WATERJET PROPULSION SYSTEM OPTIMIZATION FOR SURFACE EFFECT SHIPS

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by

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ABSTRACT

This report presents a development of design optimization techniques for waterjet propulsion systems used on surface effect ships. The emphasis is on developing a minimum system weight or a maximum system efficiency. The possibility of optimizing a ship displacement for a given propulsion plant is also presented.

The waterjet propulsion systems presented use flush inlets, constant-area nozzles, multi-stage axial-flow pumps, planetary reduction gears and marine gas turbines. The equations which govern the performance and design of these systems are developed and incorporated into a computer program. This program is a modified and improved version of an earlier computer program.

The computer program is then used to conduct a study of the U. S. Navy's contemplated 2,000 ton, 80 knot SES. The concentration of this report is on the effects of changing the jet velocity ratio, the effects of different length-to-beam ratios, the effects of gas turbine size and the optimization of ship displacement for a given waterjet propulsion system.

A Fortran computer program listing and user's guide is included. This program may be used for a number of different ships and is not restricted to the 2,000 ton class.

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SYMBOLS USED IN TEXT

A_c	Inlet area at cruise speed	ft^2
A_h	Inlet area at hump speed	ft^2
A_j	Jet area	ft^2
A_p	Pump inlet area	ft^2
C	Ratio of entering water momentum velocity to ship velocity (V_m/V_o)	
C_A	Acceleration coefficient	
C_b	Pump blockage coefficient	
C_D	Inlet drag coefficient	
C_L	Pump length coefficient	
C_w	Inlet system weight coefficient	
C_w	Pump weight coefficient	
D	Inlet system drag	lb
D_j	Nozzle exit diameter	ft
D_p	Pump inlet diameter	ft
D_{pi}	Inside diameter of pump-to-nozzle pipe	ft
D_{po}	Outside diameter of pump-to-nozzle pipe	ft
f	Moody pipe friction factor	
g	Acceleration due to gravity	ft/sec^2
h	Difference in height between outside waterline and diffuser exit	ft
Ha	Atmospheric pressure head	ft
h_e	Height of diffuser exit above inlet	ft

h_{lep}	Head loss between diffuser exit and pump inlet	ft
h_p	Height of pump above inlet	ft
h_{pe}	Change in height between diffuser exit and the pump entrance	ft
H_p	Change of head across pump	ft
H_{p1}	Head at entrance to pump	ft
H_{p2}	Head at pump exit	ft
H_2	Head at diffuser exit	ft
H_{noz}	Change of head across nozzle	ft
H_{pipe}	Change of head across pump-to-nozzle pipe	ft
HP_{loss}	Additional horsepower required to overcome the pump-to-nozzle pipe head loss	HP
HP_p	Horsepower delivered to the water	HP
K	K-factor of reduction gear	
L_p	Length of pump	ft
L_{pipe}	Length of pump-to-nozzle pipe	ft
m_g	Reduction gear ratio	
N_s	Pump specific speed	
N_{ss}	Pump suction specific speed	$\frac{rpm(gal/min)^{.5}}{ft^{.75}}$
n_p	Reduction gear input pinion RPM (engine rpm)	rpm
NPSH	Net positive suction head	ft
p_v	Vapor pressure head of water	ft
PC	Overall propulsive efficiency	

PC_{net}	Net propulsive efficiency	
ΔP	Pressure drop in pump-to-nozzle pipe	lb/ft^2
Q	Flow rate	ft^3/sec
Q	Reduction gear Q-factor	
Q_c	Flow rate at cruise speed	ft^3/sec
Q_h	Flow rate at hump speed	ft^3/sec
R	Ship resistance	lb
Re	Reynold's Number	
r_h	Pump hub radius	ft
r_t	Pump blade tip radius	ft
RPM	Rotational speed	revolutions/min
SFC	Specific fuel consumption	lb/HP-hr
SHP	Required engine power output	HP
T	Thrust	lb
t	Time interval	hr
t	Thickness of pump-to-nozzle pipe	in
U_t	Blade tip velocity	ft/sec
VAF	Variable area factor	
V	Velocity	ft/sec
V_c	Inlet velocity at cruise speed	ft/sec
V_h	Inlet velocity at hump speed	ft/sec
V_j	Jet velocity	ft/sec
V_j/V_o	Jet velocity ratio	
V_m	Momentum velocity of entering water	ft/sec
V_o	Ship velocity	ft/sec

V_z	Velocity of water entering pump	ft/sec
W	Weight of inlet system	lb
W_d	Pump weight	lb
$W_{\Delta f}$	Weight of fuel consumed in a time period Δt	lb
W_g	Weight of reduction gear	lb
W_w	Weight of water in pump	lb
ρ_t	Density of titanium	$slug/ft^3$
ρ_w	Density of water	$slug/ft^3$
ϕ	Pump flow coefficient	
ψ	Pump head coefficient	
ν	Viscosity of water	ft^2/hr
π	Pi	
σ_n	Maximum allowable stress	lb/in^2
η_g	Reduction gear efficiency	
η_{nz}	Nozzle efficiency	
η_{OA}	Inlet system overall internal efficiency	
$\eta_{OA'}$	Inlet system overall internal efficiency (uncorrected for height)	
η_p	Pump efficiency	

1. INTRODUCTION

Among the new types of high-speed marine vehicles, the surface effect ship seems to have the best potential for developing into multi-thousand ton ships.

The surface effect ship rides on a self generated cushion of air contained between rigid sidehulls and flexible fore and aft seals. The very high horsepower levels that must be transmitted through these sidehulls has made the use of waterjet propulsion systems attractive.

Some of the advantages of waterjet propulsion for surface effect ships include:

1. Reduction of underwater noise
2. Fewer underwater appendages
3. Possible elimination of rudders
4. Fewer and simpler components
5. Increased reliability and maintainability
6. Use of multiple systems per sidehull

The two biggest disadvantages of waterjet propulsion are its comparatively low propulsive efficiency and high system weight. Figure 4 shows representative propulsive efficiencies for different types of propulsors.

Propeller systems for surface effect ships have some critical disadvantages. Subcavitating propellers are unsuited for operation much above 40 knots due to blade cavitation.

Supercavitating and superventilated propellers can operate successfully at speeds above 40 knots. The problem is the amount of thrust that must be developed by each propeller. The typical horsepower level for the proposed 2,000 ton SES is approximately 135,000 SHP. If a propeller is used, half of the horsepower would have to be transmitted through each propeller. The system would also require either controllable reverse-pitch (CRP) propellers or a reversing gear.

The final support for using waterjet propulsion systems is that the Navy has given six contracts for the development of the 2,000 ton SES design. All six of these contracts specify that waterjet propulsion will be used.

The typical drag characteristics of a SES are shown in Figure 1. Low length-to-beam ratios have a high drag at hump speed and a low drag at cruise speed when compared to high length-to-beam ratios. The selection of the length-to-beam ratio for a SES will have an important impact on the waterjet propulsion system design because the design is based on both the hump and cruise conditions.

2. DEVELOPMENT OF BASIC EQUATIONS

A waterjet propulsion system draws water from outside the hull, imposes an acceleration on it and discharges it astern as a jet. The thrust is developed due to a change in momentum of the water. The momentum equation for thrust delivered by the system is:

$$T = \rho_w Q(V_j - V_m) \tag{2.1}$$

where: T = thrust developed (lb_f)

ρ_w = density of water ($slugs/ft^3$)

Q = flow rate of water (ft^3/sec)

V_j = jet velocity (ft/sec)

V_m = momentum velocity of entering water (ft/sec)

The momentum velocity of the incoming water is slightly less than the ship velocity due to the boundary layer effect.

The ratio of momentum velocity to ship velocity is defined as C. Typical values are greater than .985 (ref. 1). The thrust equation can be rewritten in terms of C and ship velocity as:

$$T = \rho_w Q(V_j/V_o - C)V_o \tag{2.2}$$

The jet velocity ratio, V_j/V_o, is the controlling system variable. Selecting the jet velocity ratio establishes the other important parameters.

The thrust must equal the resistance of the ship plus

the added drag caused by the waterjet inlet system. If an acceleration is required, the total resistance must be multiplied by an acceleration coefficient. Thrust required is therefore:

$$T = (R + D)C_A \tag{2.3}$$

where: R = ship resistance (lb_f)

D = inlet system drag (lb_f)

$C_A = 1$ for constant speed

$C_A > 1$ for increasing speed (acceleration)

The added drag of the inlet system can be expressed in terms of a drag coefficient, C_D.

$$D = \rho_w C_D Q V_o / 2 \tag{2.4}$$

Figures 19 and 23 present calculated design speed drag coefficients for varying aspect ratio inlets and 2.5 aspect ratio inlets, respectively. If no restrictions are placed on the variable area factor, the drag coefficients are nearly independent of hump speed and vary slightly with design speed.

Combining equations 2.2, 2.3 and 2.4 yields:

$$\rho_w Q(V_j/V_o - C)V_o = C_A(R + \tfrac{1}{2}\rho_w C_D Q V_o) \tag{2.5}$$

Equation 2.5 can then be solved for the required flow rate, Q, for a given ship velocity, ship drag and acceleration margin, plus a selected jet velocity ratio.

$$Q = \frac{C_A R}{\rho_w V_o (V_j/V_o - C - \frac{1}{2} C_A C_D)} \tag{2.6}$$

To determine the power requirements, the head across the pump, H_p, must be established.

The overall internal efficiency, $\eta_{OA'}$, of the inlet system is the ratio of the total head at the diffuser outlet to the total head of the incoming flow, $V_m^2/2g$. This efficiency includes all losses up to the diffuser outlet. Figures 20, 21, 24 and 25 show the variation of the overall internal efficiency with changing ship velocity. These efficiencies are applicable for an infinite Froude Number diffuser with an exit at the same elevation as the undisturbed water surface. The efficiency corrected for a change in elevation is:

$$\eta_{OA} = \eta_{OA'} - \frac{h}{V_m^2/2g} \tag{2.7}$$

The total head at the diffuser exit, H_2, is then:

$$H_2 = \frac{\eta_{OA} V_m^2}{2g} \tag{2.8}$$

The head at the pump entrance is:

$$H_{p1} = h_e - h_p + H_2 - h_{lep} \tag{2.9}$$

where: H_{p1} = head at entrance to pump (ft)

h_e = height of diffuser exit above inlet (ft)

h_p = height of pump above inlet (ft)

H_2 = head at diffuser exit (ft)

h_{lep} = head loss between diffuser exit and pump inlet (ft)

The head at the exit of the pump is:

$$H_{p2} = \frac{V_j^2}{2g} + H_{pipe} + H_{noz} \tag{2.10}$$

where: H_{pipe} = head loss in the pump-to-nozzle pipe (ft)

H_{noz} = head loss across nozzle (ft)

The head loss in the pump-to-nozzle pipe is a function of the flow rate, pipe length and pipe diameter. The solution of H_{pipe} for the optimum pipe diameter is presented in section 3.4.

The head loss due to the nozzle can be expressed in terms of a nozzle efficiency, η_{nz}. Figure 5 shows the nozzle efficiency for a typical long radius nozzle. The nozzle efficiency is the ratio of the head of the jet to the head at the nozzle entrance.

$$\eta_{nz} = \frac{V_j^2/2g}{H_{p2} - H_{pipe}} \tag{2.11}$$

Solving equation 2.11 for the head at the exit of the pump gives:

$$H_{p2} = \frac{V_j^2}{\eta_{nz} 2g} + H_{pipe} \tag{2.12}$$

Combining equations 2.10 and 2.12 gives:

$$H_{noz} = \frac{V_j^2}{2g}\left[\frac{1}{\eta_{nz}} - 1\right] \tag{2.13}$$

Equations 2.9 and 2.12 can then be combined to get the head rise required across the pump, H_p.

$$H_p = \frac{V_j^2}{2g\eta_{nz}} + H_{pipe} - \frac{\eta_{OA}V_m^2}{2g} + h_p - h_e + h_{lep} \tag{2.14}$$

Assuming that the loss between the diffuser outlet and pump entrance is small compared to the other terms, h_{lep} can be neglected. By setting h_{pe} equal to $h_p - h_e$, equation 2.14 becomes:

$$H_p = \left[\frac{(V_j/V_o)^2}{\eta_{nz}} - C^2\eta_{OA}\right]\left[\frac{V_o^2}{2g}\right] + H_{pipe} + h_{pe} \tag{2.15}$$

The power delivered to the water, HP_p, can now be determined since:

$$HP_p = H_p Q \rho_w g/550 \tag{2.16}$$

Substituting equations 2.6 and 2.15 into 2.16 gives:

$$HP_p = \frac{C_A R\left[((V_j/V_o)^2/\eta_{nz}) - C^2\eta_{OA} + (H_{pipe} + h_{pe})2g/V_o^2)\right]}{(2)(550)((V_j/V_o) - C - \frac{1}{2}C_A C_D)} \tag{2.17}$$

The shaft horsepower required is then:

$$SHP = \frac{HP_p}{\eta_p \eta_g} \tag{2.18}$$

where: η_p = pump efficiency

η_g = gear efficiency

The overall propulsive coefficient, PC, is defined as the thrust times velocity divided by the shaft horsepower.

$$PC = \frac{2\eta_p\eta_g((V_j/V_o) - C)}{((V_j/V_o)^2/\eta_{nz}) - C^2\eta_{OA} + (H_{pipe} + h_{pe})(2g/V_o^2)} \qquad (2.19)$$

By taking the derivatives of 2.17 and 2.19 with respect to the jet velocity ratio and setting the results equal to zero, expressions can be found for the jet velocity ratios for which the required horsepower is a minimum and the propulsive coefficient is a maximum. These are:

$$V_j/V_o = C + \tfrac{1}{2}C_A C_D + \sqrt{(C + \tfrac{1}{2}C_A C_D)^2 - C^2\eta_{OA}\eta_{nz} + 2(H_{pipe} + h_{pe})\eta_{nz}g/V_o^2} \qquad (2.20)$$

for minimum power and

$$V_j/V_o = C + \sqrt{C^2(1 + \eta_{OA}\eta_{nz}) + 2(H_{pipe} + h_{pe})g\eta_{nz}/V_o^2} \qquad (2.21)$$

For maximum PC. These two optimum jet velocity ratios do not occur at the same jet velocity ratio. However, they are close enough so that either could be used in determining a representative power required by the surface effect ship.

The net propulsive coefficient, PC_{net}, is defined as the hull drag times velocity divided by the shaft horsepower.

$$PC_{net} = RV_o/SHP \qquad (2.22)$$

Once a jet velocity ratio at cruise has been selected, the flow rate through the system at cruise is determined from equation 2.6. The area of the jet is then:

$$A_j = \frac{Q}{V_o(V_j/V_o)} \tag{2.23}$$

Assuming a constant area jet, the jet velocity ratio at any velocity, V, is:

$$V_j/V = Q/A_jV \tag{2.24}$$

Equation 2.23 can then be combined with equation 2.6 to solve for the jet velocity ratio at hump.

$$(V_j/V_o)_{hump} = .5C + \frac{C_AC_D}{4} + \sqrt{\left[.5C + \frac{C_AC_D}{4}\right]^2 + \frac{C_AR}{\rho_w V_o^2 A_j}} \tag{2.25}$$

All the terms in equation 2.24 are at hump speed. Once the jet velocity ratio is determined, the other system variables such as flow rate and power requirements can be found using the appropriate equations developed in this chapter. The procedure used to find the hump speed variables could be used to predict the performance at any speed.

It is apparent from equations 2.20 and 2.21 that different speeds will lead to different optimum jet velocity ratios for minimum power or maximum propulsive efficiency. Therefore, selecting the optimum jet velocity ratio at cruise will lead to a less than optimum jet velocity ratio at hump.

3. SYSTEM DESCRIPTION

The general configuration of a waterjet propulsion system for a surface effect ship is shown in Figure 2. The components of the system include the inlet system, the transition pipe, the pump, the pump-to-nozzle piping, the nozzle, the reversing gear, the propulsion engines, the fuel and the air cushion system. The arrangement and numbering of the individual waterjet systems used in this report are shown in Figure 3.

3.1 INLET SYSTEMS

The inlet system will be defined in this report to include the inlet, diffuser, fairing required by the inlet and a movable ramp or movable lip.

The inlet aspect ratio is the ratio of inlet width to inlet height. Two basic series of inlet aspect ratios are considered, one has a constant 2.5 aspect ratio and the other has an aspect ratio which varies with design speed.

The flush inlet appears to be superior to pod-strut inlets for surface effect ship application. A flush inlet lies in the same plane as the bottom of the sidehull. The important advantages of the flush inlet include less added drag, simpler methods of changing the inlet area and less chance for inlet damage caused by floating debris. For these reasons, only flush inlet systems are considered

in this report.

The most important factors effecting the inlet drag are: lip leading-edge radius, variable area factor (ratio of maximum to minimum inlet opening area), inlet aspect ratio, flow rate and sidehull fairing.

Surface effect ships usually have significant sidehull deadrise angles. Fairing of the sidehull is required to prevent inlet ventilation and cavitation. The fairing must also be designed to minimize any additional drags. Sidehull deadrise angles of more than 50 degrees are not well suited for flush inlet systems.

The surface effect ship has a need for a variable inlet area capability. The flow rate requirements at maximum speed and at hump speed (high drag) are nearly equal. This dictates that the inlet must either have a variable area capability or be able to operate over a wide range of inlet velocity ratios. Operation over a wide range of inlet velocity ratios requires large variations in the inlet lip angle-of-attack. Changing the angle-of-attack will require a larger lip leading-edge radius to prevent cavitation at the leading-edge. The larger lip radius will lead to increased inlet drag.

With a variable inlet capability, the inlet velocity ratio variations can be reduced. The lip angle-of-attack will then be small. A small lip leading-edge can then be

used which results in lower inlet drags. The minimum lip radius will usually be specified by such practical considerations as the need to place sensors near the lip or to limit vulnerability to debris damage. The variable area factor, VAF, required is:

$$VAF = \frac{A_h}{A_c} = \frac{V_c Q_h}{V_h Q_c} \qquad (3.1.1)$$

where: A = inlet area (ft^2)

V = inlet velocity (ft/sec)

Q = flow rate (ft^3/sec)

c = at cruise conditions

h = at hump conditions

For varying aspect ratio inlets, the aspect ratio is equal to the diffusion ratio. The varying aspect ratios inlets are normally more efficient and lighter. Varying aspect ratio inlets may be limited by sidehull geometry.

A movable ramp or movable lip is needed to have a variable area capability. If a movable lip is used, the lip leading-edge must not be allowed to vary more than a small amount. Figure 3 illustrates the movable ramp and the movable lip.

A diffuser is required to slow the flow down to prevent cavitation at the pump. The diffuser design has a significant effect on inlet system weight and efficiency. Minimum acceptable values of overall diffusion ratios are determined

by pump cavitation characteristics. The diffuser characteristics used are based on a study by R. A. Barr, reference 1. The study was based on a pump with a maximum suction specific speed of 16,000 and a flow coefficient of 0.15. Diffusion ratios of 3.0, 4.0 and 5.0 were required for 60, 80 and 100 knots respectively. The diffuser schedule used is as follows:

0 to 20 percent of length Diffusion = 6°

20 to 90 percent of length Diffusion = $6^\circ + 12^\circ(p - 20)/75$

90 to 100 percent of length Diffusion = $18^\circ(100 - p)/5$

where p is the percent of total diffuser length measured from the inlet. The use of smaller diffusion angles will result in higher efficiencies but heavier system weights. A diffuser outlet angle of 45 degrees is assumed in this report.

Other considerations in selecting diffuser geometry include the transition from rectangular inlets to circular pump inlets.

The weight of the inlet system, W, in terms of an inlet weight coefficient, C_w, is given in reference 1 as:

$$W = C_w Q^{1.5} \qquad (3.1.2)$$

Values of C_w are shown in Figure 21 for varying aspect ratios and in Figure 25 for 2.5 aspect ratios. In both cases, the lip leading-edge radius is .25 inches. The weight

includes structural weight and water weight. Equation 3.1.2 suggests that many smaller and separate inlets may be superior due to lighter weight than fewer and larger inlets. However, smaller systems are generally less efficient and the weight gains are offset by higher fuel weights.

3.2 TRANSITION PIPE

The transition pipe is a constant diameter pipe extending from the diffuser outlet to the pump inlet. The angle of the pipe, 45 degrees, is the same as the diffuser outlet angle. The transition pipe is used to account for any small differences in pump height and diffuser exit height. The diffuser schedule given in section 3.1 will lead to a diffuser exit height of 6.5 feet. If the pump height and the diffuser exit height vary substantially, consideration should be given to developing a new diffuser schedule. Data for flush inlet diffusers is limited to a few specific configurations. New diffuser geometries should be model tested to adequately establish final performance predictions. The transition pipe represents a means to adapt a known diffuser configuration to a specific waterjet system requirement.

3.3 PUMPS

Waterjet pumps should have high efficiency, high rotative speeds and light weight. To achieve light weight it will be necessary to use pumps with high suction specific

speeds. The acceptable values of suction specific speed are limited by the onset of cavitation. The high rotative speed leads to smaller differences in RPM between engine and pump, and thus lighter reduction gear weights.

Pumps are generally characterized by their specific speed, N_s.

$$N_s = \frac{(RPM)(Q)}{H_p^{.75}} \qquad (3.3.1)$$

Pumps can be of the axial-flow, mixed-flow or centrifugal-flow types, depending on the design requirements. Centrifugal pumps operate best for specific speeds between 500 and 4,000. Mixed-flow pumps should operate at specific speeds between 4,000 and 10,000. Axial-flow pumps are best for specific speeds greater than 10,000. Previous comparisons of pump types in references 2 and 6 determined that axial-flow pumps are the best suited for surface effect ship application. The advantages include ease of arrangement, maximum compactness and ease of adding stages. Centrifugal and mixed-flow pumps are not considered in this report.

