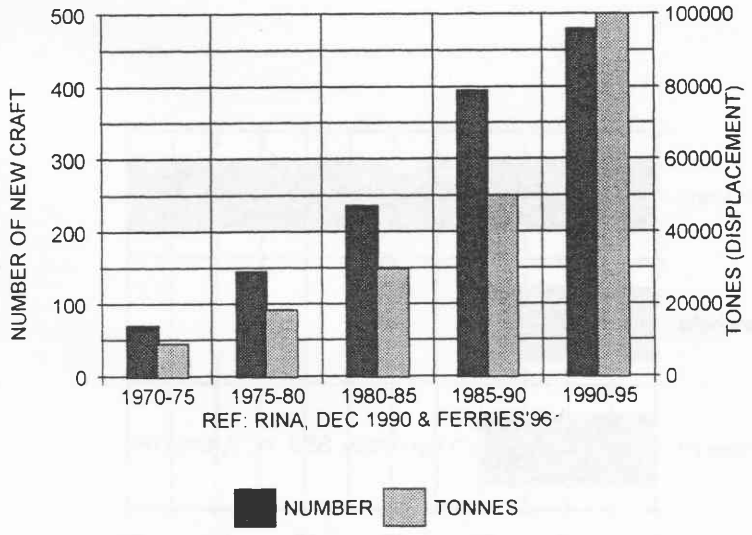
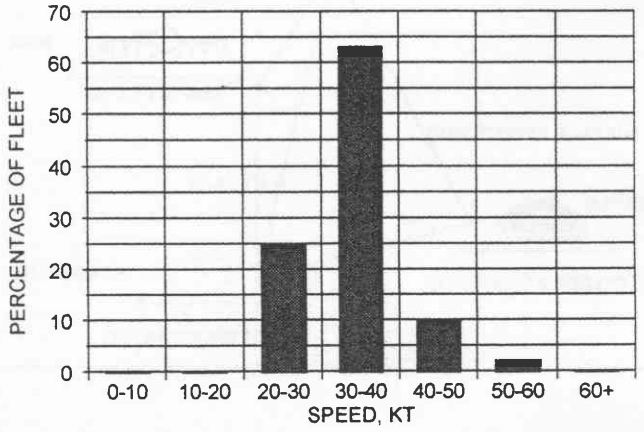



Figure 2

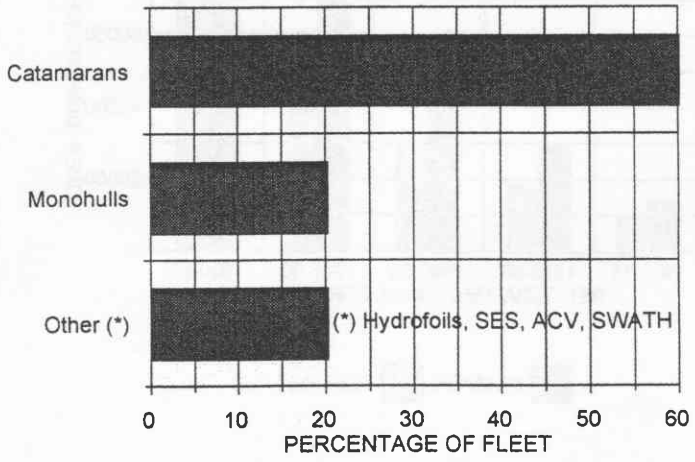
# SPEEDS OF FAST FERRIES 1996




RINA, Rapid Transport Group, London 5 Feb 1997

Figure 3

# FAST FERRIES, DISTRIBUTION BY TYPE, 1996




RINA, Rapid Transport Group, London 5 Feb 1997

Figure 4