The procedure used is to determine the rated pump RPM, pump diameter, annulus area and other related pump characteristics based on a designated flow coefficient (ϕ), head coefficient (ψ), flow rate and pump head. The purpose is not to design the pump, but to determine the general requirements and characteristics of the pump.

The diffusion ratios used in section 3.1 were based on a pump with an inlet flow coefficient of 0.15 and a maximum suction specific speed of 16,000. These values were therefore fixed in the pump design procedure.

Pump cavitation performance is based on the suction specific speed, N_{ss}.

$$N_{ss} = \frac{(RPM)(Q)^{.5}}{NPSH^{.75}} \qquad (3.3.2)$$

The net positive suction head, NPSH, is:

$$NPSH = Ha + H_{p1} - p_v \qquad (3.3.3)$$

where: Ha = atmospheric pressure head (ft)

H_{p1} = head at pump entrance (ft)

p_v = vapor pressure head of water (ft)

The large discharge and low net positive suction head at hump speed indicate that the greatest danger of cavitation will be at hump speed. The maximum suction specific speed at which waterjet pumps can operate at without excessive cavitation damage is unclear. Waterjet pumps with inducers have been built that can operate free of cavitation damage at suction specific speeds of 25,000.

Cavitation normally occurs on the first inducer stage. The inducer should produce enough headrise to keep the remaining stages from cavitating. The performance of multi-stage pumps is not badly effected by cavitation on

the inducer stage. Cavitation will normally begin at a much lower suction specific speed than the limiting suction specific speed.

The pump used in this report is assumed to operate at acceptable cavitation levels up to a specific suction speed of 16,000. The pump design procedure is based on the method described in reference 14 and will only be summarized in this report.

The head coefficients for the pump were set at 0.41 for the inducer and 0.3 for the remaining stages. The maximum allowable blade tip velocity was set at 200 feet per second. These values are consistent with existing pumps. Changing these values will only have a small effect on the overall system design since the pump represents such a small percentage of the total system weight.

The flow rate and the headrise can be calculated by equations 2.6 and 2.15 respectively. The flow coefficient, ϕ, is the ratio of the axial velocity of the entering water to the blade tip velocity.

$$\phi = V_z/U_t \qquad (3.3.4)$$

where: V_z = velocity of water entering pump (ft/sec)

U_t = blade tip velocity (ft/sec)

The headrise coefficient, ψ, relates the headrise across the pump to the blade tip velocity.

$$\psi = gH_p/U_t^2 \qquad (3.3.5)$$

With the values of the flow coefficient and the headrise coefficient set, the velocity of the water entering the pump is:

$$V_z = \phi U_t \tag{3.3.6}$$

The blade tip radius, r_t, is then found by:

$$r_t = Q\pi\left[1 - (r_h/r_t)^2\right]/V_z \tag{3.3.8}$$

Finally, the pump RPM is:

$$RPM = 30U_t/\pi r_t \tag{3.3.8}$$

The suction specific speed is then calculated by equation 3.3.2. If the suction specific speed exceeds the set limit of 16,000, the blade tip velocity is reduced resulting in a lower suction specific speed.

When an acceptable suction specific speed is found, the efficiency of the pump is determined. A pump with a diameter of 3.66 feet and an efficiency of 91.5 percent at design speed is assumed. A Reynold's Number correction is applied for the actual pump diameter to determine the pump efficiency. The propulsive efficiency and required shaft horsepower at hump speed is then calculated and compared to the available shaft horsepower. If the required shaft horsepower (including acceleration margin) is greater than the available power, the blade tip velocity is reduced. Decreasing the blade tip velocity increases pump diameter, pump weight, pump efficiency and the headrise coefficient

of the pump. The number of stages is then determined based on head coefficients of 0.41 for the inducer and 0.30 for subsequent stages. The pump head, efficiency and RPM characteristics are assumed to be parabolic. Using this assumption, the off-design pump RPM and efficiencies can be determined. With the pump RPM and efficiency at cruise speed determined, the overall propulsive coefficient, required shaft horsepower and blade tip velocity can be found. The required shaft horsepower is then compared to the available shaft horsepower and the blade tip velocity is compared to the maximum allowable blade tip velocity. If either value is unacceptable, the blade tip velocity at hump is reduced and the entire procedure is repeated. Finally, the suction specific speed at cruise is calculated. If it is too high, the blade tip velocity at hump is reduced and the entire process repeated.

The pump dry weight is approximated by:

$$W_d = C_w D_p^{2.3} \tag{3.3.9}$$

where: C_w = pump weight coefficient

D_p = pump diameter (ft)

and the weight of water in the pump by:

$$W_w = C_b A_p L_p \rho_w g \tag{3.3.10}$$

where: C_b = blockage coefficient

A_p = pump inlet area (ft^2)

L_p = pump length (ft)

The pump length is calculated in terms of a length coefficient, C_L, and the pump diameter.

$$L_p = C_L D_p \tag{3.3.11}$$

Decreasing the blade tip velocity increases the pump efficiency, pump diameter and the pump weight.

For two or three waterjet systems in a sidehull, the pump is designed to the requirements of System 2 (Figure 3). For four or five waterjet systems in a sidehull, the pump is designed to the requirements of System 3. The same pump would be used in all the systems and the small changes in thrust requirements would be achieved by using slightly different nozzle exit areas.

3.4 PUMP-TO-NOZZLE PIPING

Figure 3 shows the arrangement of each individual waterjet system. The only major difference in the individual systems is the distances from the pump exit to the nozzle located at the stern of the ship. In large surface effect ships such as the proposed Navy 2,000 ton class, the pump-to-nozzle length could be 40 feet or more. This represents a considerable weight addition and a potentially high head loss.

A large diameter pipe will have very small head losses, but very high water and pipe weights. Conversely, small diameter pipes will have small pipe and water weights,

but larger head losses.

The approach taken was to design the pipe based on a total minimum weight for cruise conditions. The weights considered were pipe weight, water weight, the proportion of the engine weight required to overcome the head loss and weight of the additional fuel required.

$$Wt = Wt_{pipe} + Wt_{water} + Wt_{\substack{add'l \\ fuel}} + Wt_{\substack{add'l \\ eng}} \qquad (3.4.1)$$

The weight of the pipe depends upon the pressure head in the pipe, pipe diameter, pipe thickness and pipe material. Due to the high flow rates, titanium was chosen as the pipe material. The allowable stress was set at 20,000 p.s.i. The thickness of the pipe is then calculated by:

$$t = \frac{H_{pipe} \rho_w D_{pi} g}{24 \, \sigma_n} \qquad (3.4.2)$$

where: t = thickness of pipe (in)

H_{pipe} = head at pipe entrance (ft)

D_{pi} = inside diameter of pipe (ft)

σ_n = maximum allowable stress (p.s.i.)

If the thickness is found to be less than 0.1 inches, it is set equal to 0.1 inches.

The weight of the pipe is:

$$Wt_{pipe} = \rho_t g L_{pipe} (D_{po}^2 - D_{pi}^2)(\pi/4) \qquad (3.4.3)$$

where: ρ_t = density of titanium (slug/ft^3)

L_{pipe} = length from pump to nozzle (ft)

D_{po} = outside diameter of pipe (ft)

Substituting:

$$D_{po} = D_{pi} + 2t \quad (3.4.4)$$

into equation 3.4.3 gives the weight of the pipe as:

$$Wt_{pipe} = g\rho_t L_{pipe}(D_{pi}t + t^2) \quad (3.4.5)$$

The weight of water in the pipe is:

$$Wt_{water} = g\rho_w L_{pipe} D_{pi}^2 \pi/4 \quad (3.4.6)$$

The additional fuel and engine weights are based on the additional horsepower required to overcome the head loss in the pipe.

$$HP_{loss} = \Delta PQ/550 \quad (3.4.7)$$

The pressure drop, ΔP, in the pipe is:

$$\Delta P = \frac{4fL_{pipe}\rho_w V^2}{2\ D_{pi}} \quad (3.4.8)$$

where: f = Moody pipe friction factor

V = velocity of water in pipe (ft/sec)

The Moody pipe friction factor is:

$$f = \frac{.046}{Re^{.2}} = \frac{.046\nu^{.2}}{V^{.2}D_{pi}^{.2}} \quad (3.4.9)$$

Since the flow rate throughout the system is constant:

$$Q = VD_{pi}^2/4 = V_j D_j^2/4 \quad (3.4.10)$$

The velocity in the pipe is then:

$$V = V_j D_j^2 / D_{pi}^2 \qquad (3.4.11)$$

Combining equations 3.4.8, 3.4.9 and 3.4.11 gives:

$$\Delta P = .092 L_{pipe} \rho_w \nu^{.2} V_j^{1.8} D_j^{3.6} / D_{pi}^{4.8} \qquad (3.4.12)$$

Combining equations 3.4.7, 3.4.10 and 3.4.12 gives:

$$HP_{loss} = .000258 L_{pipe} \rho_w \nu^{.2} Q^{2.8} / D_{pi}^{4.8} \qquad (3.4.13)$$

The weight of the additional fuel and power requirements can now be determined by:

$$Wt_{\substack{add'l \\ fuel}} = (HP_{loss})(SFC)(RANGE/V_o) \qquad (3.4.14)$$

and

$$Wt_{\substack{add'l \\ eng}} = (HP_{loss})(Wt_{eng})/SHP \qquad (3.4.15)$$

Substituting equations 3.4.5, 3.4.6, 3.4.14 and 3.4.15 into equation 3.4.1 gives the total weight equation.

$$Wt = \rho_t \pi g L_{pipe}(D_{pi} t + t^2) + \rho_w g L_{pipe} D_{pi}^2 \pi/4 + \qquad (3.4.16)$$
$$+ \frac{.000258 L_{pipe} \rho_w \nu^{.2} Q^{2.8}}{D_{pi}^{4.8}} \left[\frac{(SFC)(RANGE)}{V_o} + \frac{Wt_{eng}}{SHP} \right]$$

To find the pipe diameter resulting in minimum weight, the derivative of total weight is taken with respect to the pipe diameter.and the results set equal to zero. The equation to be solved is:

$$0 = g\rho_t \pi t L_{pipe} + 2\rho_w g D_{pi} L_{pipe} \pi/4 - \frac{(4.8)(.000258)L_{pipe}\rho_w \nu^{.2} Q^{2.8}}{D_{pi}^{5.8}} \left[\frac{(SFC)(RANGE)}{V_o} - \frac{Wt_{eng}}{SHP}\right] \quad (3.4.17)$$

or in simplified form:

$$0 = \rho_t t/\rho_w + 0.5D_{pi} - \frac{.0003949\nu^{.2} Q^{2.8}}{D_{pi}^{5.8}} \left[\frac{(SFC)(RANGE)}{V_o} - \frac{Wt_{eng}}{SHP}\right] \quad (3.4.18)$$

The head loss in the pipe for any flow rate is:

$$H_{pipe} = \Delta P/\rho_w g \quad (3.4.19)$$

The head loss in the pipe will cause an increase in the total headrise across the pump which will lead to a slight change in the flow rate. This change in flow rate is handled by repeating the pipe design process with the new flow rate.

3.5 NOZZLES

The purpose of the nozzle is to convert a pressure head into a velocity head by throttling. A nozzle will increase the velocity of the water substantially. In doing this, a certain amount of pressure head is lost. This loss is mainly a frictional loss.

Normally, for waterjet propulsion systems, a fixed area nozzle designed for cruise conditions is used. Some improvement in off-design performance could be achieved

by using variable area nozzles. By varying the jet area, a better jet velocity ratio could possibly be found at off-design speeds. Increasing the nozzle area for lower speeds would increase the pump discharge and reduce the pump head. This will normally result in increased pump RPM, increased pump efficiency and lower fuel consumption. Variable area nozzles are normally not used due to increased mechanical complexity, decreased nozzle efficiency and only small overall performance gains.

In the flow, the point where the streamlines are perfectly parallel to the centerline of the nozzle is slightly beyond the exit of the nozzle. This point is commonly referred to as the "vena contracta." The cross-sectional area is slightly smaller at this point than at the nozzle exit. For application in the thrust equation 2.1, the jet velocity should be the velocity at the vena contracta. This presents a problem in that the vena contracta area is unknown and therefore the velocity is difficult to determine.

According to experimental results presented in reference 11, the velocity at the vena contracta is roughly 0.5 to 1.0 percent higher than the jet velocity calculated by dividing the flow rate by the nozzle exit area. These experiments were based on a long radius nozzle. The vena contracta effect will recover much of the nozzle efficiency

loss if the nozzle exit velocity is defined as the jet velocity. Nozzle efficiencies greater than 99 percent are obtainable when the Reynold's Number is greater than 200,000. Figure 5 presents the nozzle efficiency as a function of the ratio of nozzle exit diameter to nozzle inlet diameter for a long radius nozzle. The vena contracta effect has been incorporated into the nozzle efficiency. Therefore, the jet velocity is actually the velocity at the nozzle exit.

The length of a long radius nozzle is approximately twice the inlet diameter. Changes in flow rate have only a small effect on nozzle efficiency if the Reynold's Number is greater than 200,000.

3.6 REVERSING BUCKET

Reverse thrust and ship control can be obtained by controlling the direction of the jet. These devices are added behind the nozzle and do not effect the normal forward performance. Such devices are much lighter and therefore more desirable on a weight basis than auxiliary propulsion systems (for reverse thrust) or rudders (for directional control).

3.7 PROPULSION ENGINES

Engines for surface effect ships are normally limited to marine gas turbines. However, in the case of small ships requiring less than 10,000 total shaft horsepower

and desiring maximum ranges, the use of lightweight, high-speed diesels should be considered. Although the high-speed diesels weigh much more, the weight difference may be recovered due to the poor specific fuel consumption of small gas turbines.

Table 1 lists the characteristics of some of the marine gas turbines available now or presently under development. The inputs required for the design sequence are normal SHP, maximum SHP, specific fuel consumption at normal SHP, shaft RPM, engine dry weight and engine length. As in reference 12, the specific fuel consumption is approximated by:

$$SFC \doteq \left[\frac{SHP_{required}}{SHP_{normal}}\right]^{n} \qquad (3.7.1)$$

where: $n = 0.25$ if $SHP_{req}/SHP_{nor} > 0.7$

$n = 0.75$ if $SHP_{req}/SHP_{nor} < 0.7$

Off-design engine RPM is based on the corresponding pump RPM and the reduction gear ratio. It is assumed that the engine can develop the required power at the indicated shaft RPM. Good pump and gas turbine matching is achievable in waterjet systems. Maximum pump efficiency usually occurs along the same power-RPM path as engine minimum specific fuel consumption. If the pump and engine are matched at the design point, they tend to be closely matched at most operating conditions.

The selection of engine type depends on many considerations. Operating engines close to maximum power is desirable because the best specific fuel consumption normally occurs at maximum power. Larger engines are normally better because of the general decrease in specific fuel consumption as engine size increases. The use of the fewest possible engines is desirable for simplicity and reliability reasons. The operational profile of a ship is also important. For ships that operate at many different speeds, it may be attractive to have slightly more, but smaller systems so that at certain speeds some systems could be shut down to achieve better fuel consumption.

Because of limited engine availability, it is often necessary to use larger than optimum engines. At the present time, there is a significant lack of marine gas turbines in the 5,000 to 12,000 horsepower range.

3.8 REDUCTION GEARS

Planetary reduction gears are assumed because they are normally about half the weight and more compact than conventional spur or helical reduction gears. Due to their compactness, planetary gears can be placed low in the sidehull, while other types of reduction gears must be placed on the lowest complete deck.

Planetary reduction gears have been built to handle up to 40,000 SHP at a maximum reduction gear ratio of 4 : 1.

The largest marine gas turbine, the FTA-C, has a SHP of 36,800 so that planetary reduction gears do not constrain the waterjet system design. Large reduction gears are normally custom designed, so availability is not a controlling factor.

The reduction gear ratio is determined by either the hump condition or cruise condition, depending on which horsepower level is closest to the normal horsepower rating of the selected engine. The reduction gear ratio is then the ratio of the pump RPM to the engine RPM at normal horsepower.

The weight of the reduction gear is estimated using the Dudley method. The Dudley method involves the use of two factors, K and Q. The gear tooth stress is approximately proportional to the square root of the gear's K-factor. A K-factor of 500 is representative of planetary gears proposed for surface effect ships. Q relates the gear's required geometry to the reduction gear weight and is defined as:

$$Q = SHP(m_g + 1)^3/(n_p m_g) \qquad (3.8.1)$$

where: SHP = maximum horsepower required

m_g = reduction gear ratio

n_p = engine RPM at normal SHP

The weight equation for planetary reduction gears is then:

$$W_g = 9{,}500Q/K \qquad (3.8.2)$$

This weight includes the gear, casing oil reservoir, oil

pump and stub shaft.

The use of planetary reduction gears does restrict the waterjet system design to one engine per pump.

3.9 FUEL

The fuel consumption is found by dividing the endurance time into many small time increments. The fuel required for each time increment is based on the average SHP required during that particular time period.

$$W_{\Delta f} = (SFC)(SHP)(\Delta t) \qquad (3.9.1)$$

where: $W_{\Delta f}$ = fuel weight consumed during a particular time period (lb)

SFC = fuel consumption rate corresponding to the average SHP (lb/HP-hr)

SHP = average SHP required during particular time period

The fuel weight used is then subtracted from the total ship weight and a new drag for the ship is calculated using a constant weight-to-drag ratio. The weight-to-drag ratio of an actual surface effect ship will not remain constant, but will decrease slightly as ship displacement decreases. The percent decrease is greater on a small SES than on a large SES. For the 2,000 ton example, the fuel weight represents only about 15 percent of the total displacement. Therefore, the assumption of a constant weight-to-drag ratio does not introduce any significant errors. For small surface effect ships and those that have a high ratio of fuel weight to

ship displacement, the variation of the weight-to-drag ratio as fuel is consumed should be accounted for.

Since the jet area is constant and $Q = V_j A_j$, equation 2.5 can be rewritten as:

$$A_j \rho_w (V_j^2 - V_m V_j) = R + \tfrac{1}{2} C_D \rho_w A_j V_j V_o \qquad (3.9.2)$$

where: R = ship drag after fuel weight is removed (lb)

V_j = required jet velocity for new R (ft/sec)

The required jet velocity is the only unknown in equation 3.9.2 and can therefore be solved for.

The new shaft horsepower required is then:

$$SHP = \frac{\rho_w g A_j V_j \left[V_j^2/(\eta_{nz} 2g) - V_m^2 \eta_{OA}/2g + H_{pipe} + h_{pe} \right]}{550\, \eta_p \eta_g} \qquad (3.9.3)$$

The fuel for the next time increment is calculated using the new SHP calculated in equation 3.9.3.

If there is an odd number of waterjet systems per sidehull, the fuel consumption is based on the middle system. The assumption made is that the larger amount of fuel required for the forward system will be offset by the smaller amount of fuel required by the after system.

If there is an even number of waterjet systems per sidehull, the decrease in fuel required by the after system is subtracted from the total fuel weight.

3.10 AIR CUSHION SYSTEM

A surface effect ship is supported partially by the sidehull buoyancy, but mostly by a cushion of air. Normally, 10 to 20 percent of the total propulsive horsepower is required to operate the air cushion system. The air cushion system is normally designed before the rest of the propulsion system because of its large impact on ship drag. It is possible that the lift fans and propulsors could be operated off the same engines, but this leads to complicated and less reliable systems.

The optimization of the air cushion pressure is a function of such variables as length-to-beam ratio, payload weight ratio, range, operating environment, seal design and stability requirements. The controlling variables are the payload weight ratio and the seal design. Increasing the payload weight ratio will require higher cushion pressures and an increased drag if the total displacement is not allowed to change.

The momentum drag of the air cushion represents an important part of the total ship drag. The total ship drag is assumed to be known in this report which therefore requires that the air cushion system design must have been completed.

There are two areas in which the air cushion system has a direct effect on the propulsor design. First, up to

10 percent of the air cushion horsepower can be recovered as a jet thrust through the rear seals. The percent recovered is a function of seal design, cushion pressure and forward speed. The jet thrust recovered through the seals represents less than 2 percent of the total thrust. The second effect, is that as fuel for the air cushion system is consumed the drag of the ship will decrease. In the 2,000 ton example, the total fuel weight represented about 13 percent of the ship weight. This indicates that the fuel for the air cushion system would represent between 1 and 3 percent of the ship's total weight.

The total effects of the air cushion system on the waterjet design are small and are not considered in this report.

Including the air cushion system would not make the waterjet propulsion system more competitive with a propeller system. The resultant effects of the air cushion system are independent of the propulsor type used.

4. RESULTS

Five different surface effect ships were analyzed to provide examples of waterjet propulsion system performance and characteristics. All the ships had a 2,000 ton displacement and an 80 knot cruise speed. The only characteristics that did vary were the length-to-beam ratio, hump speed, hump drag, cruise drag and the engine type. These characteristics are:

Ship	Length/ Beam Ratio	Hump Speed	Hump Drag	Cruise Drag	Engine Type
1	1.5	27	440,000	223,000	FT9D
2	2.0	30	325,000	230,000	FT9D
3	3.0	38	265,000	235,000	FT9D
4	4.0	45	210,000	241,000	FT9D
5	2.0	30	325,000	230,000	LM2500

4.1 JET VELOCITY RATIO EFFECTS

The jet velocity ratio was the only independent variable in the design process. All the other terms were either inputs or dependent on the jet velocity ratio and inputs. The jet velocity ratio was increased in steps until a limiting constraint was encountered. Figures 6 and 7 present changes in the system component weights for an increasing jet velocity for Ship 2. The numbers were different, but the basic trends were the same in all ships analyzed.