# WHOLE-SHIP DESIGN SYNTHESIS MODELS

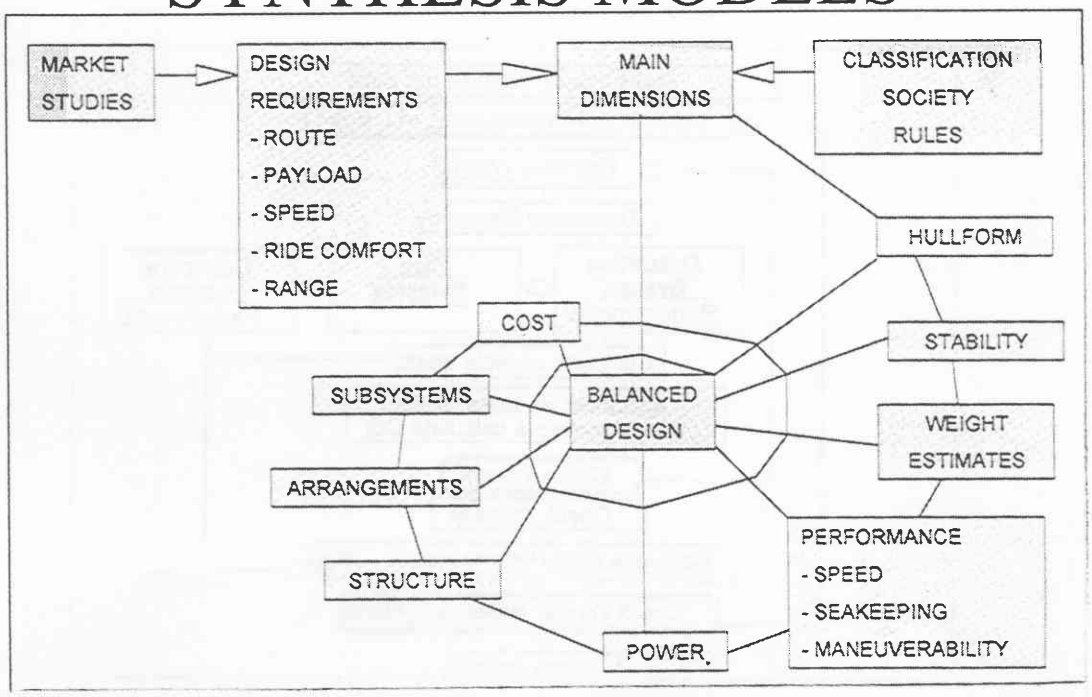



Figure 5

# WHOLE-SHIP DESIGN SYNTHESIS MODELS

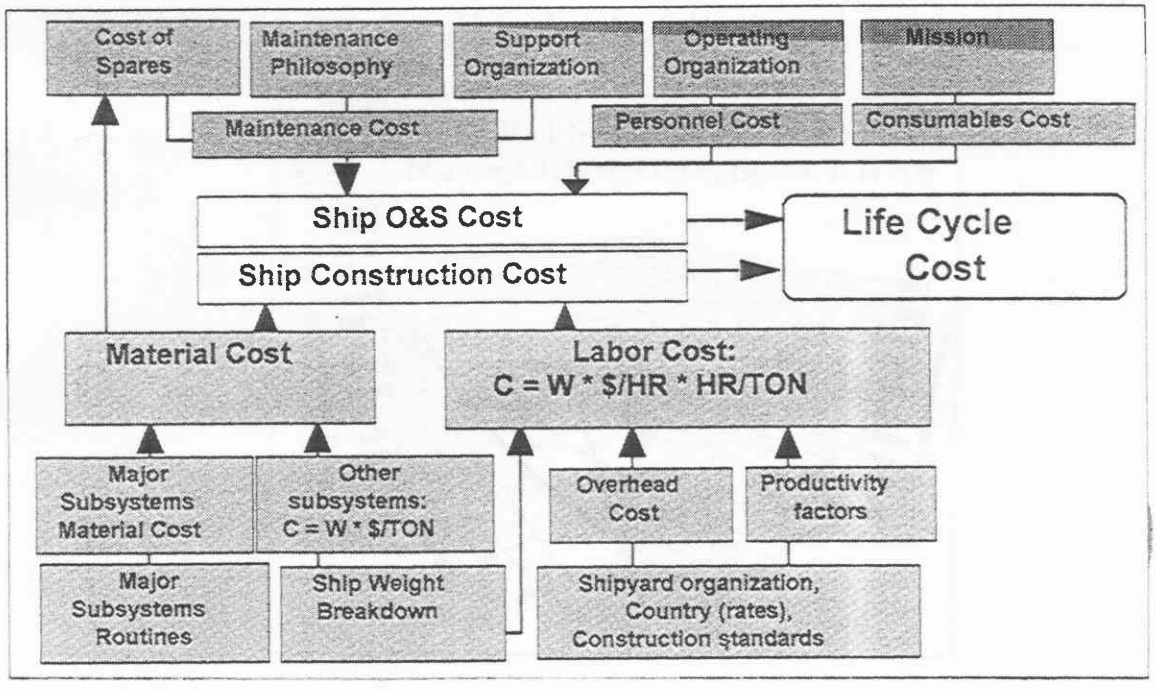



Figure 6

# WHOLE-SHIP DESIGN SYNTHESIS MODELS
# TYPICAL SYNTHESIS ENGINE

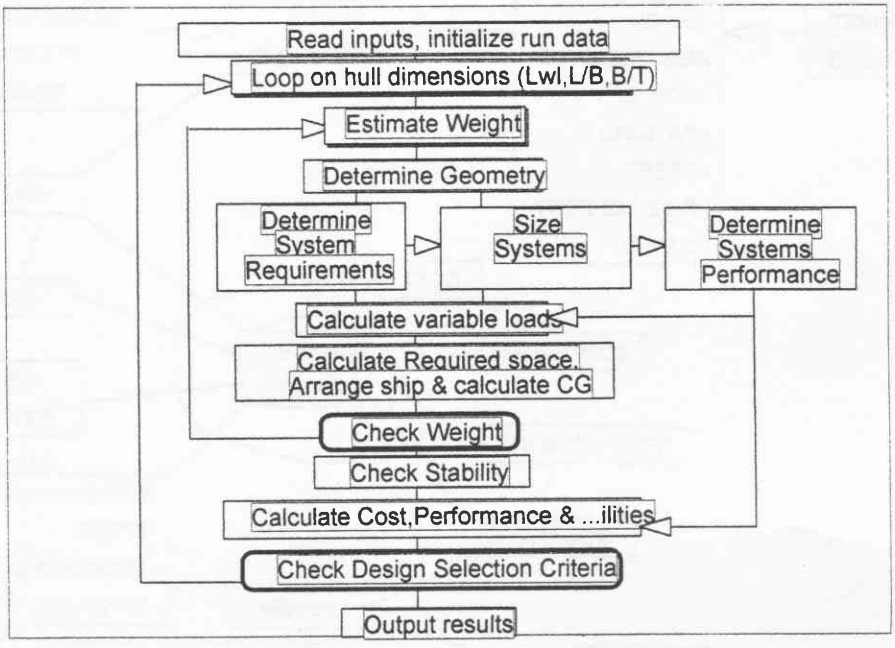