From the weight summaries, it can be seen that the

inlet system represents only about 7 percent of the total system weight, while the fuel weight (1,000 mile range) represents about 76 percent of the total system weight. The inlet system, however, is the controlling component in establishing the jet velocity ratio for a minimum weight ratio. For Ship 2, the inlet system weight decreased by 24 tons over the range of feasible jet velocity ratios while the maximum change in fuel weight was only 4 tons.

The maximum net propulsive efficiency occurs at a much lower jet velocity ratio. For the five ships considered, the jet velocity ratio for maximum net propulsive efficiency had a system weight 4 to 6 percent greater than the minimum weight system. Conversely, the minimum weight system had a net propulsive efficiency which was 3 to 5 percent less than the maximum possible net propulsive efficiency. However, due to poorer engine performance at lower power levels, not all the gains in net propulsive efficiency were reflected in fuel useage. The minimum weight system used less than 2 percent more fuel than the system with maximum propulsive efficiency. As the length-to-beam ratio decreased, the percent savings in fuel useage between the minimum weight system and the system with the maximum net propulsive efficiency also decreased.

Using the net propulsive efficiency leads to a better design than using the overall propulsive efficiency. The

overall propulsive efficiency does not penalize the system which has a high inlet system drag, since the thrust required is a function of the hull drag and the inlet system drag. The results show that the lowest cruise horsepower requirement occurs at the same jet velocity ratio as the maximum net propulsive efficiency. The jet velocity ratio for maximum net propulsive efficiency is always higher than the jet velocity ratio for maximum overall propulsive efficiency.

Beside the system weight and the propulsive efficiency, the other controlling parameter is the pump cavitation level. The suction specific speed is a good indicator of the amount of cavitation. In all cases, the cruise suction specific speed decreased with an increasing jet velocity ratio, while the hump suction specific speed increased with an increasing jet velocity ratio.

4.2 LENGTH-TO-BEAM RATIO EFFECTS

Changing the length-to-beam ratio for a surface effect ship will cause significant changes in the cruise drag, hump drag and hump speed. Figure 9 shows the effect of the length-to-beam ratio on cruise drag and hump drag. The changes in drag and ship speed will have an effect on all the components of the waterjet system. The results for Ships 1, 2, 3 and 4 demonstrate these effects.

Figure 10 shows the effect of a changing length-to-beam ratio on the minimum weight ratio attainable. The results

indicate that for the 2,000 ton class, a length-to-beam ratio of about 3 is best for obtaining the minimum weight ratio. Ship 3 (L/B = 3) is superior to Ship 2 (L/B = 2) because of the constraining effect of Ship 2's hump drag. Both ships were constrained by the hump horsepower, but Ship 3 reached a much higher jet velocity before this limiting constraint was reached. When these two ships are compared at the same jet velocity ratio, Ship 2 has a lower weight ratio. Figures 11, 12 and 13 show the system component weights as a function of the length-to-beam ratio.

Comparing propulsive efficiencies, Figure 14, with length-to-beam ratios is somewhat misleading, in that the differences in drag will result in different power levels at hump and cruise speeds. A better comparison can be made on a basis of fuel and horsepower requirements at the jet velocity ratio corresponding to the maximum net propulsive efficiency. Figure 15 shows the shaft horsepower requirements at different length-to-beam ratios for the minimum weight ratio system and the maximum propulsive efficiency system. Generally, low length-to-beam ratios have lower power requirements near cruise speed while high length-to-beam ratios have lower power requirements near hump speed. At cruise speed, a length-to-beam ratio of 2 results in the best fuel consumption.

Figure 16 presents the pump suction specific speed for

for changing length-to-beam ratios. The cruise suction specific speed favors a low length-to-beam ratio while the hump suction specific speed favors a high length-to-beam ratio. The hump suction specific speed is much higher than that at cruise speed and therefore for pump design purposes a high length-to-beam ratio is desirable.

Ship 1 (L/B = 1.5) required two more engines than Ships 2, 3 and 4 due to the hump power requirements. This system was competitive with the other systems on a weight basis only if cruising is performed on 4 engines.

For the 2,000 ton class SES, a length-to-beam ratio between 2 and 3 appears to be the best. The final selection of the length-to-beam ratio depends upon the relative importance of system weight, system efficiency and pump performance.

4.3 EFFECTS OF ENGINE SIZE

The impact of the number of individual waterjet systems was analyzed by comparing Ship 2 and Ship 5. Ship 2 used 4 FT9D gas turbines while Ship 5 used 6 LM2500 gas turbines. These two types of gas turbines were selected because the total combined horsepower and the specific fuel consumption rates were approximately equal.

A waterjet system weight comparison shows Ship 2 to be 6.4 tons lighter than Ship 5. Ship 2 has larger reduction gear, pump and inlet system weights, while Ship 5 has larger

engine, fuel, pump-to-nozzle pipe and nozzle weights. Generally, poorer performance characteristics in smaller engines will cause much larger increases in fuel weights.

A comparison of the pump data shows that the design with fewer engines has larger, but slower pumps. For Ship 2, the pump RPM, suction specific speed and blade tip velocity are all lower than those on Ship 5. Due to these better pump characteristics, Ship 2 is able to operate at a higher jet velocity ratio, which leads to the lower system weight.

The reliability and maintainability of Ship 2 will be better because of fewer components and better pump characteristics.

4.4 DISPLACEMENT OPTIMIZATION

The optimization of ship displacement for a given waterjet propulsion system with 4 FT9D gas turbines was computed for ships with length-to-beam ratios of 1.5, 2, 3 and 4. The results, shown in Figure 17, indicate that a length-to-beam ratio of 3 has the largest optimum ship displacement. The optimum ship displacement for maximum propulsive efficiency was the same as the optimum displacement for the minimum system weight ratio.

Figure 18 shows a typical system weight ratio versus jet velocity ratio curve. The slope of this curve at the point where the limiting constraint (available power or pump suction specific speed) is reached, indicates the

direction in which the displacement should change. A negative slope indicates the displacement should be decreased while a positive slope indicates the displacement should increase. The optimum displacement will occur as the absolute value of the slope decreases. In most cases it occurs before the slope actually reaches zero. The optimum displacement in the ships studied, with the exception of the ship with a length-to-beam ratio of 1.5, had less than a one-half percent improvement in either the minimum weight ratio or the maximum propulsive efficiency. This is due to the fact that the engines and the ships are very well matched in these particular cases. For the ship with a length-to-beam ratio of 1.5, the displacement had to be reduced significantly just to have enough power to accelerate through the hump region.

5. CONCLUSIONS

The relatively high system weight and low propulsive efficiency of waterjet propulsion are the major disadvantages when compared to other types of propulsion systems.

Any attempts at reducing the system weight should be directed toward the fuel weight, which represents over 70 percent of the system weight. Gas turbines such as the LM2500 and the FT9D have excellent specific fuel consumption rates making it doubtful that a reduction in system weight could be obtained by using different engines. The high fuel weight is caused by the low efficiency of the system. Although small improvements in the flush inlet system or the internal efficiency may be possible, only a small improvement in the overall system efficiency would result. A 10 percent increase in internal efficiency will result in less than a 1 percent increase in overall system propulsive efficiency.

The possibility of improving the propulsive efficiency or minimum weight ratio by optimizing the ship displacement does not appear to offer any significant improvements for the 2,000 ton class. The non-propulsion system considerations will probably have a much more important effect on the ship displacement selected. If the engines and the contemplated ship displacement are not well matched, optimizing the ship displacement will result in significant improvements.

Length-to-beam ratios between 2 and 3 plus the fewest possible number of engines appear to give the best results for either maximum efficiency or minimum system weight.

Pump suction specific speed favors high length-to-beam ratios at hump speed and low length-to-beam ratios at cruise speed. At length-to-beam ratios of 2 or less, the fuel weight for the system with maximum net propulsive efficiency and the minimum weight ratio system is about the same. Therefore, for low length-to-beam ratios, the minimum system weight optimization appears to be the best. At high length-to-beam ratios the best optimization technique will depend on the relative importance of system weight, system efficiency and pump cavitation levels.

In conclusion, it appears that significant improvements cannot be made in either waterjet system weight or net propulsive efficiency. Minor improvements will occur as more experimental data on flush inlets, diffusers, axial-flow pumps and ship drag becomes available. Waterjet propulsion for surface effect ships will remain a good alternative due to system simplicity, reliability and maintainability.

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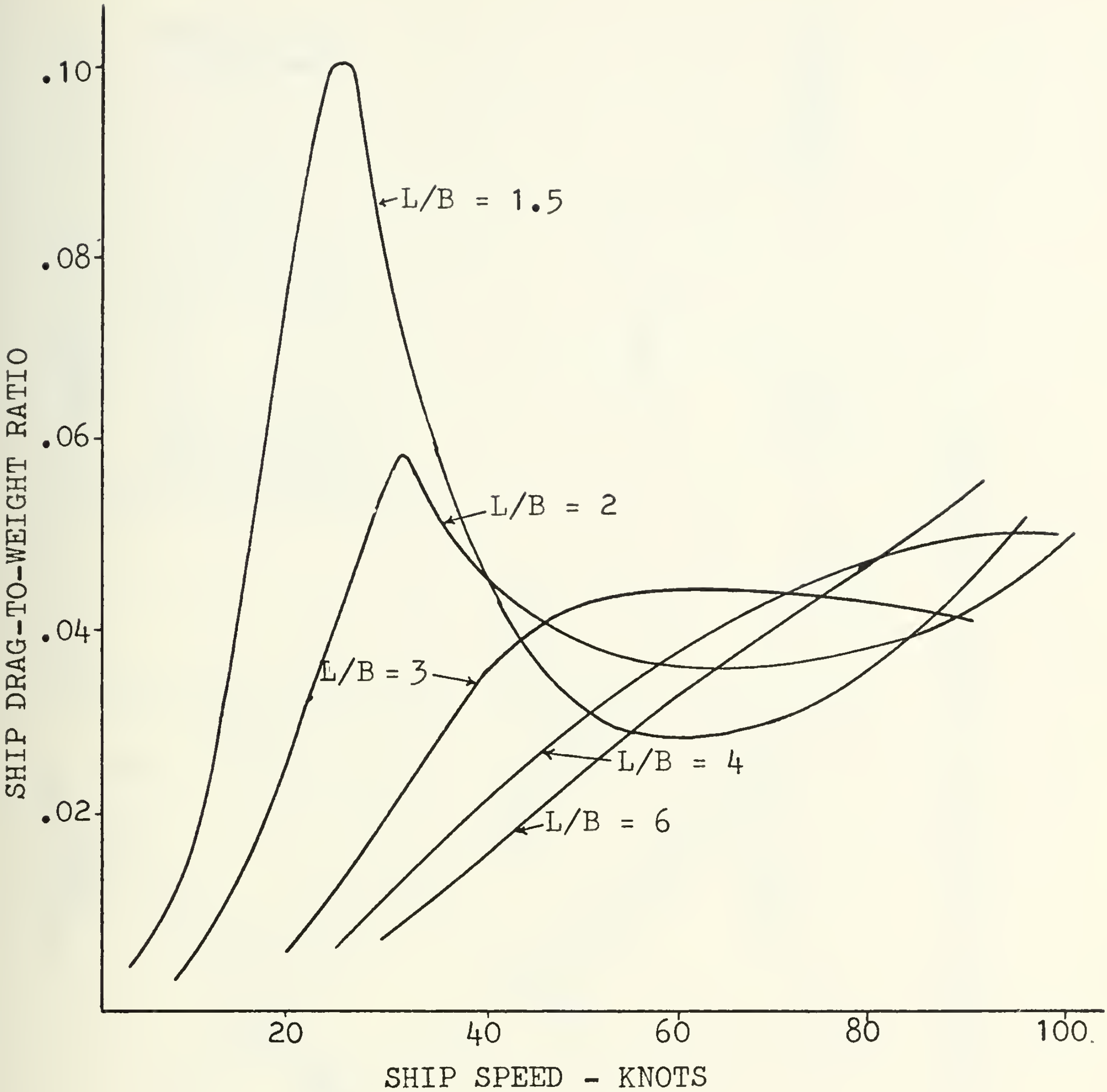


Figure 1 - VARIATION OF SHIP DRAG-TO-WEIGHT RATIO WITH SHIP SPEED FOR A 2,000 TON FAMILY OF SURFACE EFFECT SHIPS

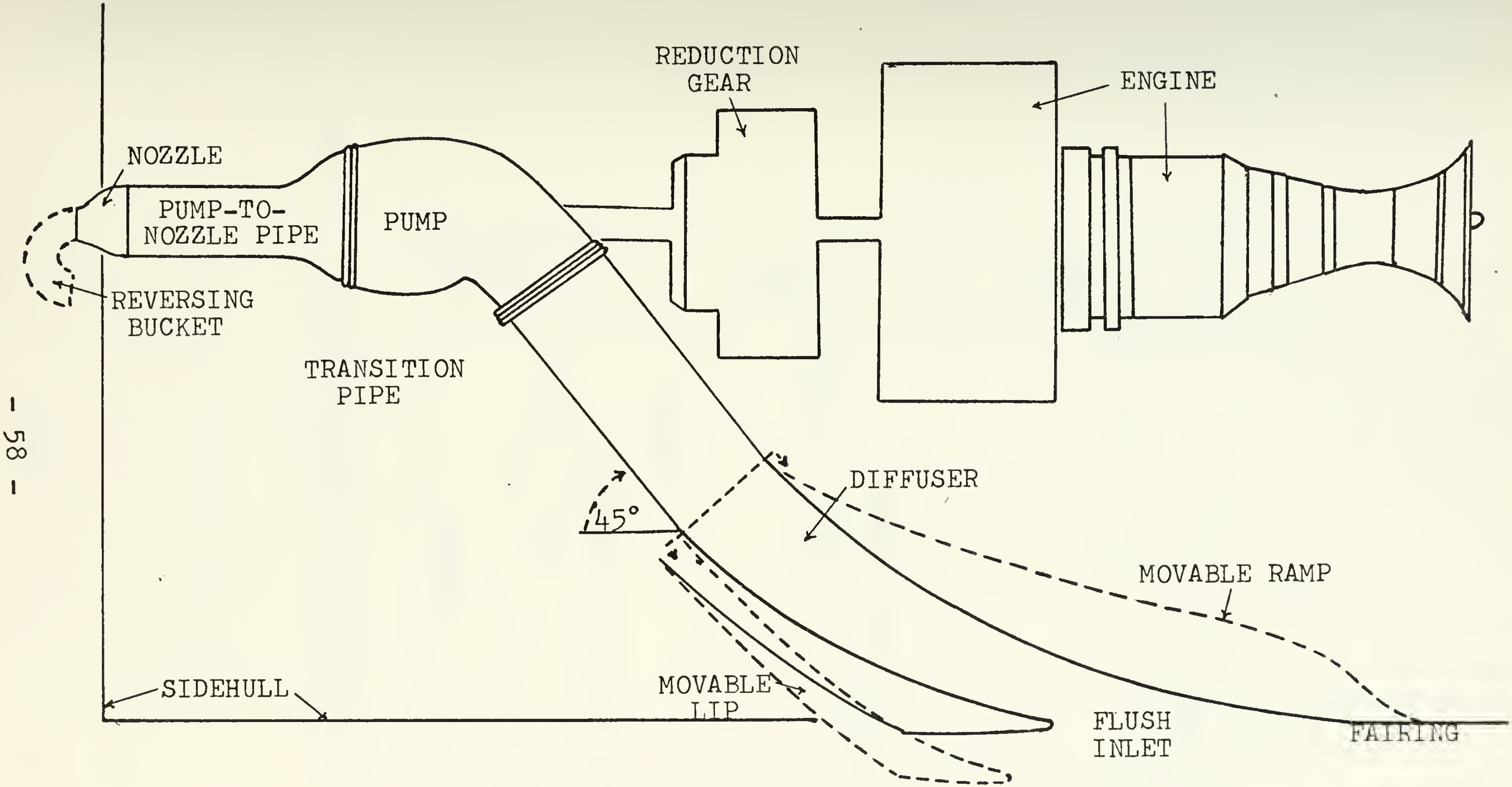


Figure 2 - WATERJET PROPULSION SYSTEM COMPONENTS

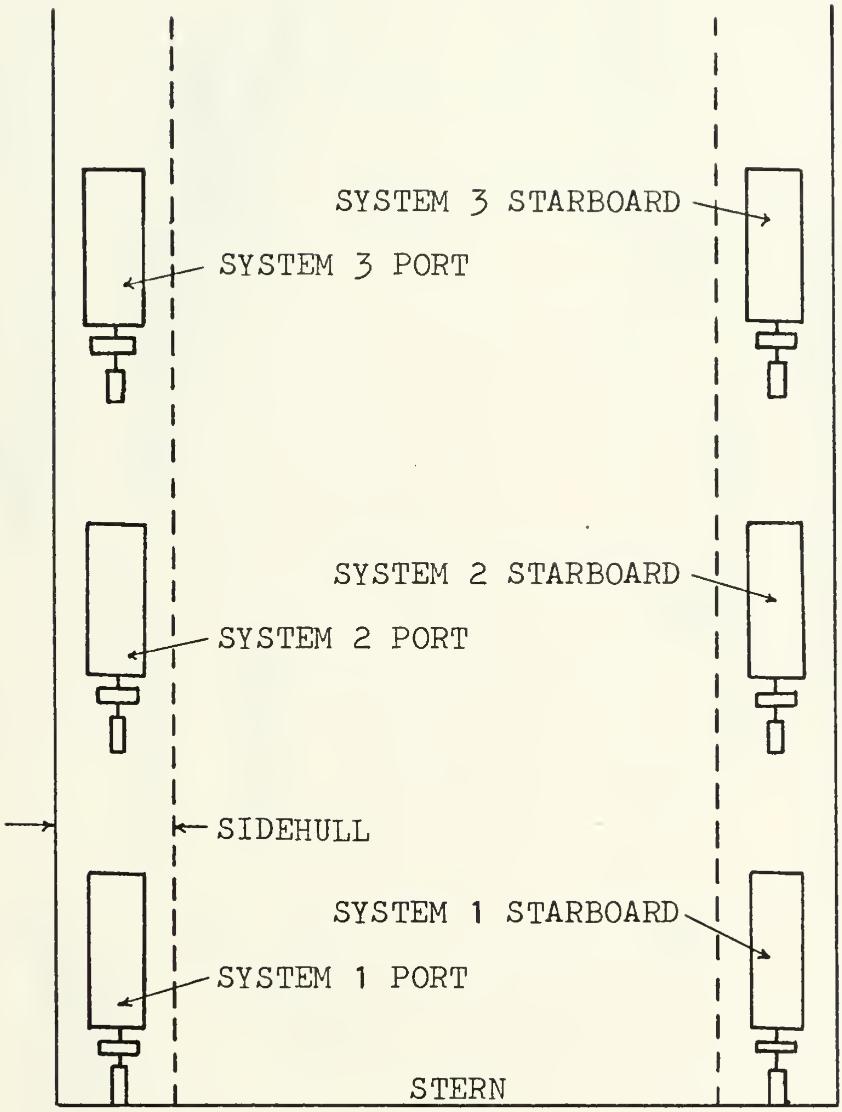


Figure 3 - WATERJET SYSTEM ARRANGEMENT FOR SURFACE EFFECT SHIPS

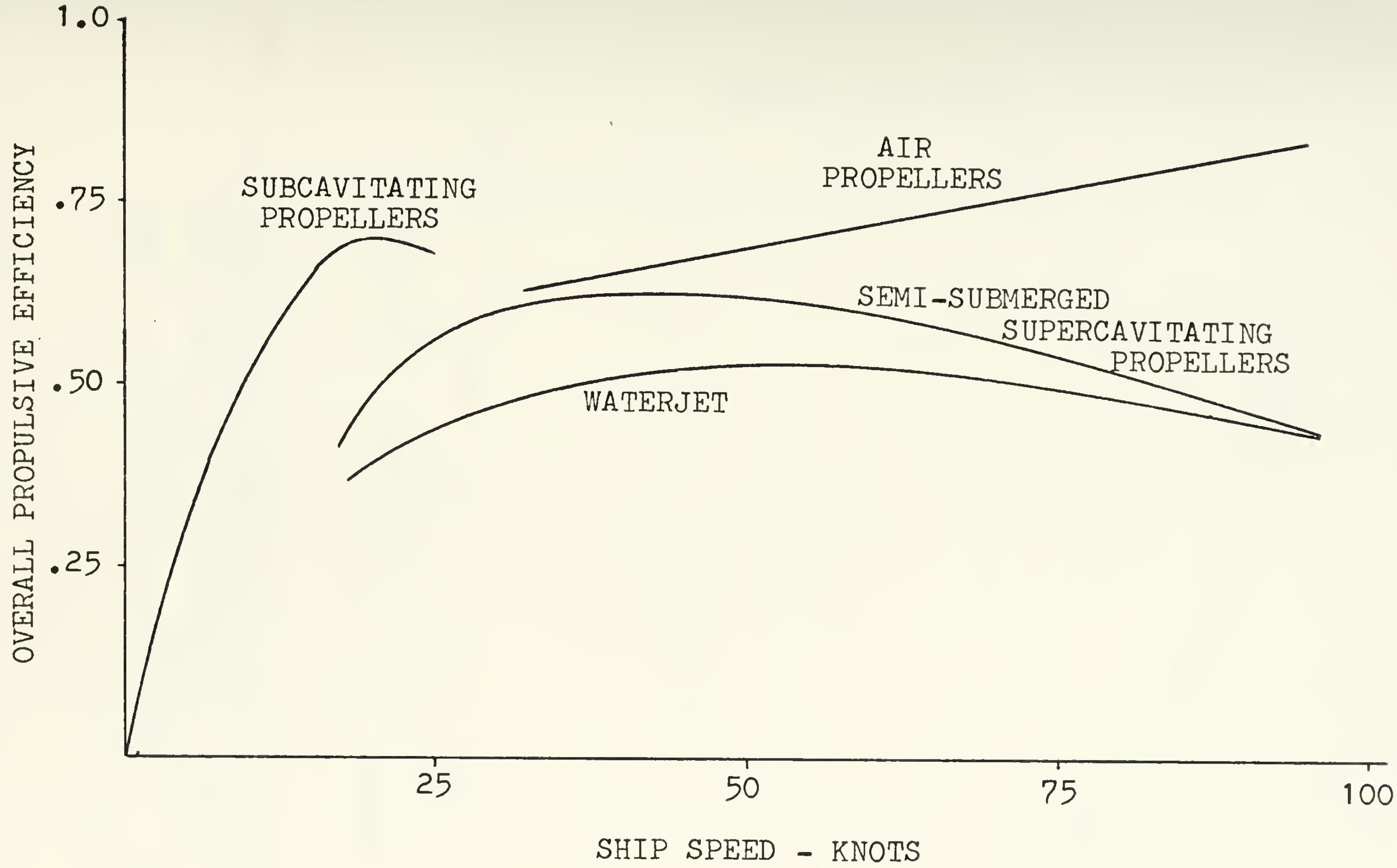


Figure 4 - COMPARATIVE PROPULSIVE EFFICIENCIES

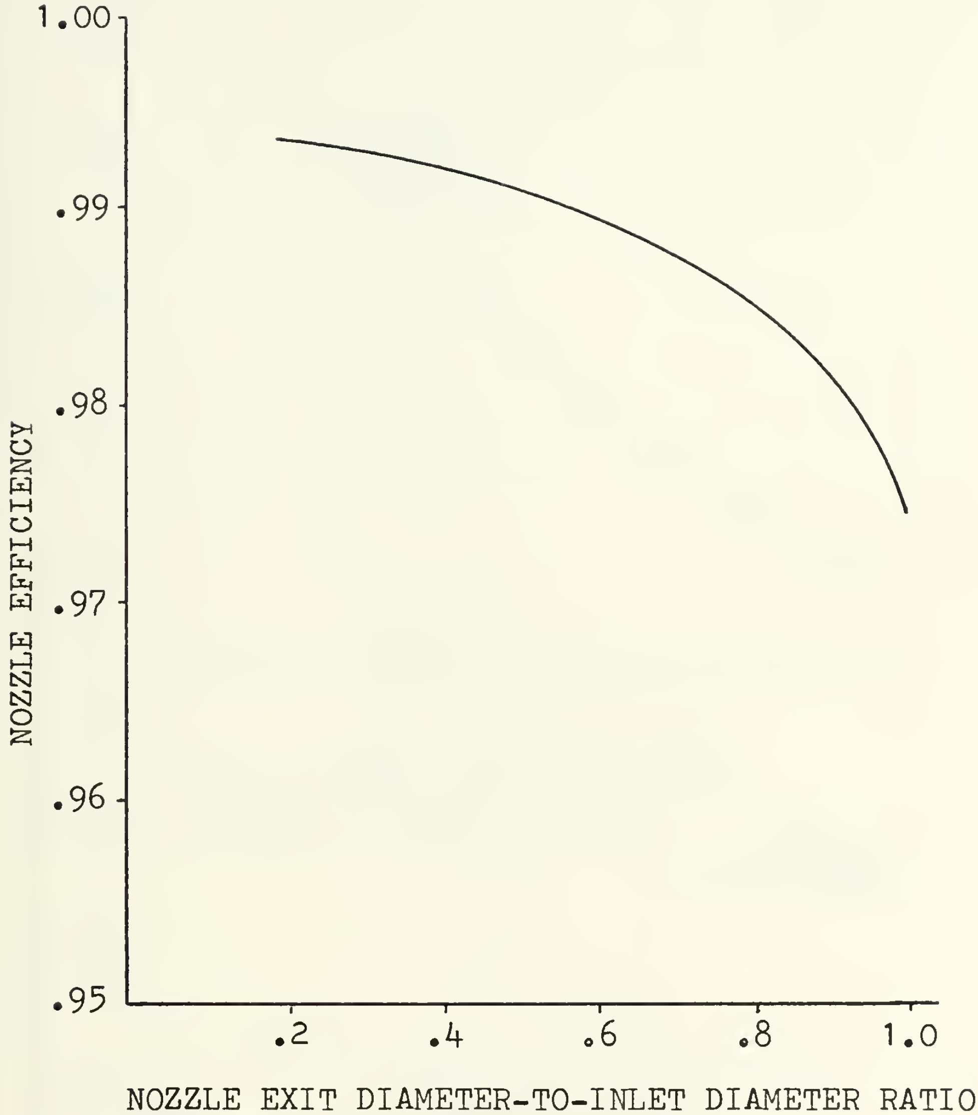


Figure 5 - VARIATION OF NOZZLE EFFICIENCY WITH THE NOZZLE EXIT DIAMETER-TO-INLET DIAMETER RATIO (d/D) FOR A LONG RADIUS NOZZLE

$(\eta_{nz} = -.0375(d/D)^2 + .0275(d/D) + .988)$

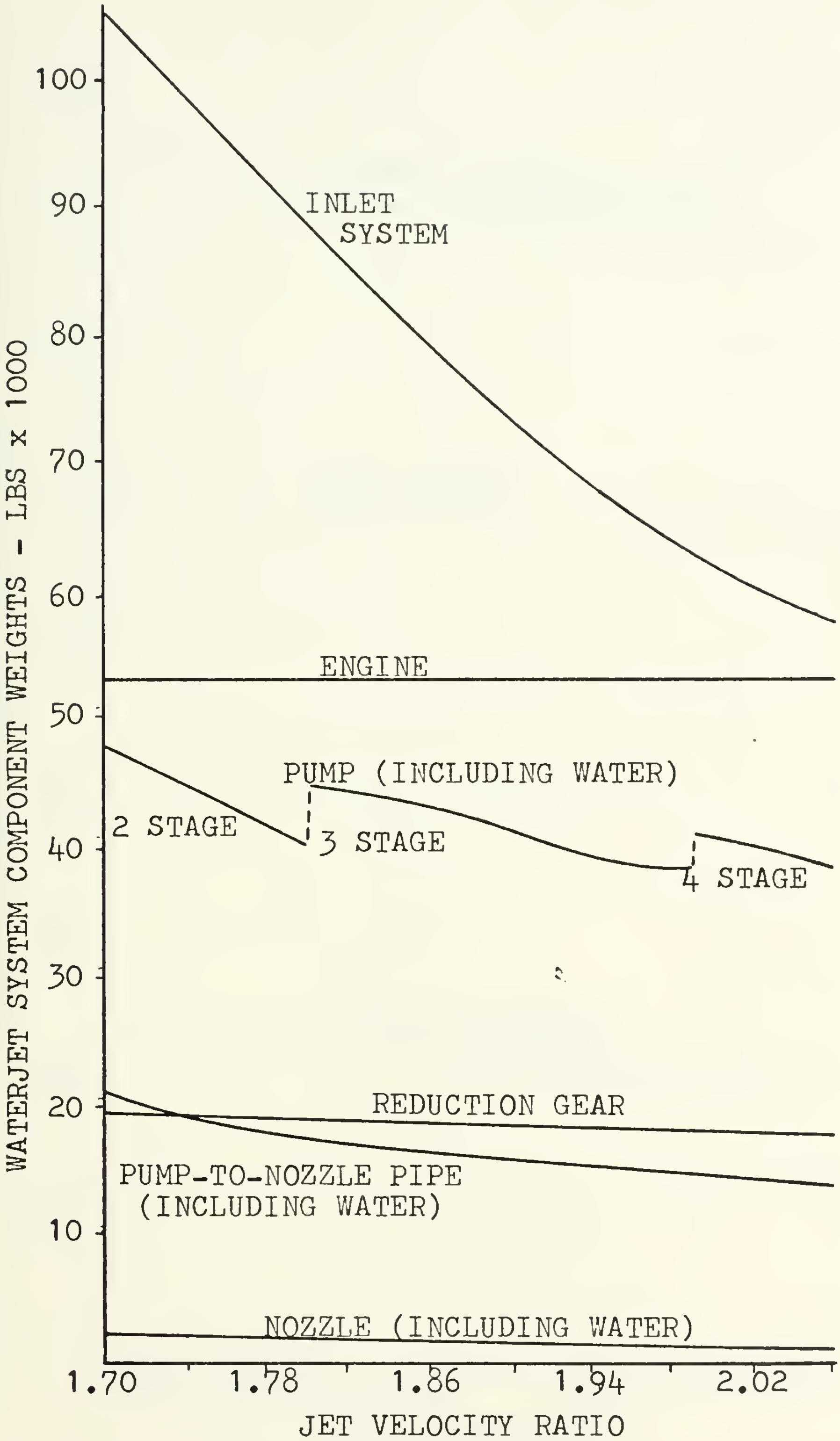


Figure 6 - VARIATION OF WATERJET SYSTEM COMPONENT WEIGHTS WITH JET VELOCITY RATIO FOR A 2,000 TON SES WITH A LENGTH-TO-BEAM RATIO OF 2 and 4 FT9D GAS TURBINES

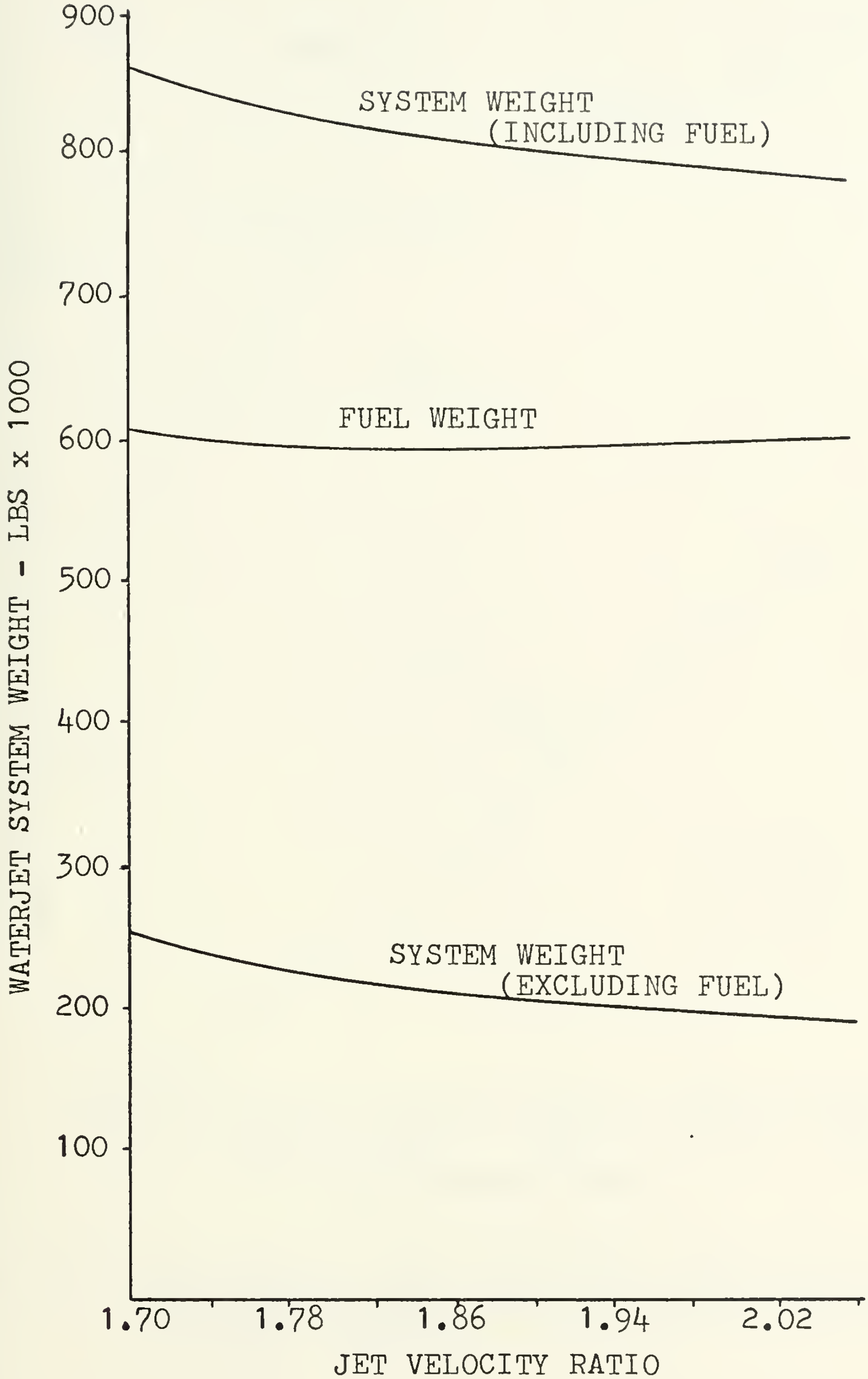


Figure 7 - VARIATION OF WATERJET SYSTEM WEIGHTS WITH JET VELOCITY RATIO FOR A 2,000 TON SES WITH A LENGTH-TO-BEAM RATIO OF 2 AND 4 FT9D GAS TURBINES

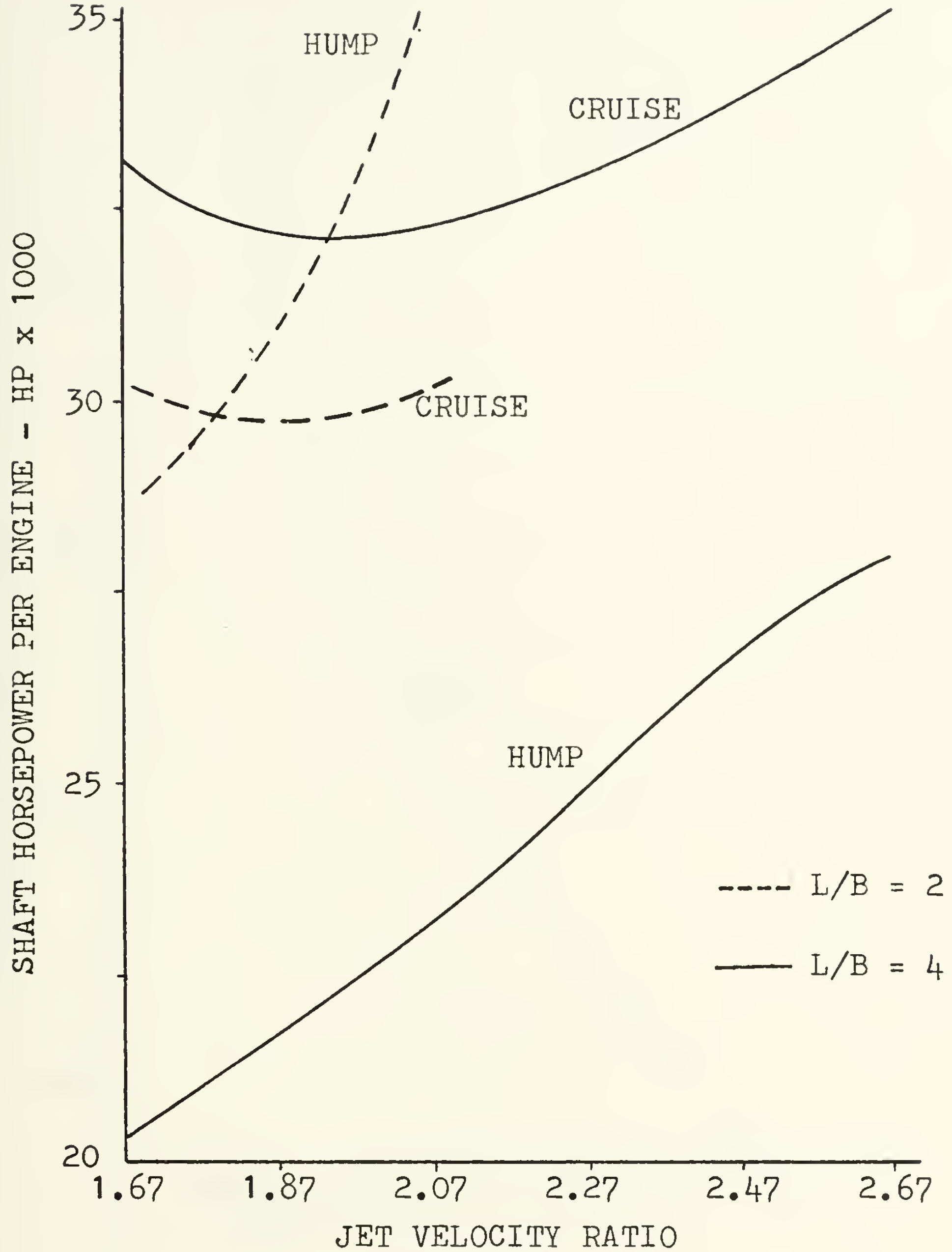


Figure 8 - VARIATION OF SHAFT HORSEPOWER PER ENGINE WITH JET VELOCITY RATIO FOR A 2,000 TON SES USING 4 FT9D GAS TURBINES

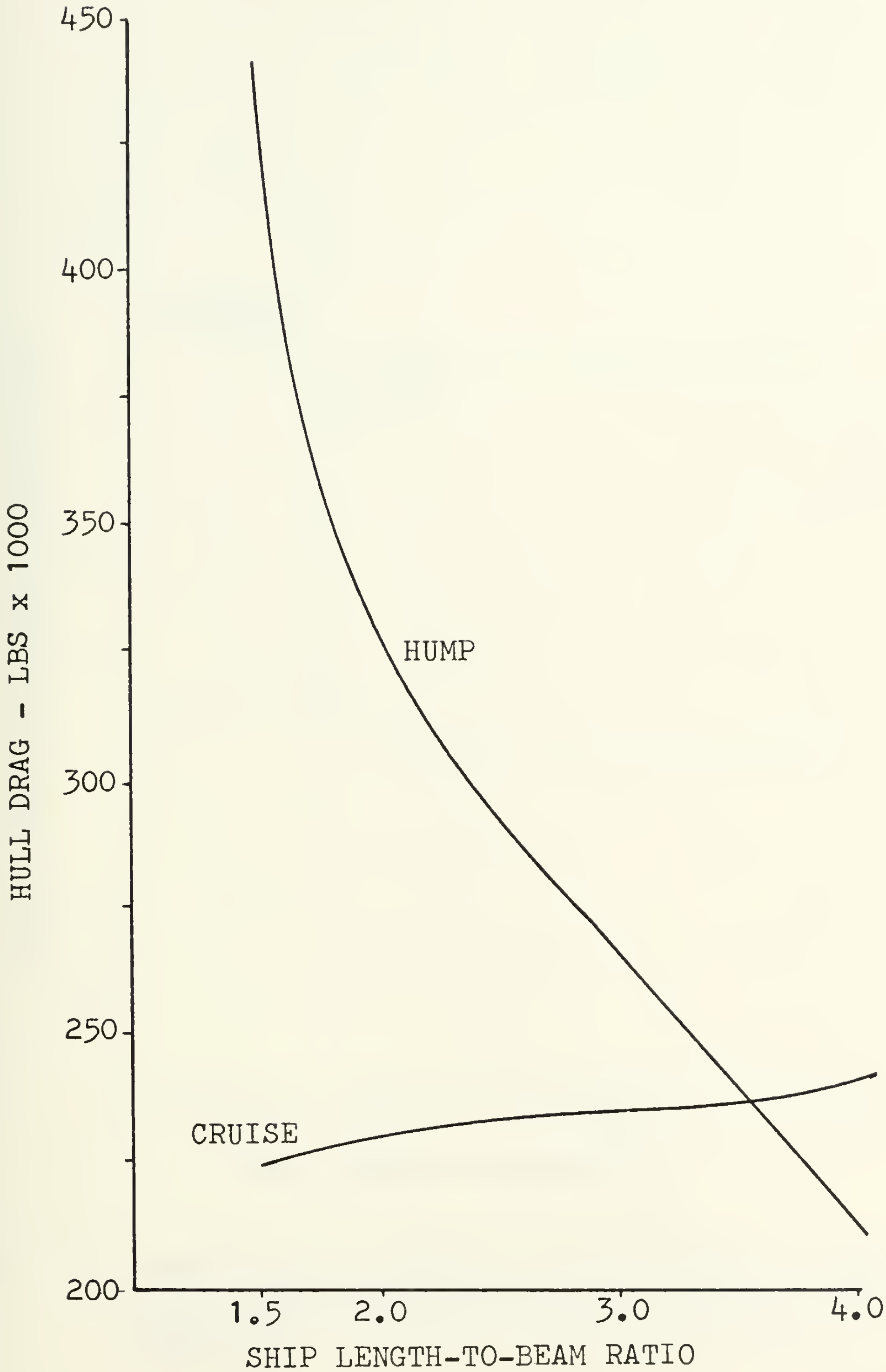


Figure 9 - VARIATION OF HULL DRAG WITH SHIP LENGTH-TO-BEAM RATIO FOR A 2,000 TON SES

Figure 10 - VARIATION OF WATERJET SYSTEM WEIGHT-TO-SHIP DISPLACEMENT RATIO WITH SHIP LENGTH-TO-BEAM RATIO FOR A 2,000 TON SES USING FT9D GAS TURBINES