Figure 7

# TYPICAL EXAMPLE OF WHOLE SHIP DESIGN SYNTHESIS AND PARAMETRIC ANALYSIS

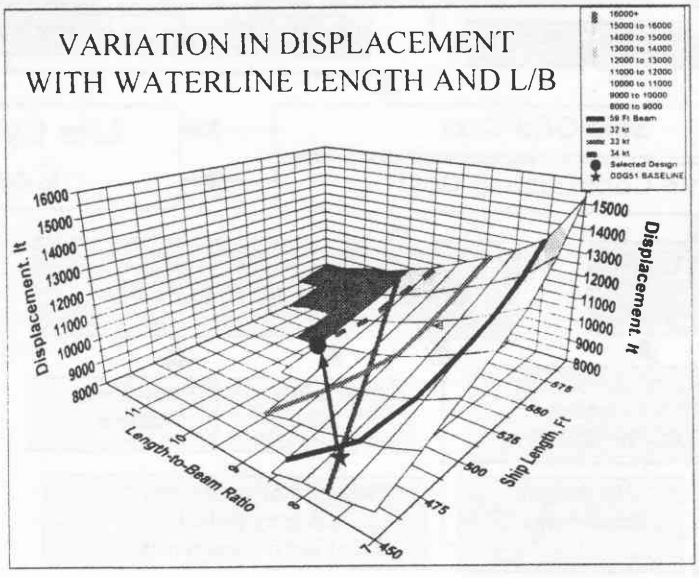



Figure 8

# TYPICAL EXAMPLE OF WHOLE SHIP DESIGN SYNTHESIS AND PARAMETRIC ANALYSIS

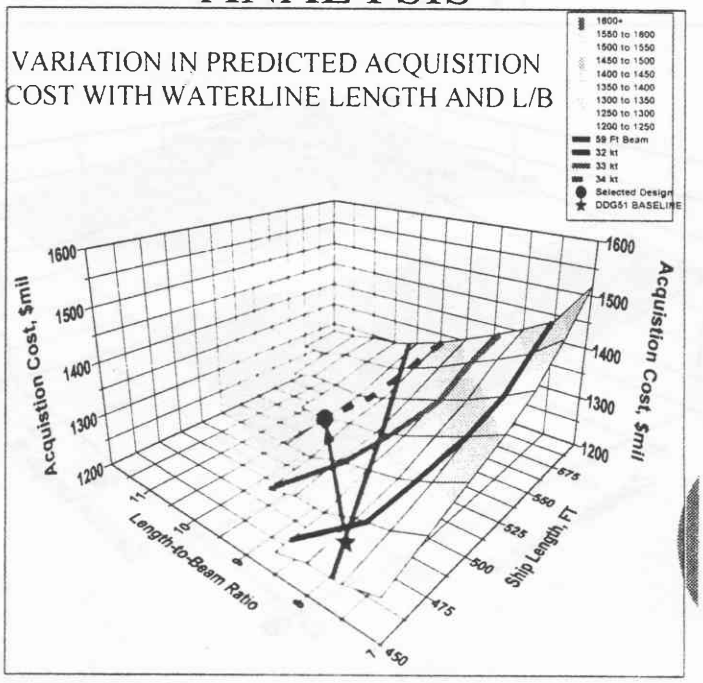



Figure 9

# TYPICAL EXAMPLE OF WHOLE SHIP DESIGN SYNTHESIS AND PARAMETRIC ANALYSIS

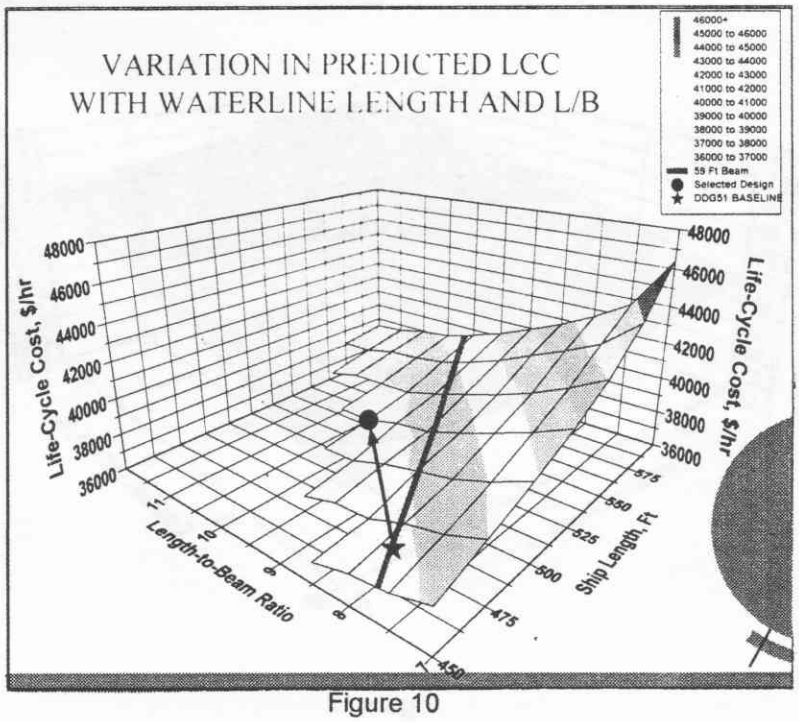



Figure 10

# PARAMETRIC RESULTS FOR A 25 KT SES

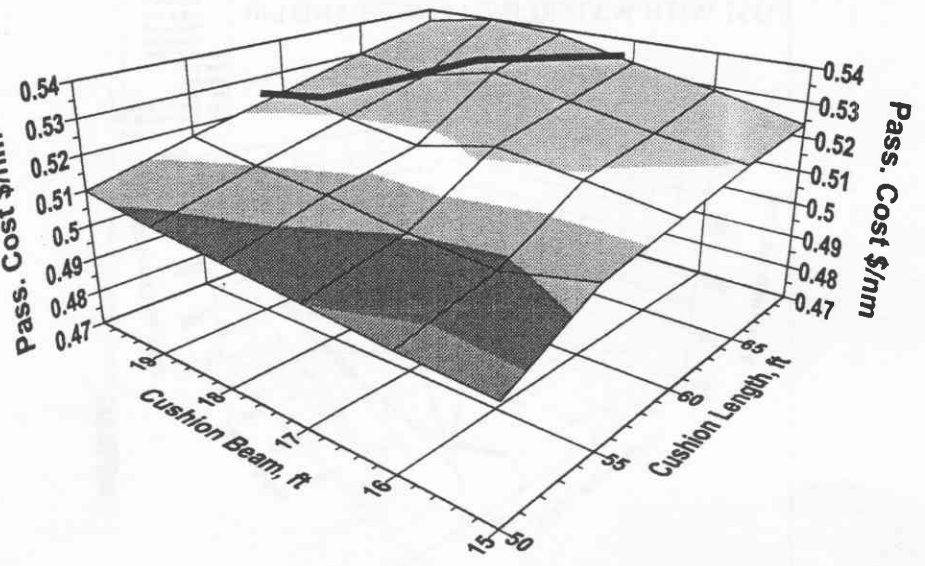



Figure 11