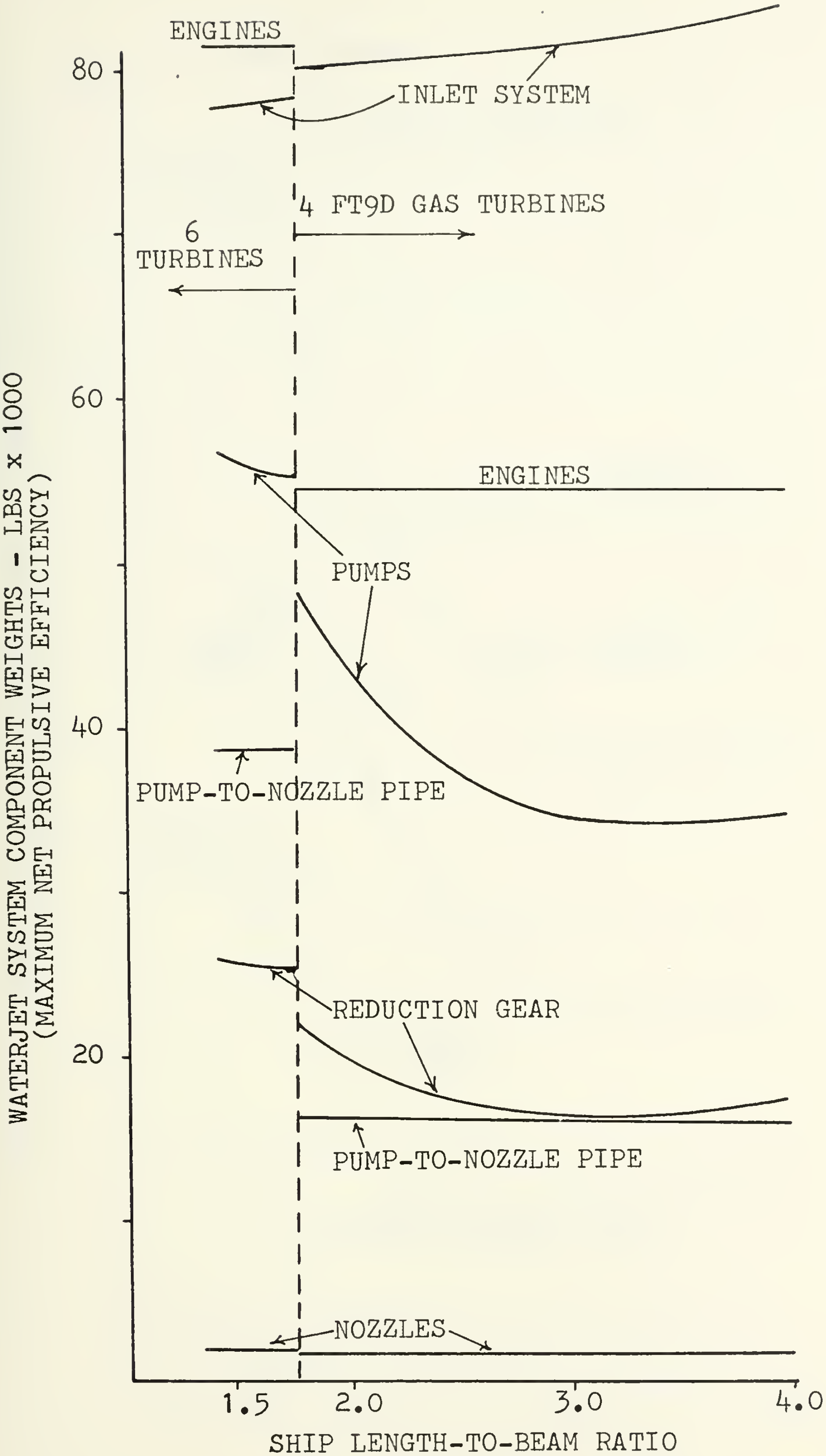


Figure 11 - VARIATION OF WATERJET SYSTEM COMPONENT WEIGHTS (AT MAXIMUM NET PROPULSIVE EFFICIENCY) WITH THE SHIP LENGTH-TO-BEAM RATIO FOR A 2,000 TON SES

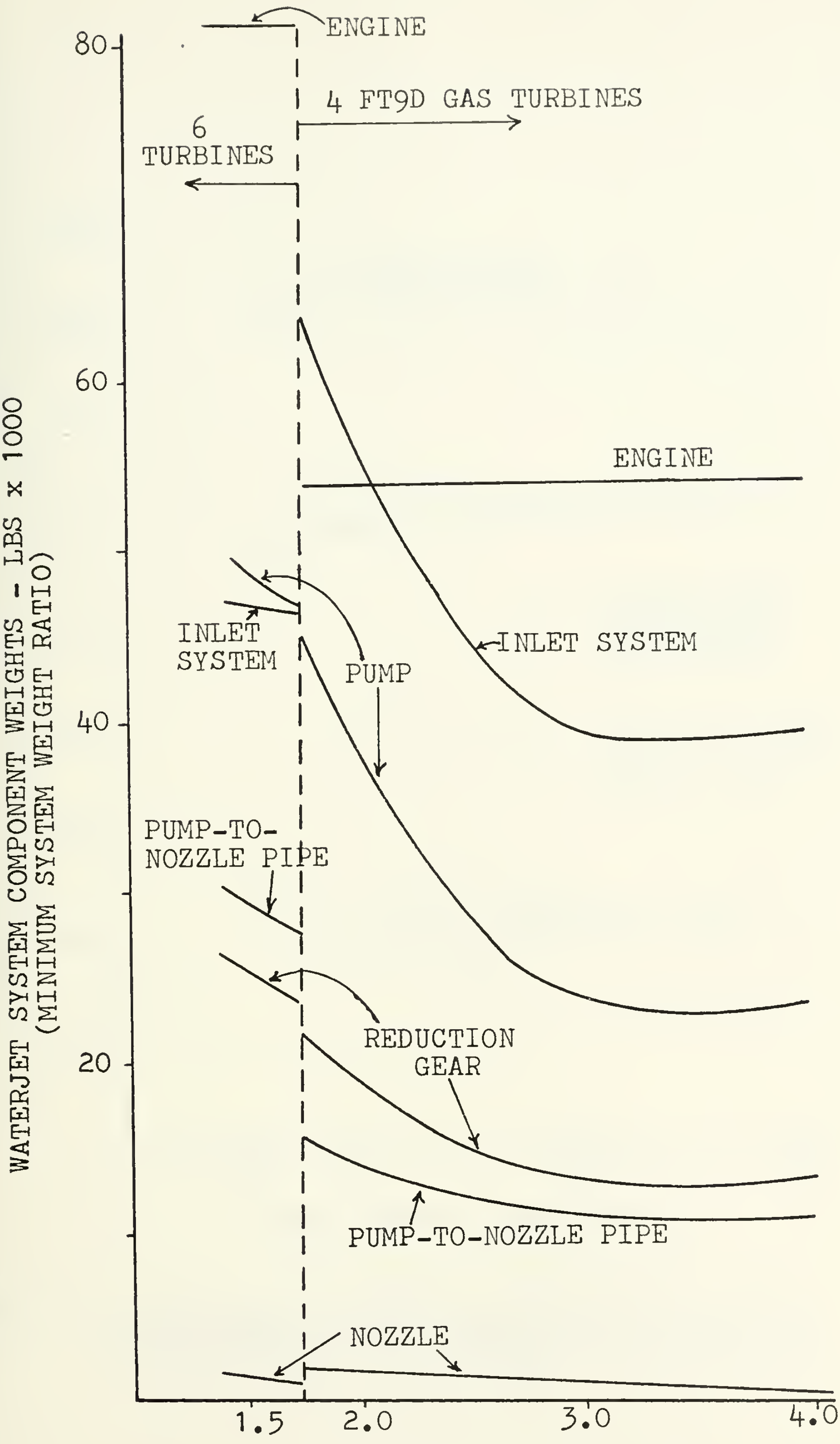


Figure 12 - VARIATION OF WATERJET SYSTEM COMPONENT WEIGHTS (AT THE MINIMUM SYSTEM WEIGHT RATIO) WITH THE SHIP LENGTH-TO-BEAM RATIO FOR A 2,000 TON SES

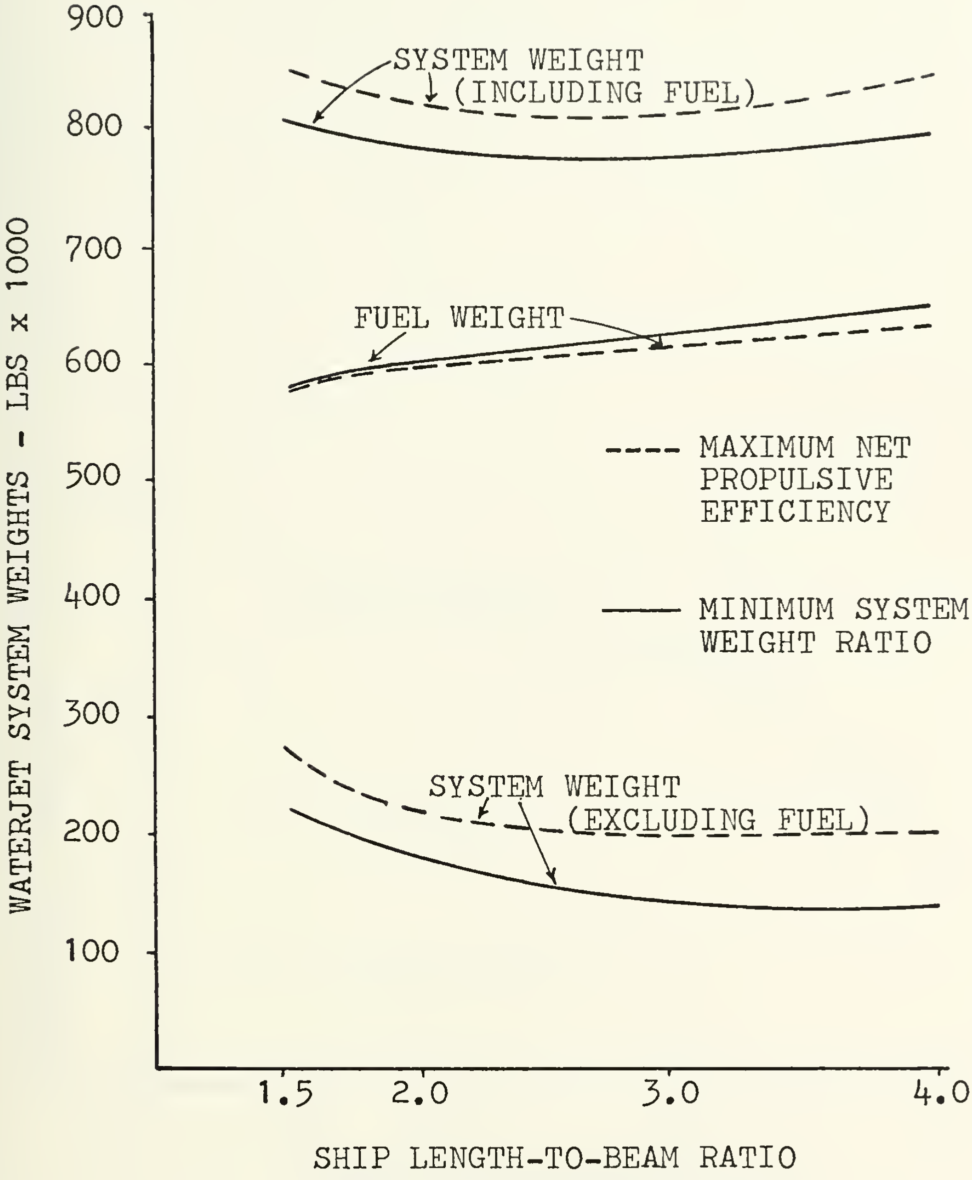


Figure 13 - VARIATION OF WATERJET SYSTEM WEIGHTS WITH SHIP LENGTH-TO-BEAM RATIO FOR A 2,000 TON SES WITH FT9D GAS TURBINES

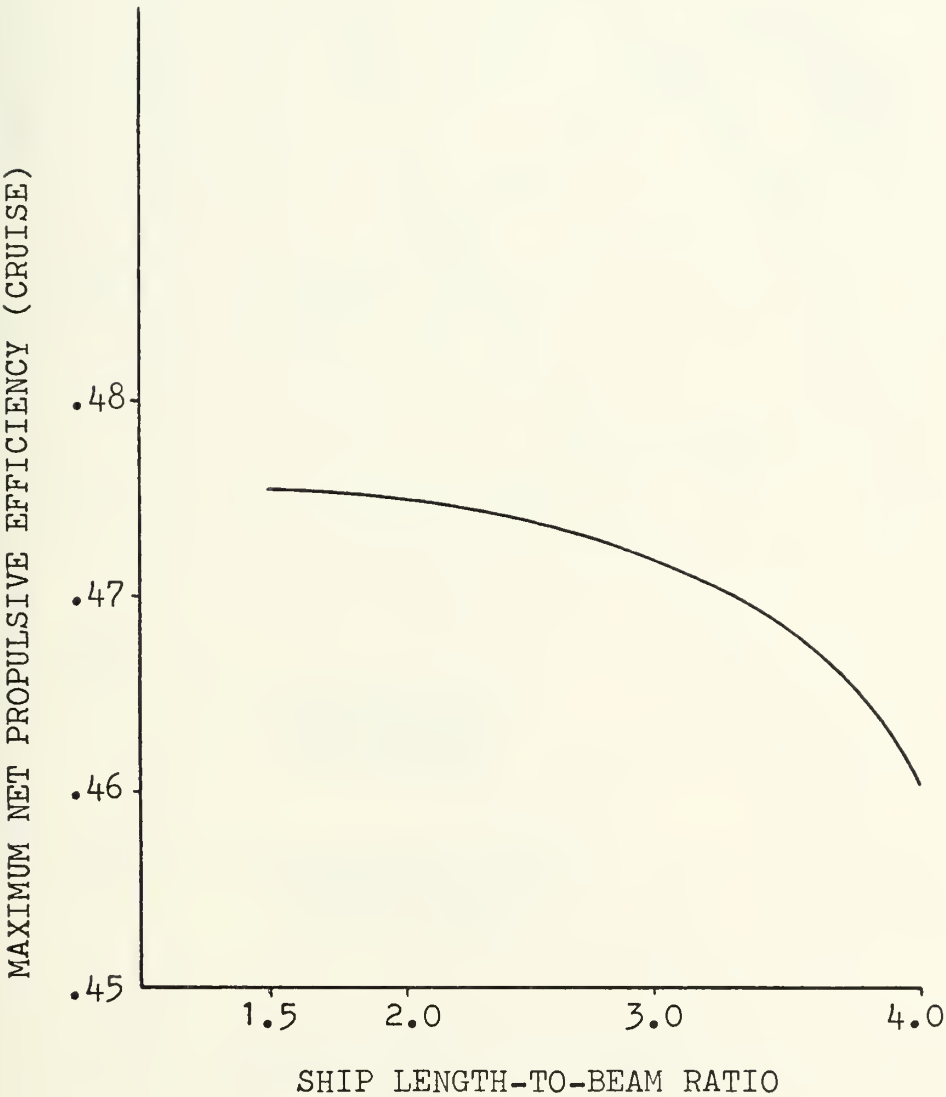


Figure 14 - VARIATION OF THE MAXIMUM NET PROPULSIVE EFFICIENCY (CRUISE) WITH THE SHIP LENGTH-TO-BEAM RATIO FOR A 2,000 TON SES USING 4 FT9D GAS TURBINES

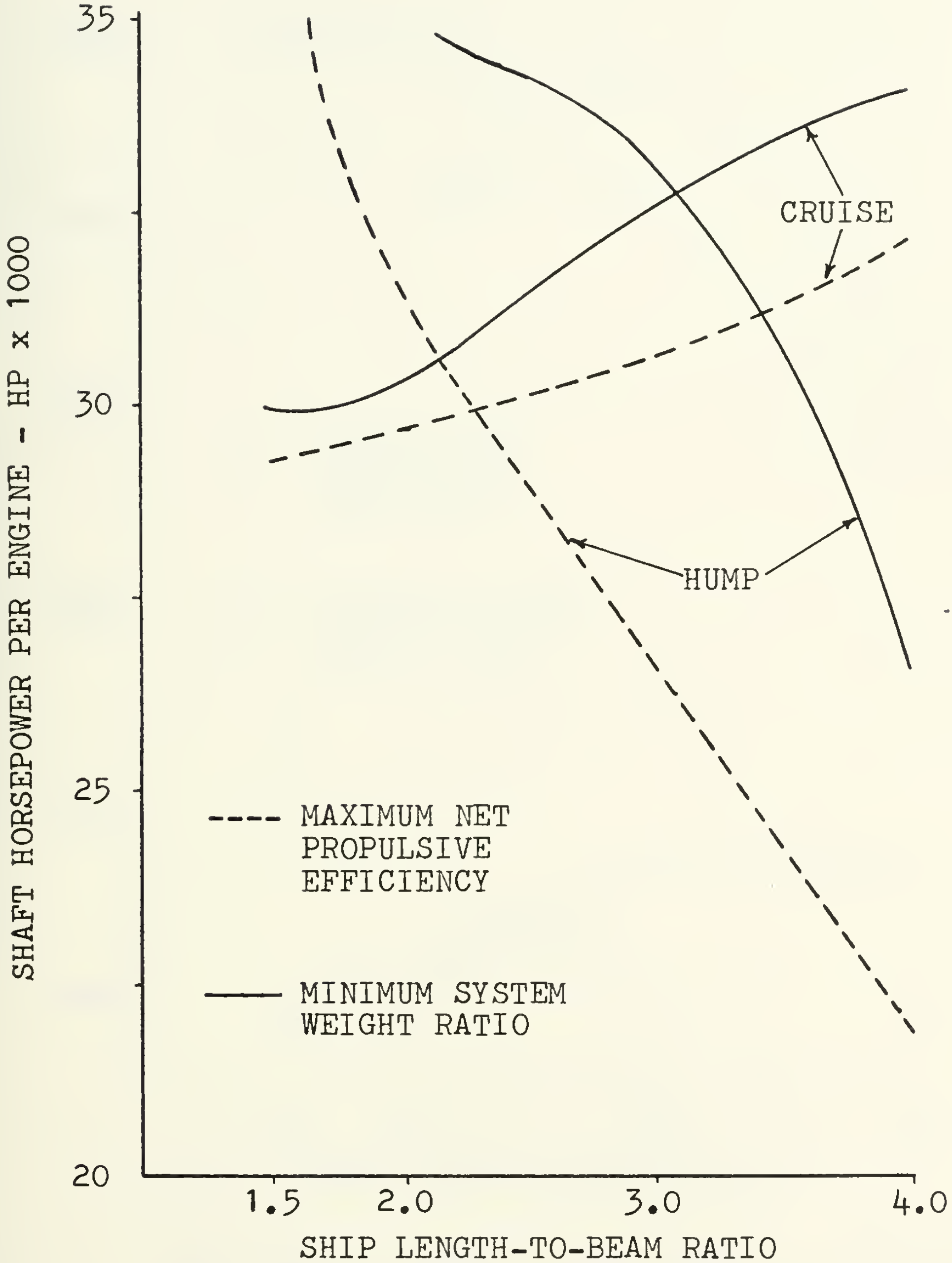


Figure 15 - VARIATION OF SHAFT HORSEPOWER PER ENGINE WITH SHIP LENGTH-TO-BEAM RATIO FOR A 2,000 TON SES WITH 4 FT9D GAS TURBINES

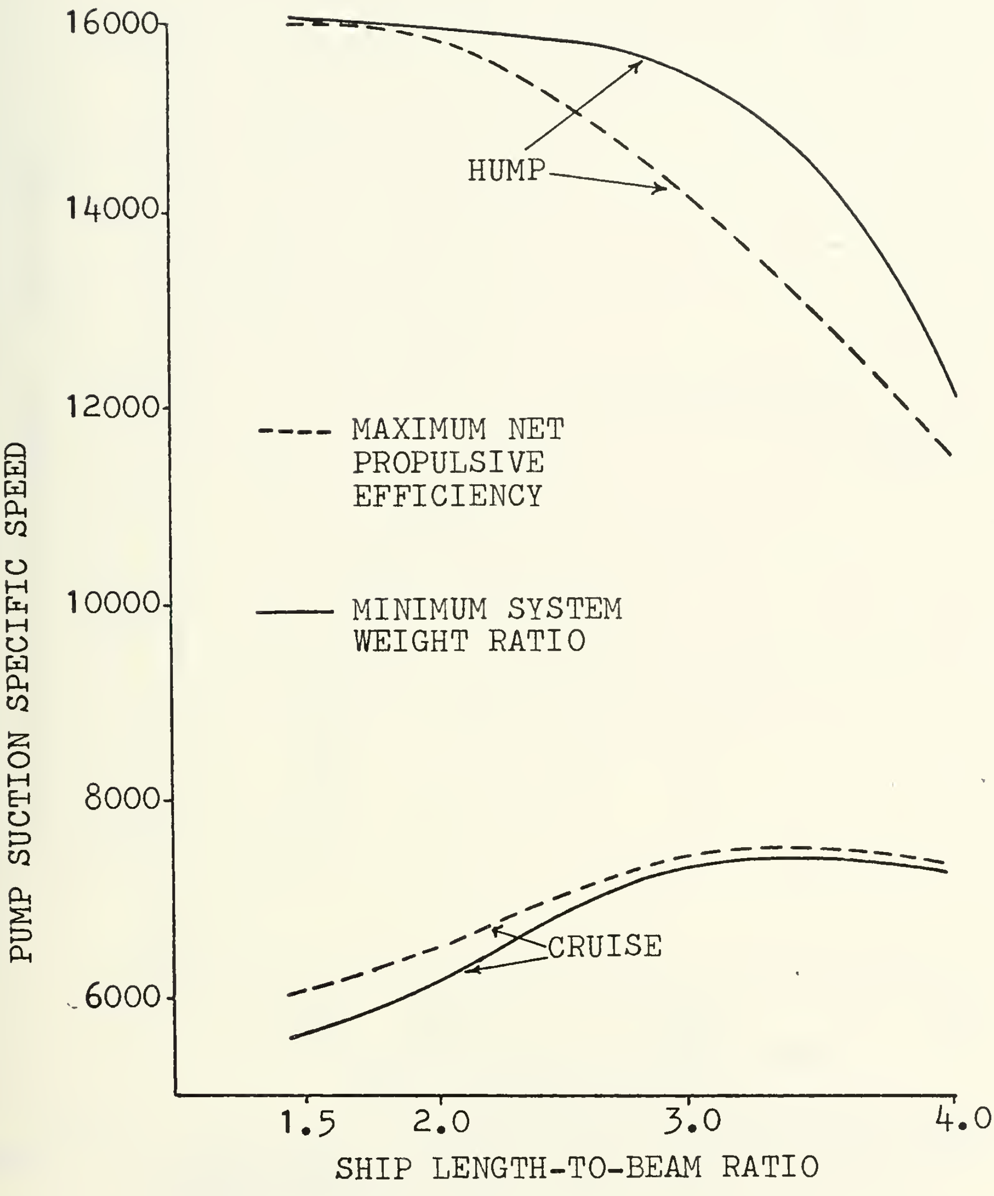


Figure 16 - VARIATION OF PUMP SUCTION SPECIFIC SPEED WITH SHIP LENGTH-TO-BEAM RATIO FOR A 2,000 TON SES USING 4 FT9D GAS TURBINES

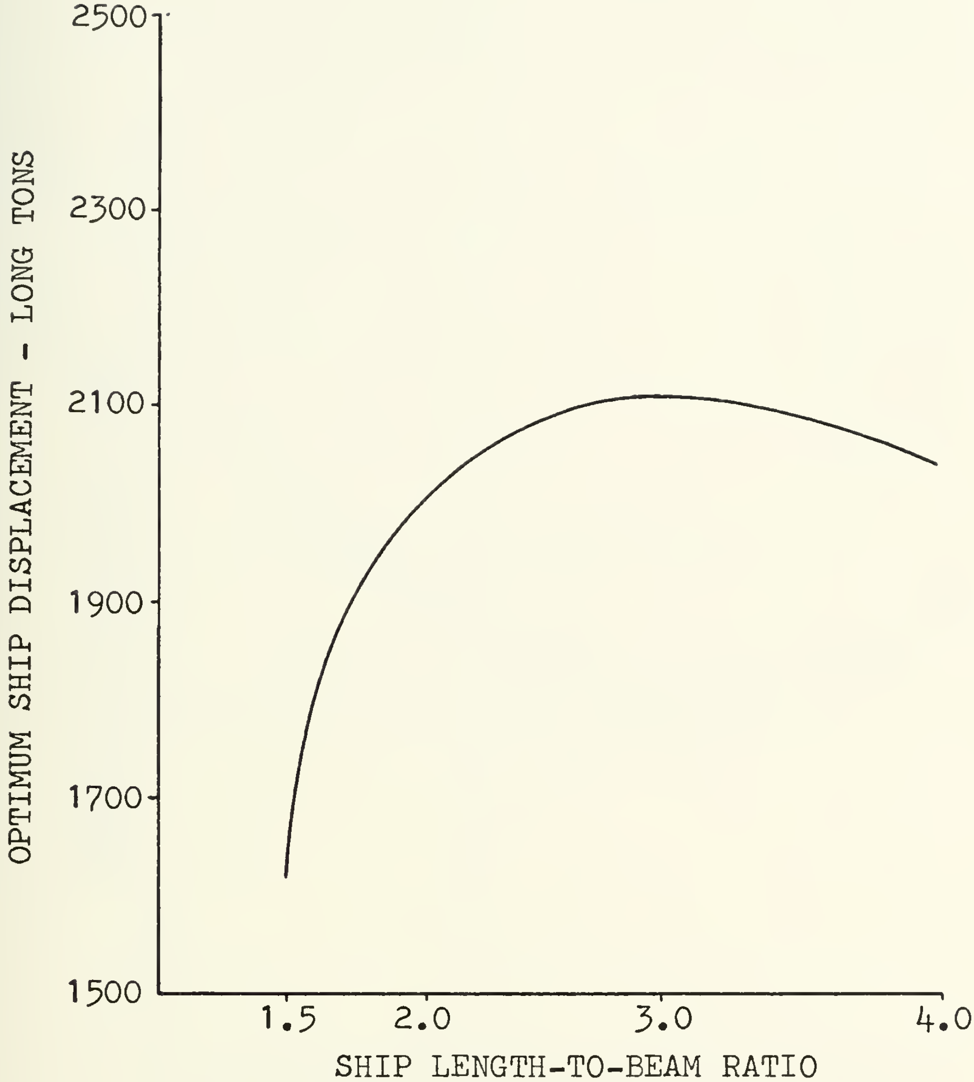


Figure 17 - VARIATION OF OPTIMUM SHIP DISPLACEMENT WITH SHIP LENGTH-TO-BEAM RATIO FOR 4 FT9D GAS TURBINES

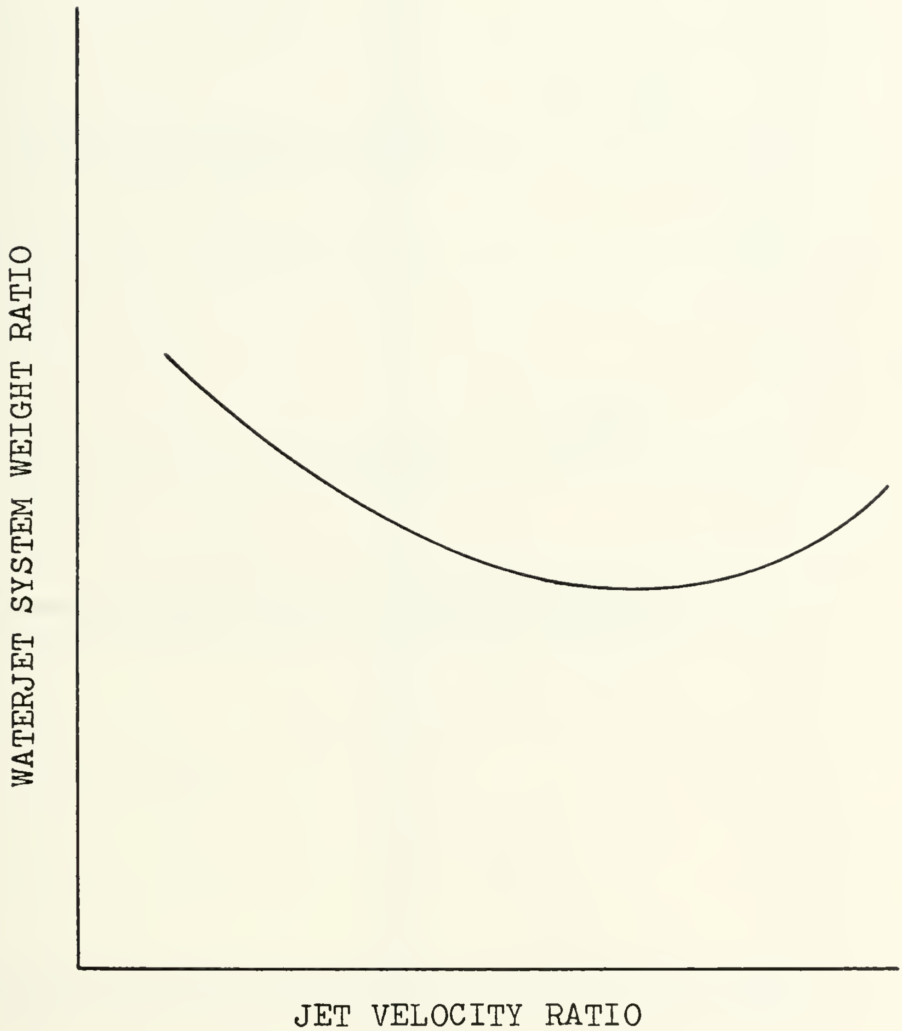


Figure 18 - REPRESENTATIVE VARIATION OF WATERJET SYSTEM WEIGHT RATIO WITH JET VELOCITY RATIO

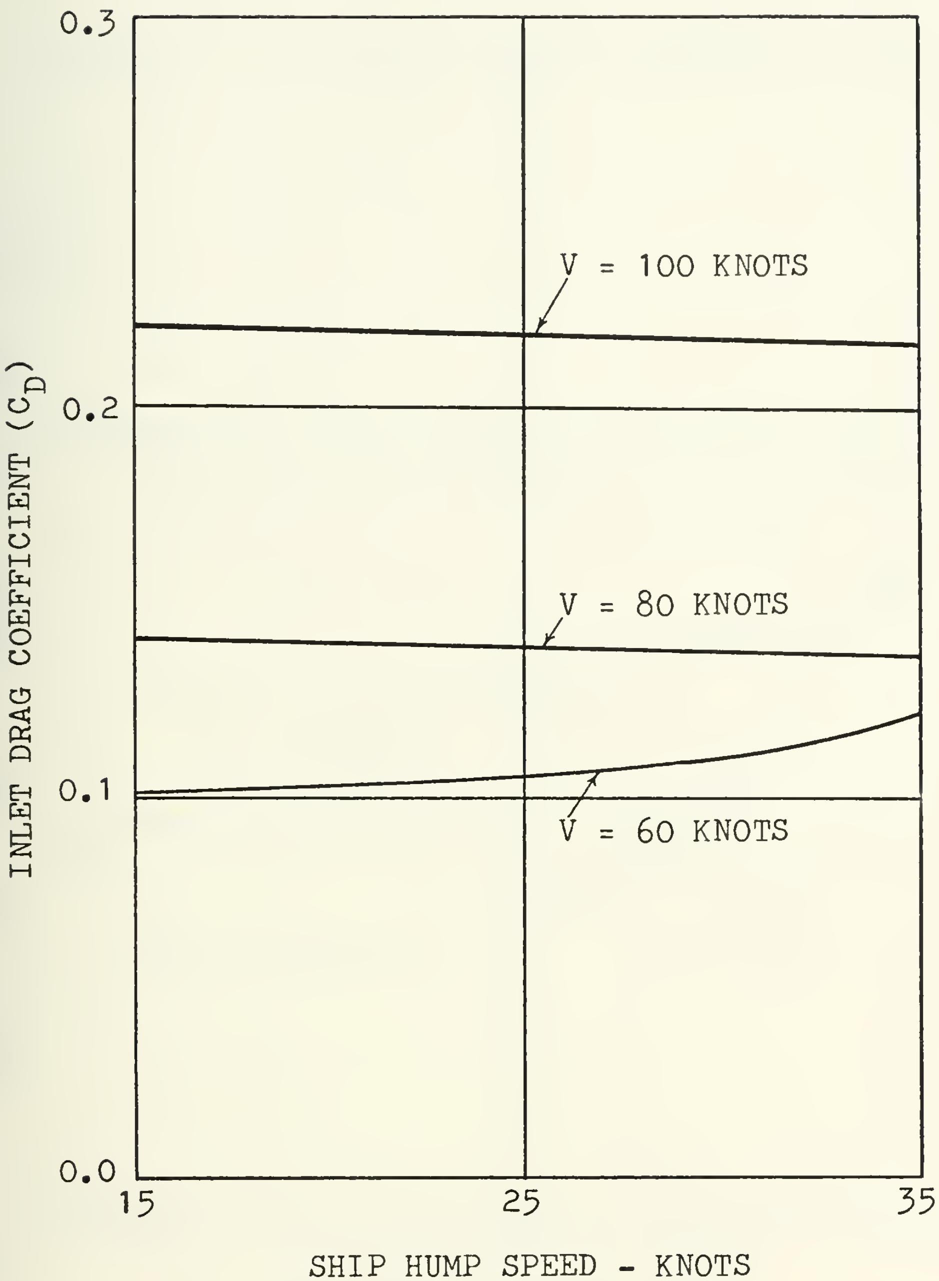


Figure 19 - INLET DRAG COEFFICIENT FOR VARYING ASPECT RATIO INLETS (reference 1)

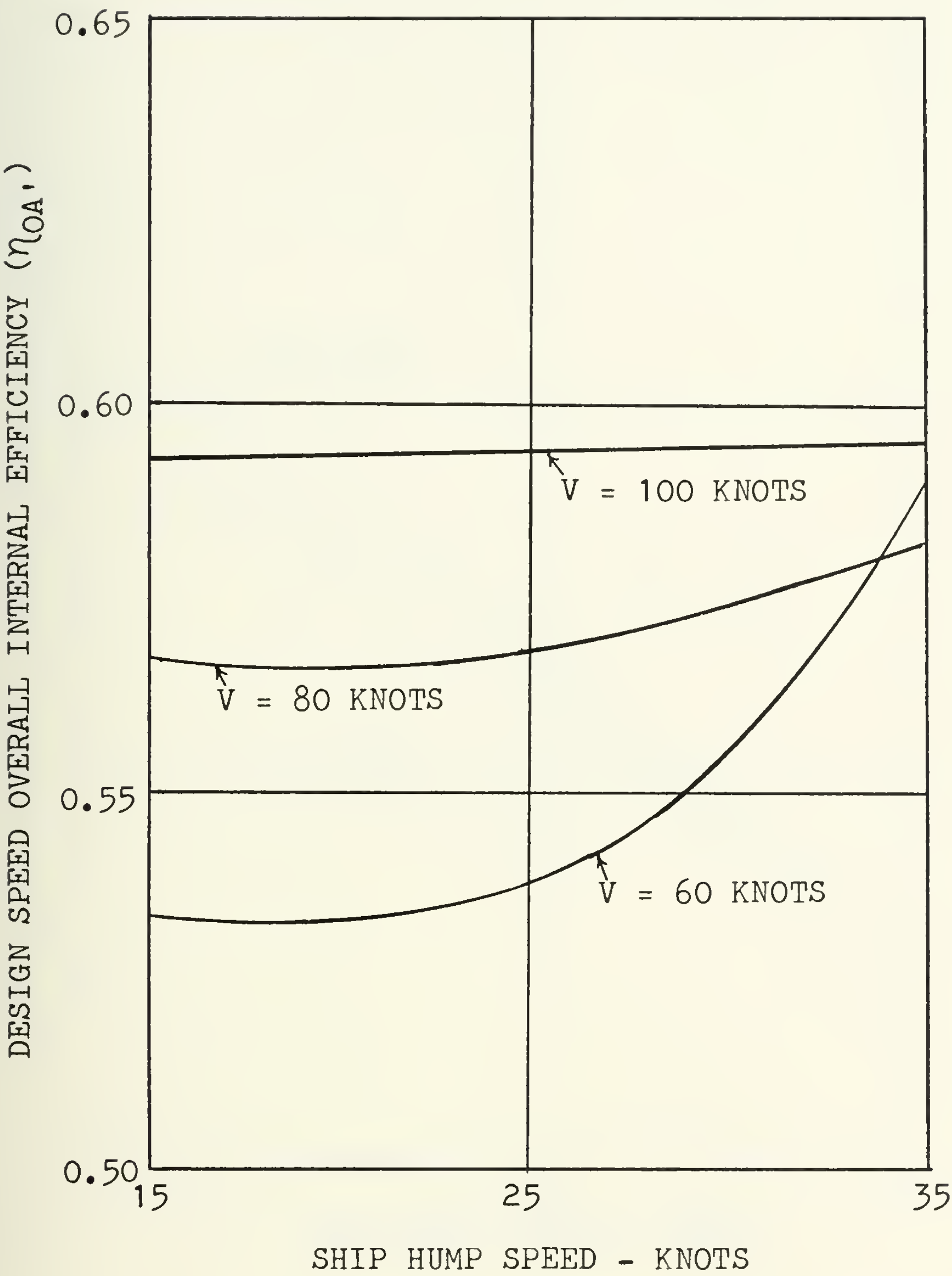


Figure 20 - DESIGN SPEED OVERALL INTERNAL EFFICIENCY FOR VARYING ASPECT RATIO INLETS (reference 1)

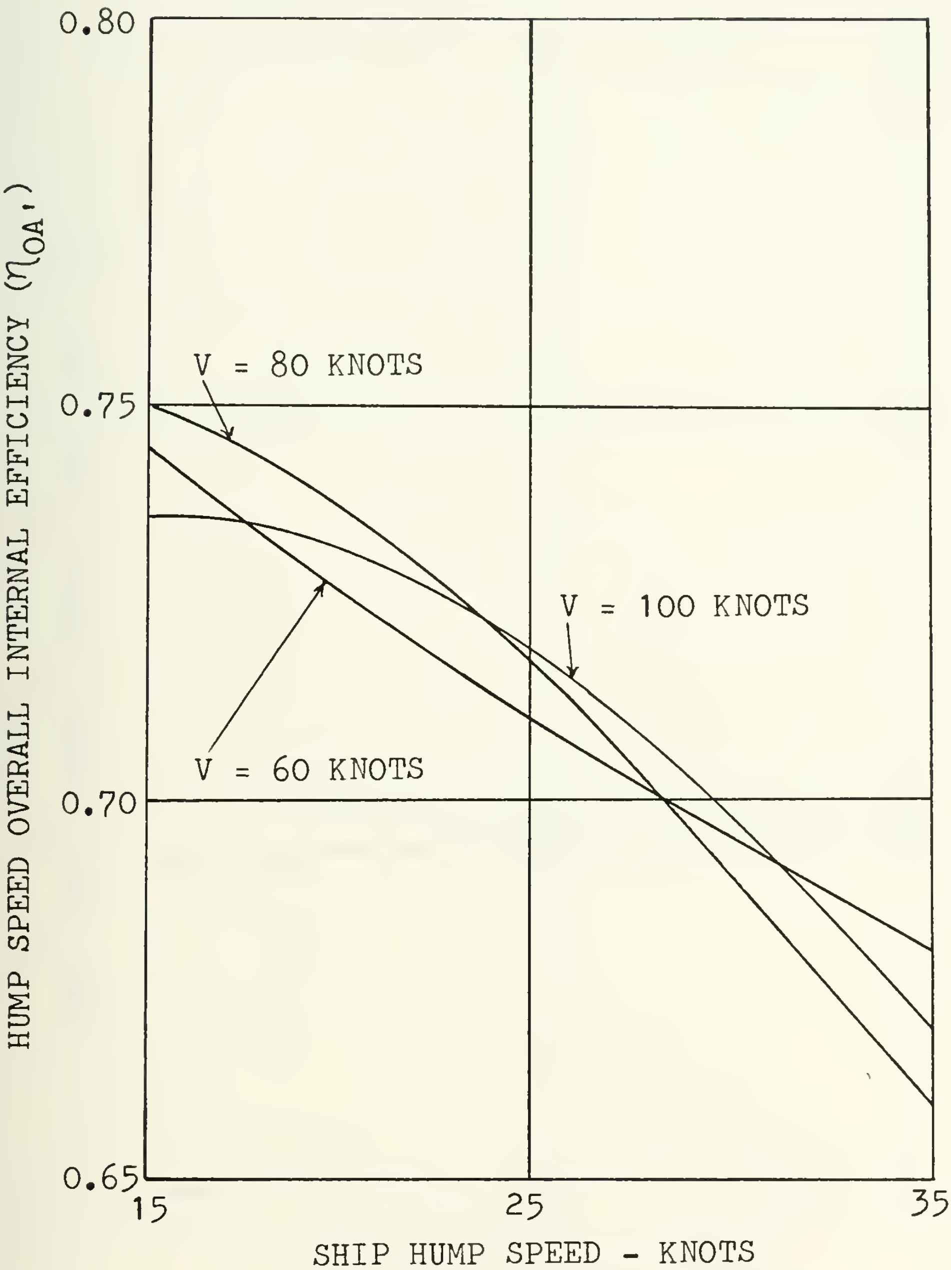


Figure 21 - HUMP SPEED OVERALL INTERNAL EFFICIENCY FOR VARYING ASPECT RATIO INLETS (reference 1)