# PARAMETRIC RESULTS FOR A 35 KT SES

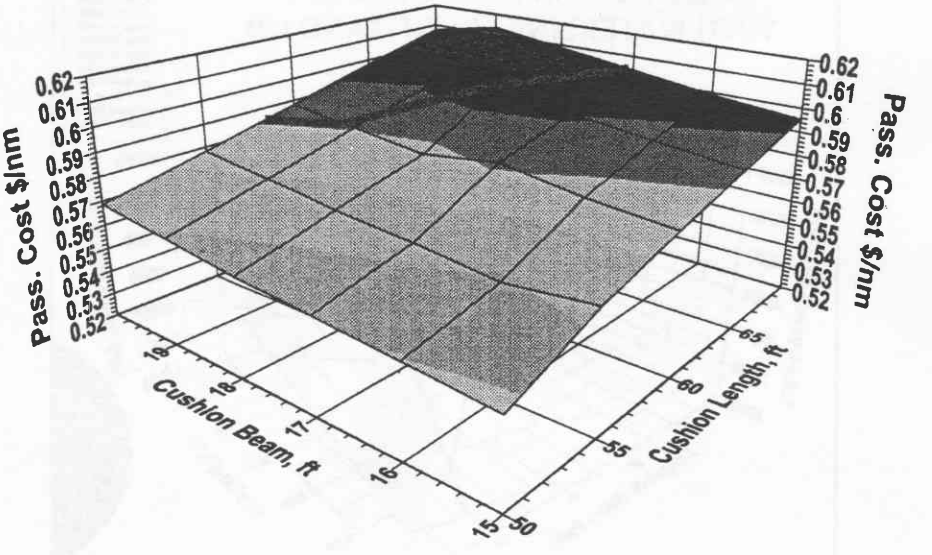



Figure 12

# CASE STUDY #1

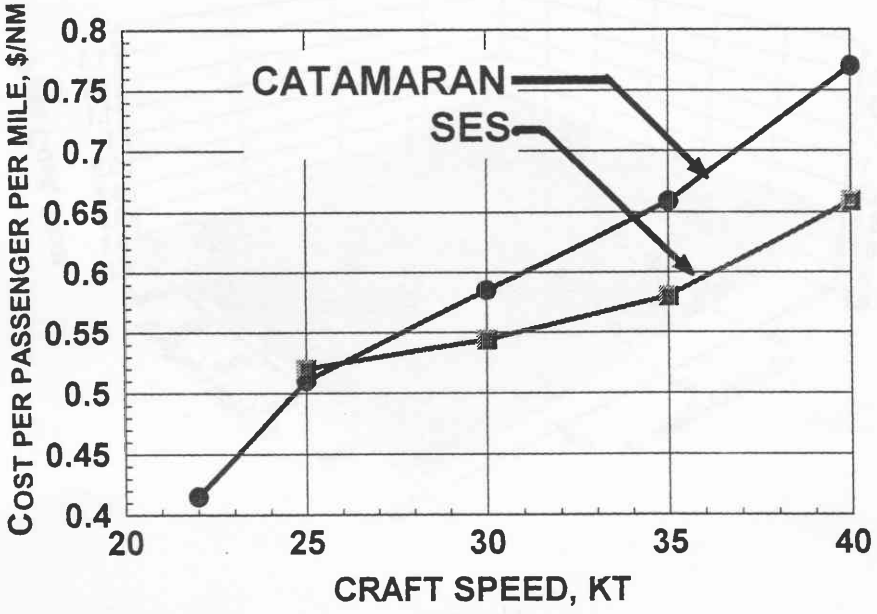



Figure 13

# RESULTS FOR A 30 KT DIESEL POWERED SES

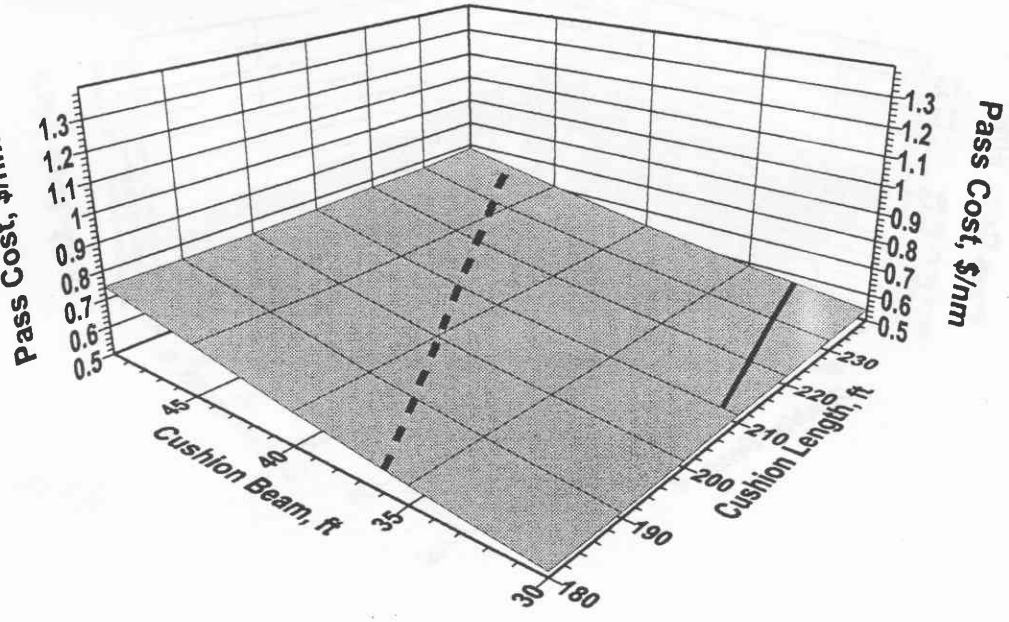



Figure 14

# RESULTS FOR A 30 KT GAS TURBINE POWERED SES

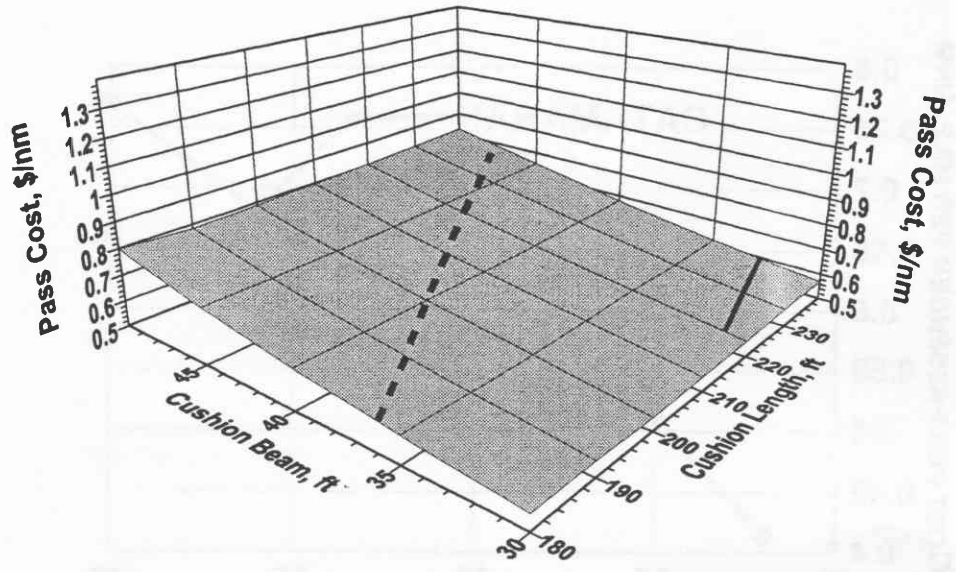



Figure 15

# RESULTS FOR A 40 KT DIESEL POWERED SES

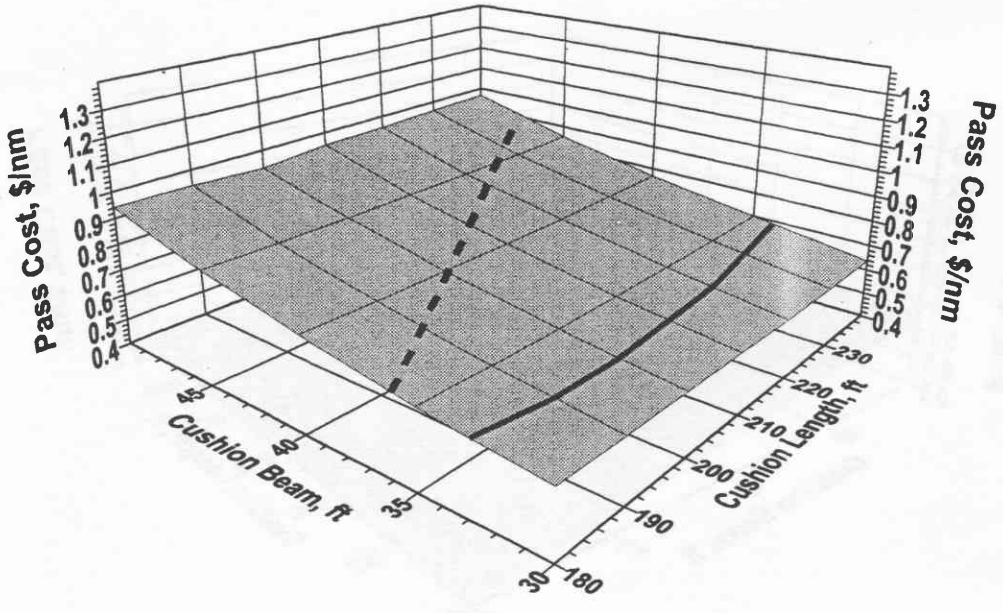



Figure 16

# RESULTS FOR A 40 KT GAS TURBINE POWERED SES

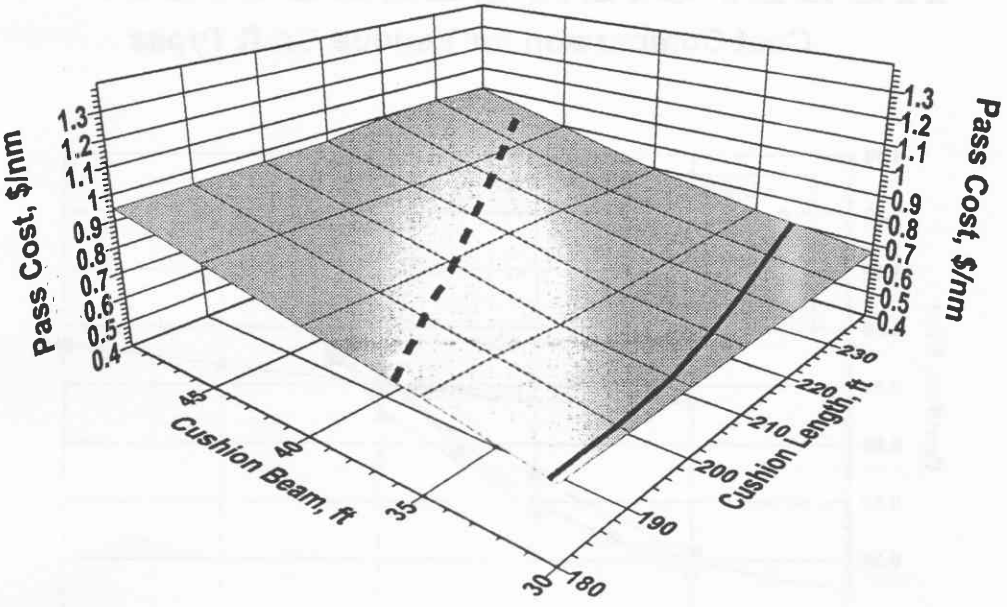