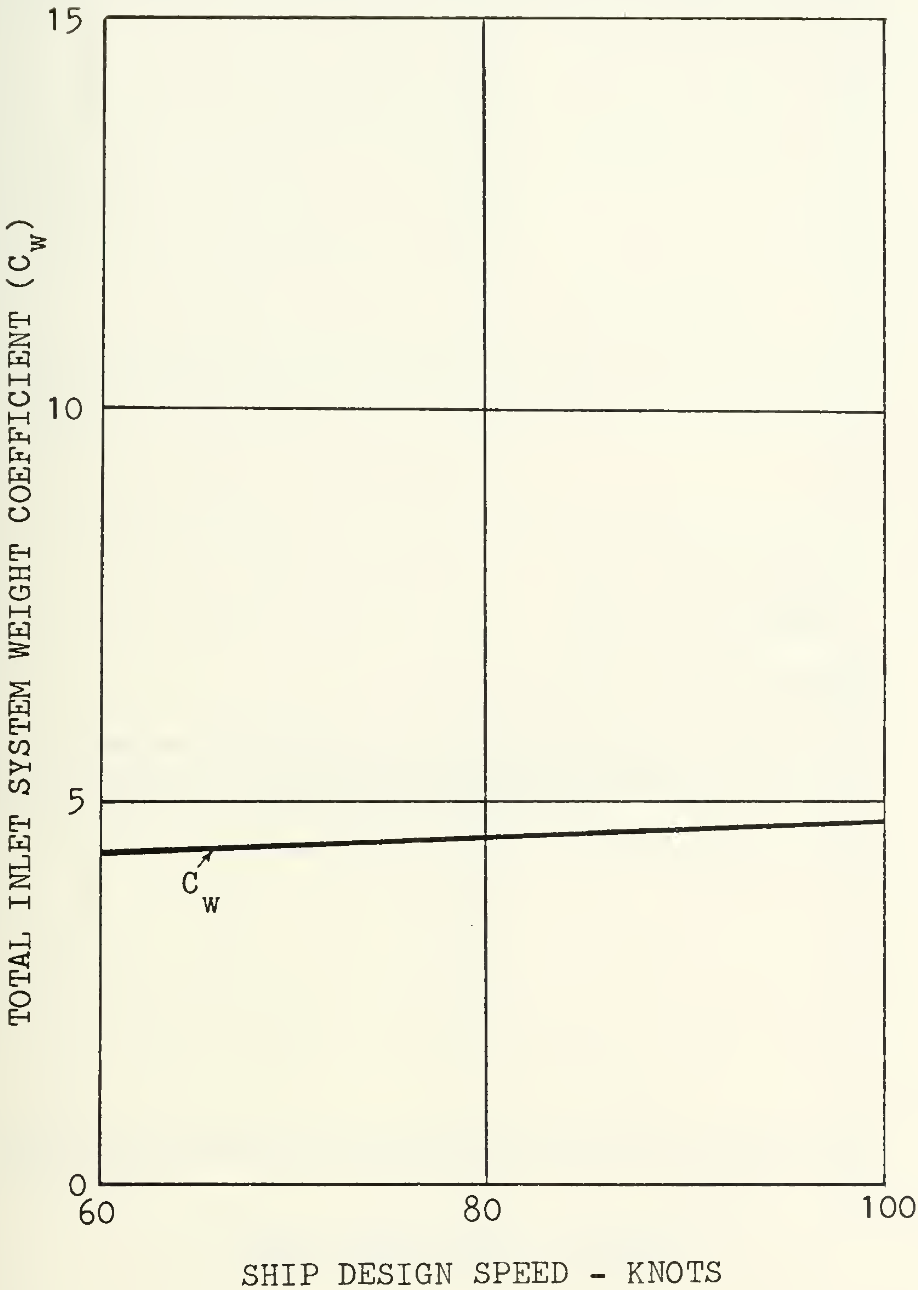
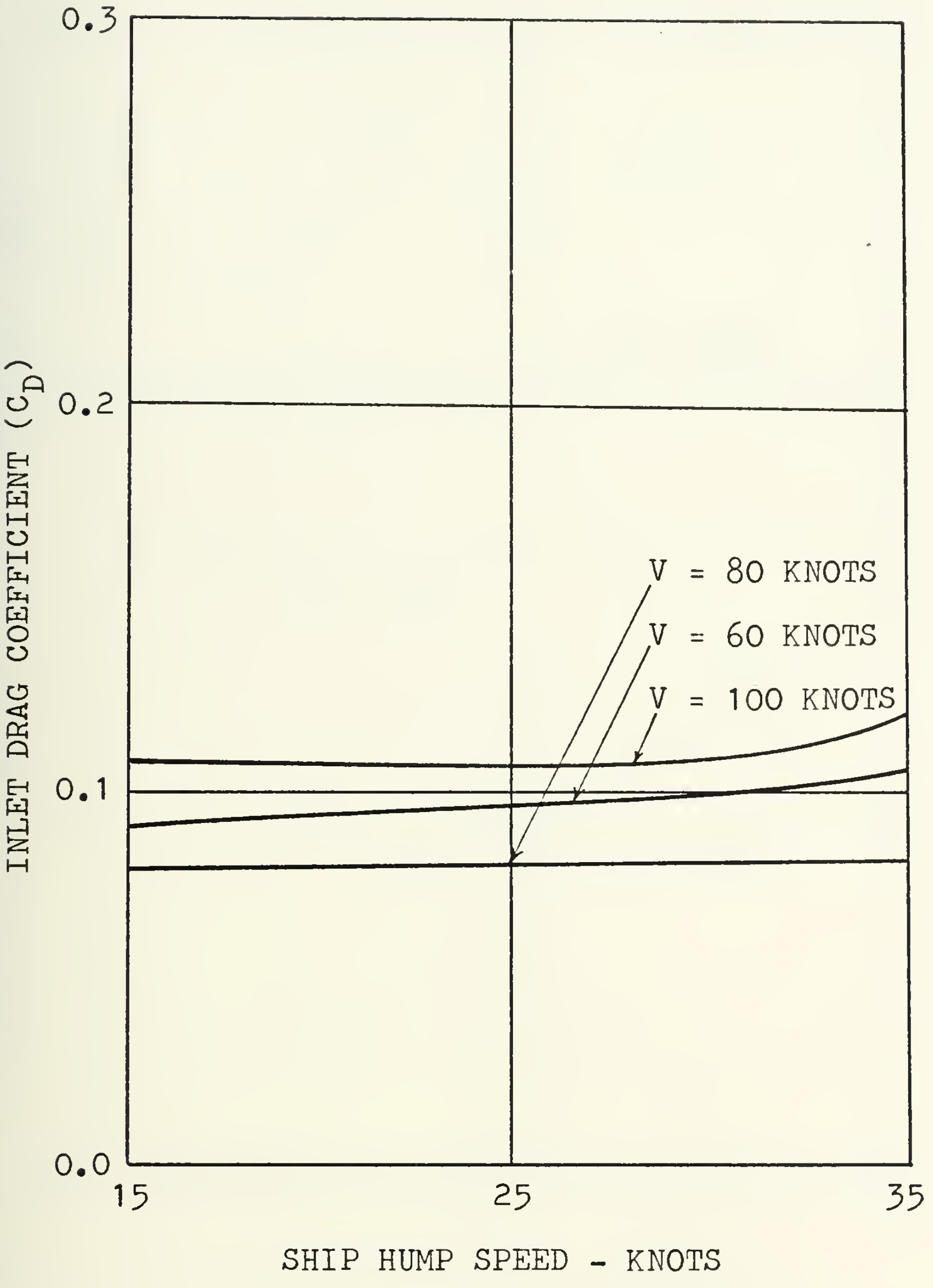


Figure 22 - TOTAL INLET SYSTEM WEIGHT COEFFICIENT FOR VARYING ASPECT RATIO INLETS (reference 1)



igure 23 - INLET DRAG COEFFICIENT FOR 2.5 ASPECT RATIO INLETS (reference 1)

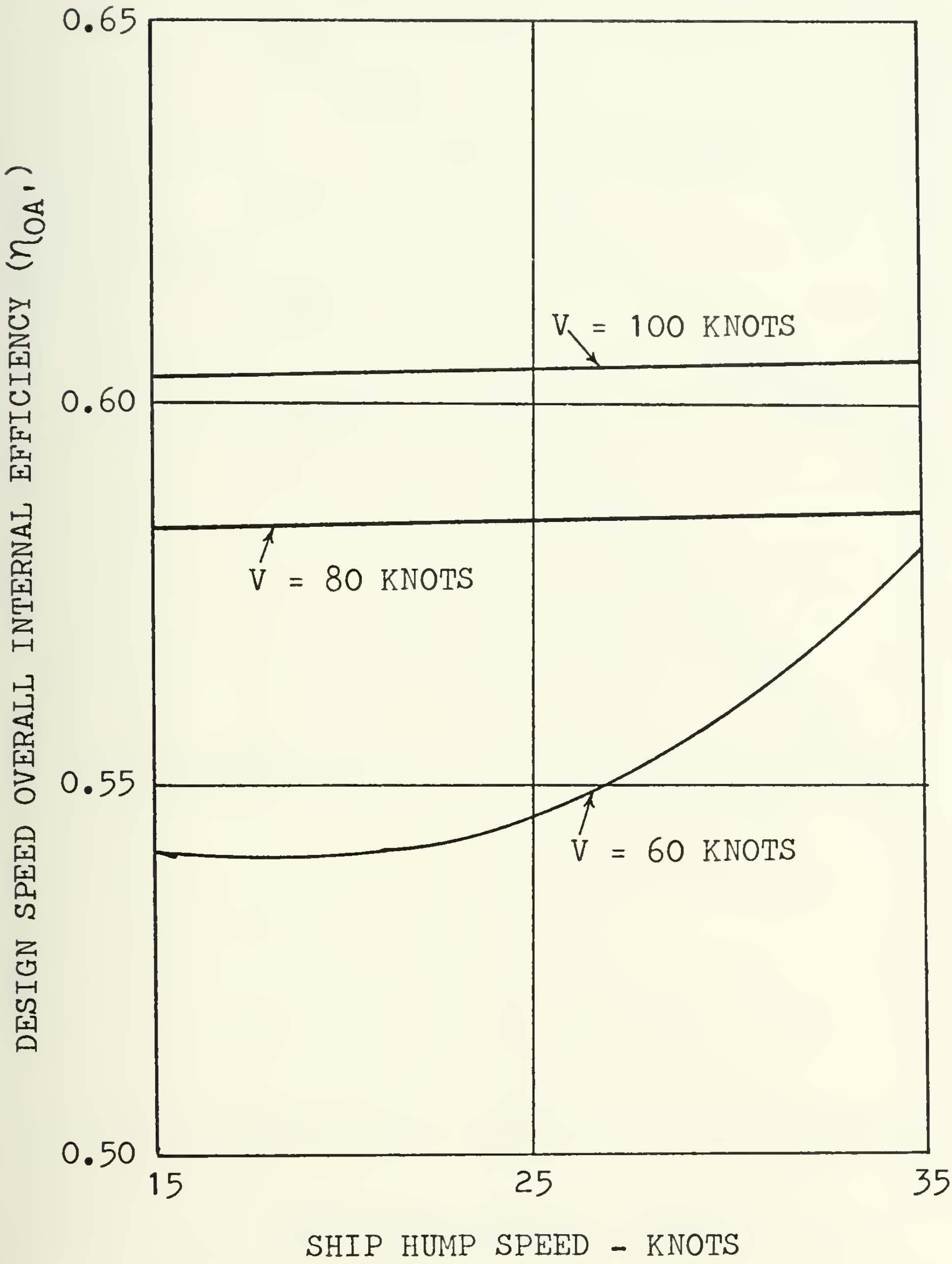


Figure 24 - DESIGN SPEED OVERALL INTERNAL EFFICIENCY FOR 2.5 ASPECT RATIO INLETS (reference 1)

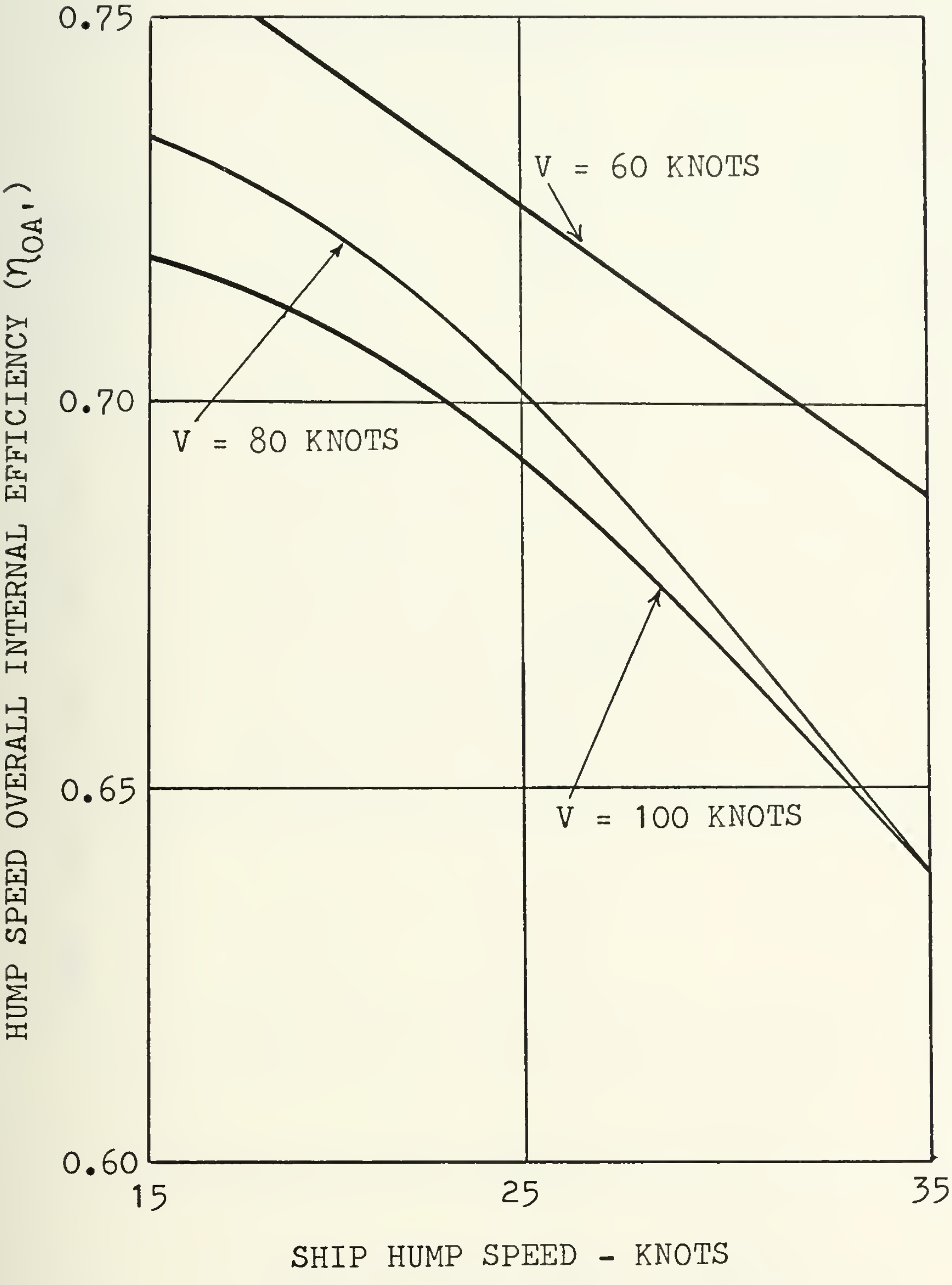


Figure 25 - HUMP SPEED OVERALL INTERNAL EFFICIENCY FOR 2.5 ASPECT RATIO INLETS (reference 1)

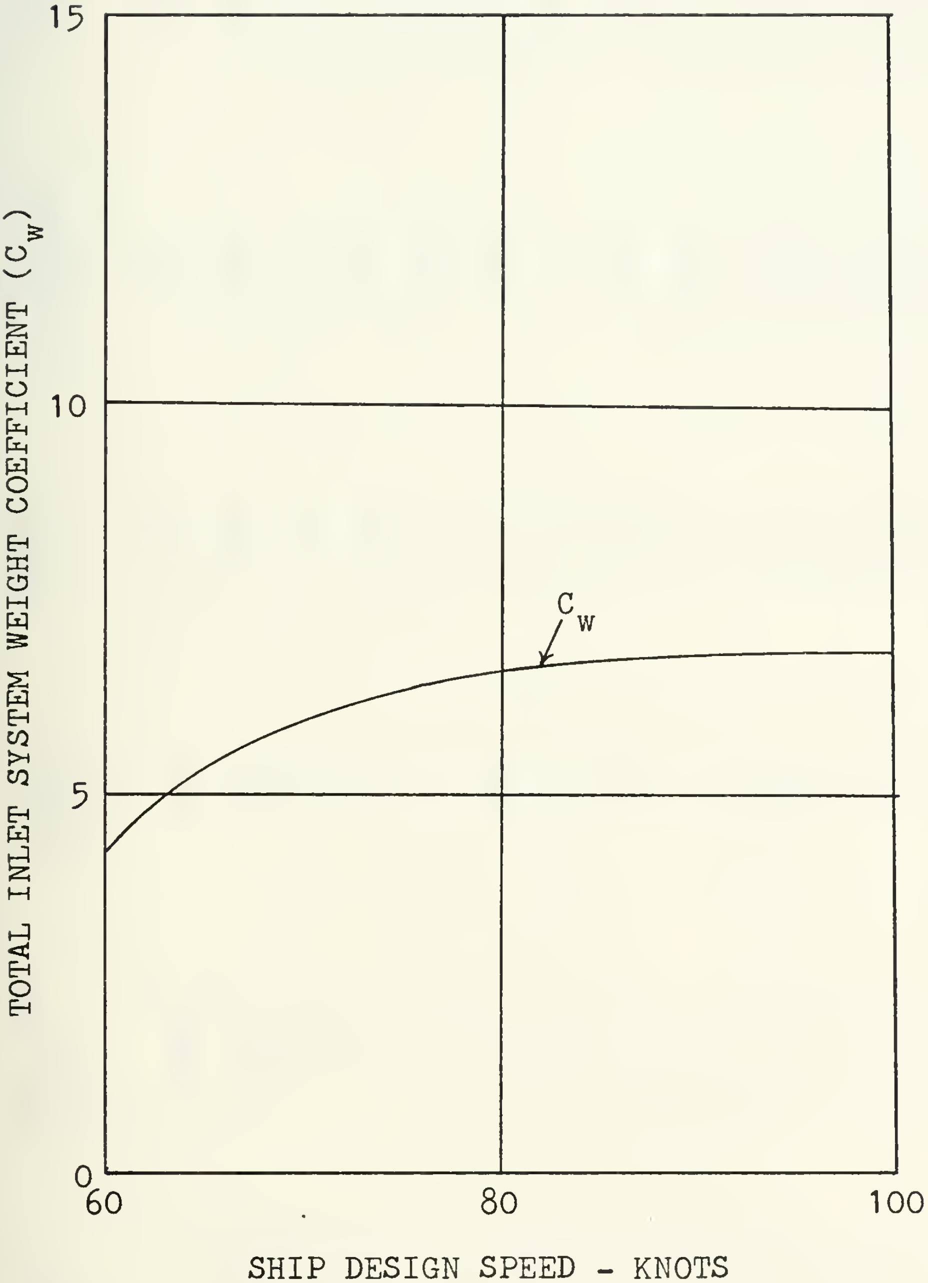


Figure 26 - TOTAL INLET SYSTEM WEIGHT COEFFICIENT FOR 2.5 ASPECT RATIO INLETS (reference 1)

TABLE 1 - CHARACTERISTICS OF CURRENT MARINE GAS TURBINES

Turbine	Normal Power HP	Max. Int. Power HP	SFC at Normal Power	Turbine RPM	Turbine Dry Weight lbs	Turbine Length ft.
TF 35	2,220	2,840	.59	14,500	1,050	4.083
TF 40	2,850	3,060	.55	14,500	1,050	4.083
PROTEUS	2,800	3,510	.63	1,500	3,200	8.333
PROTEUS	2,800	3,510	.63	1,000	3,300	8.333
TYNE 1A	3,320	4,250	.49	3,110	2,800	8.667
TYNE 1C	4,160	5,300	.47	3,110	2,800	8.667
FT12A	2,220	2,840	.79	9,000	1,010	8.250
LM 1500	12,500	14,000	.575	5,500	7,500	18.667
LM 2500	22,200	22,500	.41	3,400	10,500	22.250
FT4A-2C	19,150	24,200	.52	3,600	14,200	26.000
FT4A-12	21,750	26,950	.52	3,600	14,200	26.000
FT4C-2	27,600	34,400	.48	3,600	14,200	26.000
FT9D	35,000	35,000	.40	3,600	13,400	24.750
GTPF 990	5,000	5,000	.48	16,500	4,600	10.200

APPENDIX A

COMPUTER RESULTS

The computer results of the surface effect ships studied are presented in 4 page groups. The first page lists the general ship characteristics. The second page presents a table of summary data for all the acceptable jet velocity ratios. The third page presents the complete system data for the minimum weight ratio system. The fourth page presents the complete system data for the maximum net propulsive efficiency system.