Figure 17

# COMPARISON OF DIESEL AND GAS TURBINE ENGINES

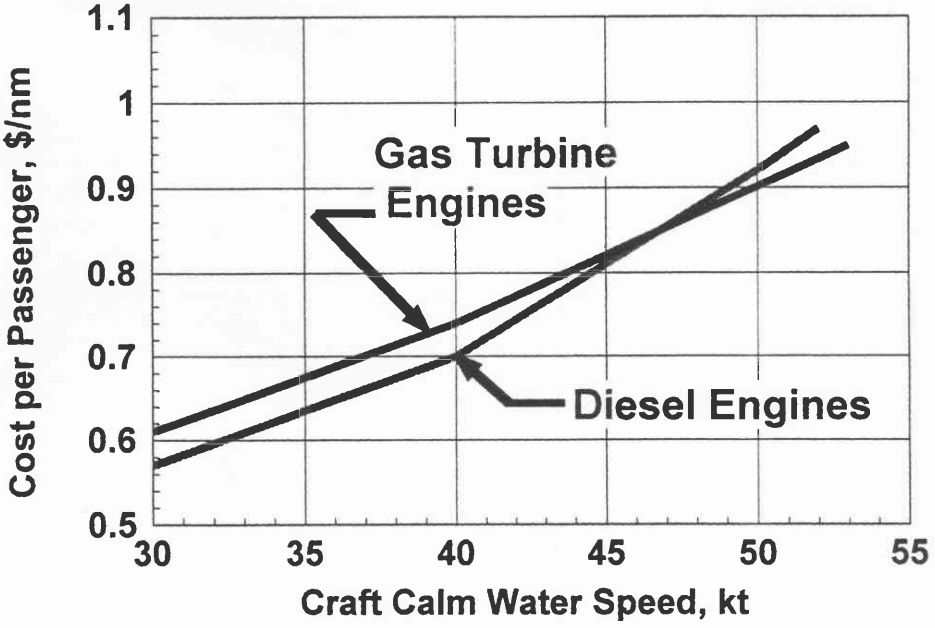



Figure 18

# CASE STUDY #3 - HULLFORM SELECTION

**Cost Comparison for Various Craft Types**

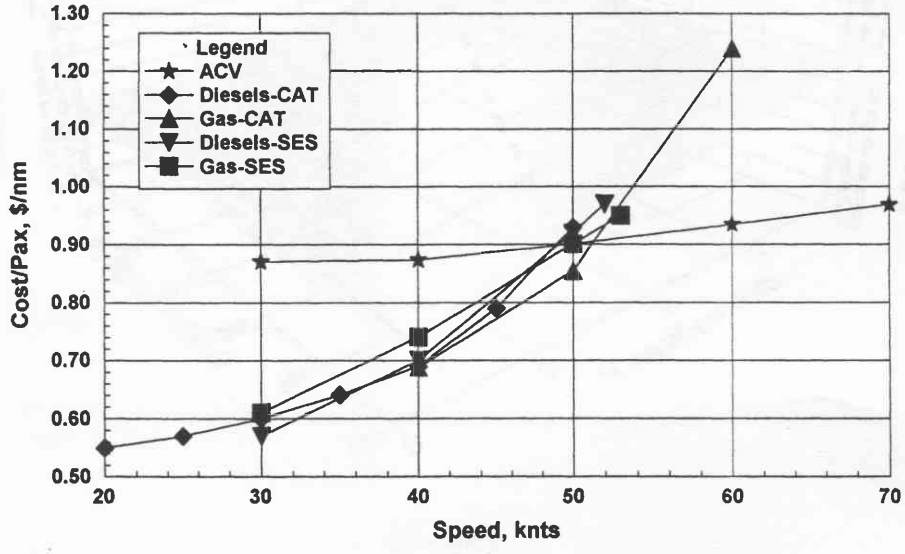



Figure 19