The results for the 2,000 ton SES presented are:

Length/ Beam Ratio	Cruise Speed	Hump Speed	Engine Type	Pages
4.0	80	45	FT9D	85 - 88
3.0	80	38	FT9D	93 - 96
2.0	80	30	FT9D	101 - 104
2.0	80	30	LM2500	105 - 108
1.5	80	27	FT9D	109 - 112

The results for the optimum displacement of an SES using 4 FT9D gas turbines presented are:

Length/ Beam Ratio	Cruise Speed	Hump Speed	Displacement	Pages
4.0	80	45	2050	89 - 92
3.0	80	38	2100	97 - 100
2.0	80	30	2000	101 - 104
1.5	80	27	1600	113 - 116

*** SES WATERJET PROPULSION SYSTEM WITH FLUSH INLET ***

SHIP CHARACTERISTICS

	CRUISE	HUMP
VELOCITY, KNOTS	80.0	45.0
SHIP DRAG, LBS	241000.	210000.
ACCELERATION COEFFICIENT	1.00	1.20

LENGTH-TO-BEAM RATIO....................	4.00
DISPLACEMENT, LONG TONS................	2000.
ENDURANCE, NAUTICAL MILES..............	1000.
GAS TURBINE PLANT SELECTED.............	FT 9D
REQUIRED NUMBER OF GAS TURBINES.......	4

INLET ASPECT RATIO................................	VARYING
HEIGHT OF DIFFUSER OUTLET ABOVE BASELINE.......	6.5 FEET
HEIGHT OF PUMP CENTERLINE ABOVE BASELINE.......	6.5 FEET
HEIGHT OF OUTSIDE WATERLINE ABOVE BASELINE.....	2.0 FEET

VELOCITY RATIO	WEIGHT RATIO	PROPULSIVE EFFICIENCY CRUISE (OVERALL)	PROPULSIVE EFFICIENCY CRUISE (NET)	PROPULSIVE EFFICIENCY HUMP (NET)	HORSEPOWER HUMP	HORSEPOWER CRUISE	SUCTION SPECIFIC SPEED HUMP
1.8311	0.1912	0.4987	0.4597	0.3393	21379.8	32201.5	11603.8
1.8711	0.1885	0.4979	0.4607	0.3346	21684.2	32129.0	11603.8
1.9111	0.1861	0.4966	0.4611	0.3299	21994.9	32099.0	11702.3
1.9511	0.1841	0.4950	0.4610	0.3252	22310.5	32104.8	11801.0
1.9911	0.1832	0.4930	0.4605	0.3206	22629.5	32139.9	11801.0
2.0311	0.1817	0.4907	0.4597	0.3161	22950.9	32199.8	11900.1
2.0711	0.1804	0.4882	0.4584	0.3117	23277.9	32287.0	11999.4
2.1111	0.1793	0.4855	0.4569	0.3073	23607.1	32393.5	11999.4
2.1511	0.1784	0.4826	0.4552	0.3031	23939.7	32519.6	12098.9
2.1911	0.1776	0.4795	0.4532	0.2989	24273.9	32660.8	12098.9
2.2311	0.1771	0.4764	0.4510	0.2948	24610.1	32816.4	12098.9
2.2711	0.1771	0.4731	0.4487	0.2908	24949.3	32986.5	12198.8
2.3111	0.1768	0.4698	0.4463	0.2869	25287.4	33164.5	12198.8
2.3511	0.1764	0.4663	0.4437	0.2831	25629.8	33356.6	12298.9
2.3911	0.1762	0.4629	0.4411	0.2793	25972.7	33557.5	12298.9
2.4311	0.1760	0.4594	0.4383	0.2757	26318.0	33768.1	12399.3
2.4711	0.1760	0.4558	0.4355	0.2721	26663.5	33985.7	12399.3
2.5111	0.1760	0.4523	0.4327	0.2686	27010.1	34210.3	12399.3
2.5511	0.1765	0.4487	0.4297	0.2652	27359.1	34443.2	12500.0
2.5922	0.1766	0.4452	0.4268	0.2619	27706.6	34679.2	12500.0
2.6311	0.1767	0.4416	0.4238	0.2586	28056.3	34922.6	12500.0

SYSTEM WEIGHTS AT MIN. TOTAL WEIGHT RATIO, VJVO = 2.471

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	12534.08	TRANSITION WATER ***=	0.00
FUEL ***********=	650575.38	PUMP-TO-NOZZLE PIPE =	2895.58
PUMP DRY *******=	19014.52	PUMP-TO-NOZZLE WATER=	7361.93
PUMP WATER *****=	4138.89	NOZZLE *************=	275.47
INLET SYSTEM ***=	38816.45	NOZZLE WATER *******=	533.85

TOTAL WEIGHT = 789746.00 LBS OR 352.57 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	4		
PUMP RPM-CRUISE **=	1421.28	PUMP RPM-HUMP ******=	1315.00
PUMP EFF.-CRUISE *=	89.6455	PUMP EFF.-HUMP *****=	91.0529
S. SPEC. SP.-CRUISE=	7240.23	S. SPEC. SP.-HUMP **=	12399.32
N.P.S.H.-CRUISE **=	195.39	N.P.S.H.-HUMP ******=	80.61
PUMP HEAD-CRUISE *=	1632.00	PUMP HEAD-HUMP *****=	1424.70
PUMP INLET DIA. **=	2.6869	PUMP LENGTH ********=	5.9917
FLOW COEF.-CRUISE =	0.1529	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	199.95	TIP VELO.-HUMP *****=	185.00
PUMP FLOW-CRUISE *=	157.70	PUMP FLOW-HUMP *****=	143.18

INLET DRAG-CRUISE =	11237.1	TOTAL RESIST.-CRUISE=	252237.1

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	2.9178	INLET AREA-HUMP *****=	4.7097
INLET HEIGHT-CRUISE=	0.9085	INLET HEIGHT-HUMP ***=	1.4665
INLET WIDTH *******=	3.2116	INLET DIFFUSION RATIO=	3.5349
VARIABLE AREA FACT.=	1.6141	REDUCTION GEAR RATIO =	2.5329

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	2.6364
NOZZLE INLET DIA. *=	1.3182	NOZZLE EXIT DIA. ****=	0.7755

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.3182
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************=	0.3385
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	38.4300

SYSTEM WEIGHTS AT MAX. NET PROPULSIVE EFF., VJVO = 1.911

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	16215.30	TRANSITION WATER ***=	0.00
FUEL ***********=	636251.69	PUMP-TO-NOZZLE PIPE =	3834.68
PUMP DRY *******=	27005.64	PUMP-TO-NOZZLE WATER=	11539.69
PUMP WATER *****=	6979.70	NOZZLE *************=	497.82
INLET SYSTEM ***=	82309.56	NOZZLE WATER *******=	1241.52

TOTAL WEIGHT = 839475.56 LBS OR 374.77 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	2		
PUMP RPM-CRUISE **=	1108.30	PUMP RPM-HUMP ******=	982.33
PUMP EFF.-CRUISE *=	87.8049	PUMP EFF.-HUMP *****=	91.4108
S. SPEC. SP.-CRUISE=	7253.43	S. SPEC. SP.-HUMP **=	11603.80
N.P.S.H.-CRUISE **=	195.39	N.P.S.H.-HUMP ******=	80.61
PUMP HEAD-CRUISE *=	924.11	PUMP HEAD-HUMP *****=	746.42
PUMP INLET DIA. **=	3.4413	PUMP LENGTH ********=	6.1599
FLOW COEF.-CRUISE =	0.1540	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	199.70	TIP VELO.-HUMP *****=	177.00
PUMP FLOW-CRUISE *=	260.29	PUMP FLOW-HUMP *****=	224.71

INLET DRAG-CRUISE = 18547.2 TOTAL RESIST.-CRUISE= 259547.1

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	4.8160	INLET AREA-HUMP *****=	7.3914
INLET HEIGHT-CRUISE=	1.1708	INLET HEIGHT-HUMP ***=	1.7970
INLET WIDTH *******=	4.1133	INLET DIFFUSION RATIO=	3.5131
VARIABLE AREA FACT.=	1.5348	REDUCTION GEAR RATIO =	3.2482

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	3.3007
NOZZLE INLET DIA. *=	1.6504	NOZZLE EXIT DIA. ****=	1.1329

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.6504
PUMP-TO-NOZZLE PIPE THICKNESS - FEET ***************=	0.3593
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	38.6400

*** SES WATERJET PROPULSION SYSTEM WITH FLUSH INLET ***

SHIP CHARACTERISTICS

	CRUISE	HUMP
VELOCITY, KNOTS	80.0	45.0
SHIP DRAG, LBS	247025	215250.
ACCELERATION COEFFICIENT	1.00	1.20

LENGTH-TO-BEAM RATIO....................	4.00
DISPLACEMENT, LONG TONS.................	2050.
ENDURANCE, NAUTICAL MILES...............	1000.
GAS TURBINE PLANT SELECTED..............	FT 9D
REQUIRED NUMBER OF GAS TURBINES.........	4

INLET ASPECT RATIO................................	VARYING
HEIGHT OF DIFFUSER OUTLET ABOVE BASELINE.......	6.5 FEET
HEIGHT OF PUMP CENTERLINE ABOVE BASELINE.......	6.5 FEET
HEIGHT OF OUTSIDE WATERLINE ABOVE BASELINE.....	2.0 FEET

VELOCITY RATIO	WEIGHT RATIO	PROPULSIVE EFFICIENCY CRUISE (OVERALL)	PROPULSIVE EFFICIENCY CRUISE (NET)	PROPULSIVE EFFICIENCY HUMP (NET)	HORSEPOWER HUMP	HORSEPOWER CRUISE	SUCTION SPECIFIC SPEED HUMP
1.6708	0.2076	0.4950	0.4473	0.3539	21009.7	33919.2	11310.0
1.7108	0.2021	0.4975	0.4521	0.3539	21012.7	33556.1	11310.0
1.7508	0.1976	0.4987	0.4556	0.3491	21301.5	33302.5	11407.7
1.7908	0.1937	0.4991	0.4581	0.3443	21599.8	33120.1	11505.6
1.8308	0.1904	0.4988	0.4598	0.3395	21906.0	32997.0	11603.8
1.8708	0.1877	0.4980	0.4608	0.3347	22218.0	32922.6	11603.8
1.9108	0.1853	0.4968	0.4613	0.3300	22536.3	32891.6	11702.3
1.9508	0.1832	0.4951	0.4612	0.3253	22859.7	32897.3	11801.0
1.9908	0.1824	0.4931	0.4607	0.3207	23186.6	32933.2	11801.0
2.0308	0.1808	0.4909	0.4598	0.3162	23515.9	32994.6	11900.1
2.0708	0.1795	0.4884	0.4586	0.3118	23851.1	33084.0	11999.4
2.1108	0.1784	0.4856	0.4571	0.3074	24188.5	33193.0	11999.4
2.1508	0.1775	0.4827	0.4553	0.3032	24529.4	33322.3	12098.9
2.1908	0.1767	0.4797	0.4533	0.2990	24871.9	33467.0	12098.9
2.2308	0.1761	0.4765	0.4512	0.2949	25216.4	33626.5	12098.9
2.2708	0.1762	0.4732	0.4489	0.2909	25563.7	33800.3	12198.8
2.3108	0.1758	0.4699	0.4465	0.2870	25910.2	33982.7	12198.8
2.3508	0.1754	0.4665	0.4439	0.2832	26261.1	34279.7	12298.9
2.3908	0.1752	0.4630	0.4412	0.2794	26612.5	34385.3	12298.9
2.4308	0.1750	0.4595	0.4385	0.2758	26966.4	34601.4	12399.3
2.4708	0.1750	0.4560	0.4357	0.2722	27320.6	34824.3	12399.3

SYSTEM WEIGHTS AT MIN. TOTAL WEIGHT RATIO, VJVO = 2.471

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	13021.26	TRANSITION WATER ***=	0.00
FUEL ***********=	661821.31	PUMP-TO-NOZZLE PIPE =	2658.12
PUMP DRY *******=	19565.58	PUMP-TO-NOZZLE WATER=	7747.96
PUMP WATER *****=	4296.02	NOZZLE *************=	257.37
INLET SYSTEM ***=	40291.27	NOZZLE WATER *******=	568.54

TOTAL WEIGHT = 803827.25 LBS OR 358.85 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	4		
PUMP RPM-CRUISE **=	1401.79	PUMP RPM-HUMP ******=	1298.76
PUMP EFF.-CRUISE *=	89.6633	PUMP EFF.-HUMP *****=	91.0712
S. SPEC. SP.-CRUISE=	7230.28	S. SPEC. SP.-HUMP **=	12399.32
N.P.S.H.-CRUISE **=	195.39	N.P.S.H.-HUMP ******=	80.61
PUMP HEAD-CRUISE *=	1627.96	PUMP HEAD-HUMP *****=	1427.27
PUMP INLET DIA. **=	2.7205	PUMP LENGTH ********=	6.0666
FLOW COEF.-CRUISE =	0.1531	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	199.68	TIP VELO.-HUMP *****=	185.00
PUMP FLOW-CRUISE *=	161.67	PUMP FLOW-HUMP *****=	146.79

INLET DRAG-CRUISE = 11520.0 TOTAL RESIST.-CRUISE= 258544.9

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	2.9913	INLET AREA-HUMP *****=	4.8281
INLET HEIGHT-CRUISE=	0.9199	INLET HEIGHT-HUMP ***=	1.4848
INLET WIDTH *******=	3.2517	INLET DIFFUSION RATIO=	3.5349
VARIABLE AREA FACT.=	1.6141	REDUCTION GEAR RATIO =	2.5681

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	2.7046
NOZZLE INLET DIA. *=	1.3523	NOZZLE EXIT DIA. ****=	0.7852

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.3523
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************=	0.3037
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	38.5200

SYSTEM WEIGHTS AT MAX. NET PROPULSIVE EFF., VJVO = 1.911

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	16885.86	TRANSITION WATER ***=	0.00
FUEL ***********=	648190.69	PUMP-TO-NOZZLE PIPE =	3906.29
PUMP DRY *******=	27791.28	PUMP-TO-NOZZLE WATER=	11784.31
PUMP WATER *****=	7245.72	NOZZLE *************=	513.05
INLET SYSTEM ***=	85450.69	NOZZLE WATER *******=	1284.24

TOTAL WEIGHT = 856651.94 LBS OR 382.43 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	2		
PUMP RPM-CRUISE **=	1094.55	PUMP RPM-HUMP ******=	970.16
PUMP EFF.-CRUISE *=	87.8201	PUMP EFF.-HUMP *****=	91.4285
S. SPEC. SP.-CRUISE=	7253.44	S. SPEC. SP.-HUMP **=	11603.80
N.P.S.H.-CRUISE **=	195.39	N.P.S.H.-HUMP ******=	80.61
PUMP HEAD-CRUISE *=	923.68	PUMP HEAD-HUMP *****=	746.13
PUMP INLET DIA. **=	3.4844	PUMP LENGTH ********=	6.2371
FLOW COEF.-CRUISE =	0.1540	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	199.70	TIP VELO.-HUMP *****=	177.00
PUMP FLOW-CRUISE *=	266.87	PUMP FLOW-HUMP *****=	230.39

INLET DRAG-CRUISE = 19016.1 TOTAL RESIST.-CRUISE= 266041.1

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	4.9377	INLET AREA-HUMP *****=	7.5781
INLET HEIGHT-CRUISE=	1.1856	INLET HEIGHT-HUMP ***=	1.8195
INLET WIDTH *******=	4.1649	INLET DIFFUSION RATIO=	3.5130
VARIABLE AREA FACT.=	1.5347	REDUCTION GEAR RATIO =	3.2890

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	3.3355
NOZZLE INLET DIA. *=	1.6678	NOZZLE EXIT DIA. ****=	1.1472

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.6678
PUMP-TO-NOZZLE PIPE THICKNESS - FEET ***************=	0.3622
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	38.7300

*** SES WATERJET PROPULSION SYSTEM WITH FLUSH INLET ***

SHIP CHARACTERISTICS

	CRUISE	HUMP
VELOCITY, KNOTS	80.0	38.0
SHIP DRAG, LBS	235000.	265000.
ACCELERATION COEFFICIENT	1.00	1.20

LENGTH-TO-BEAM RATIO....................	3.00
DISPLACEMENT, LONG TONS................	2000.
ENDURANCE, NAUTICAL MILES..............	1000.
GAS TURBINE PLANT SELECTED............	FT 9D
REQUIRED NUMBER OF GAS TURBINES.......	4

INLET ASPECT RATIO...............................	VARYING
HIEGHT OF DIFFUSER OUTLET ABOVE BASELINE.......	6.5 FEET
HEIGHT OF PUMP CENTERLINE ABOVE BASELINE.......	6.5 FEET
HEOGHT OF OUTSIDE WATERLINE ABOVE BASELINE.....	2.0 FEET

VELOCITY RATIO	WEIGHT RATIO	PROPULSIVE EFFICIENCY CRUISE (OVERALL)	PROPULSIVE EFFICIENCY CRUISE (NET)	PROPULSIVE EFFICIENCY HUMP (NET)	HORSEPOWER HUMP	HORSEPOWER CRUISE	SUCTION SPECIFIC SPEED HUMP
1.6860	0.1982	0.5108	0.4619	0.3166	24422.7	31244.4	13868.9
1.7260	0.1934	0.5128	0.4661	0.3128	24713.1	30964.3	13981.5
1.7660	0.1894	0.5130	0.4689	0.3066	25215.7	30779.7	14207.7
1.8060	0.1861	0.5126	0.4708	0.3006	25720.8	30657.8	14321.2
1.8460	0.1833	0.5117	0.4718	0.2948	26228.1	30588.7	14435.0
1.8860	0.1809	0.5102	0.4722	0.2891	26737.6	30564.2	14549.1
1.9260	0.1789	0.5082	0.4720	0.2837	27249.2	30577.6	14663.5
1.9660	0.1780	0.5059	0.4713	0.2785	27762.1	30623.4	14778.2
2.0060	0.1765	0.5033	0.4702	0.2734	28273.7	30693.8	14893.2
2.0460	0.1753	0.5004	0.4687	0.2685	28789.2	30792.1	15008.5
2.0860	0.1742	0.4972	0.4669	0.2638	29305.8	30911.6	15124.1
2.1260	0.1734	0.4939	0.4648	0.2592	29823.4	31049.9	15240.0
2.1660	0.1726	0.4904	0.4625	0.2548	30341.9	31204.8	15356.2
2.2060	0.1721	0.4868	0.4600	0.2505	30859.9	31373.3	15356.2
2.2460	0.1723	0.4831	0.4574	0.2464	31379.5	31555.8	15472.7
2.2860	0.1719	0.4793	0.4546	0.2424	31898.0	31747.9	15589.4
2.3260	0.1717	0.4755	0.4517	0.2385	32417.5	31951.5	15589.4
2.3660	0.1716	0.4716	0.4487	0.2347	32937.2	32164.3	15589.4
2.4060	0.1715	0.4677	0.4457	0.3211	33457.2	32385.7	15589.4
2.4460	0.1715	0.4638	0.4425	0.2275	33977.8	32614.9	15589.4
2.4860	0.1721	0.4599	0.4394	0.2241	34498.7	32851.3	15589.4

SYSTEM WEIGHTS AT MIN. TOTAL WEIGHT RATIO, VJVO = 2.406

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	12469.02	TRANSITION WATER ***=	0.00
FUEL ***********=	629295.87	PUMP-TO-NOZZLE PIPE =	2765.07
PUMP DRY *******=	19613.06	PUMP-TO-NOZZLE WATER=	7656.14
PUMP WATER *****=	4309.62	NOZZLE *************=	268.84
INLET SYSTEM ***=	38991.81	NOZZLE WATER *******=	569.11

TOTAL WEIGHT = 769538.31 LBS OR 343.54 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	4		
PUMP RPM-CRUISE **=	1389.95	PUMP RPM-HUMP ******=	1402.59
PUMP EFF.-CRUISE *=	91.0676	PUMP EFF.-HUMP *****=	91.0728
S. SPEC. SP.-CRUISE=	7314.29	S. SPEC. SP.-HUMP **=	15589.43
N.P.S.H.-CRUISE **=	189.92	N.P.S.H.-HUMP ******=	69.43
PUMP HEAD-CRUISE *=	1544.24	PUMP HEAD-HUMP *****=	1610.89
PUMP INLET DIA. **=	2.7233	PUMP LENGTH ********=	6.0730
FLOW COEF.-CRUISE =	0.1535	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	198.20	TIP VELO.-HUMP *****=	200.00
PUMP FLOW-CRUISE *=	161.26	PUMP FLOW-HUMP *****=	159.02

INLET DRAG-CRUISE = 11642.6 TOTAL RESIST.-CRUISE= 246642.6

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	2.9837	INLET AREA-HUMP *****=	6.1942
INLET HEIGHT-CRUISE=	0.9166	INLET HEIGHT-HUMP ***=	1.9029
INLET WIDTH *******=	3.2552	INLET DIFFUSION RATIO=	3.5513
VARIABLE AREA FACT.=	2.0760	REDUCTION GEAR RATIO =	2.5667

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	2.6885
NOZZLE INLET DIA. *=	1.3443	NOZZLE EXIT DIA. ****=	0.7947

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.3443
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************=	0.3175
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	38.5300

SYSTEM WEIGHTS AT MAX. NET PROPULSIVE EFF., VJVO = 1.886

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	15451.75	TRANSITION WATER ***=	0.00
FUEL ***********=	614743.81	PUMP-TO-NOZZLE PIPE =	3690.73
PUMP DRY *******=	27012.12	PUMP-TO-NOZZLE WATER=	11748.39
PUMP WATER *****=	6981.88	NOZZLE *************=	483.43
INLET SYSTEM ***=	80610.56	NOZZLE WATER *******=	1275.88

TOTAL WEIGHT = 815598.37 LBS OR 364.11 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	2		
PUMP RPM-CRUISE **=	1107.12	PUMP RPM-HUMP ******=	1054.37
PUMP EFF.-CRUISE *=	90.4507	PUMP EFF.-HUMP *****=	91.4110
S. SPEC. SP.-CRUISE=	7421.73	S. SPEC. SP.-HUMP **=	14434.96
N.P.S.H.-CRUISE **=	189.92	N.P.S.H.-HUMP ******=	69.43
PUMP HEAD-CRUISE *=	900.99	PUMP HEAD-HUMP *****=	846.04
PUMP INLET DIA. **=	3.4416	PUMP LENGTH ********=	6.1605
FLOW COEF.-CRUISE =	0.1550	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	199.51	TIP VELO.-HUMP *****=	190.00
PUMP FLOW-CRUISE *=	261.71	PUMP FLOW-HUMP *****=	241.27

INLET DRAG-CRUISE = 18894.3   TOTAL RESIST.-CRUISE= 253894.2

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	4.8421	INLET AREA-HUMP *****=	9.3979
INLET HEIGHT-CRUISE=	1.1771	INLET HEIGHT-HUMP ***=	2.2845
INLET WIDTH *******=	4.1137	INLET DIFFUSION RATIO=	3.4949
VARIABLE AREA FACT.=	1.9408	REDUCTION GEAR RATIO =	3.2517

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	3.3304
NOZZLE INLET DIA. *=	1.6652	NOZZLE EXIT DIA. ****=	1.1435

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.6652
PUMP-TO-NOZZLE PIPE THICKNESS - FEET ***************=	0.3430
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	38.6400

*** SES WATERJET PROPULSION SYSTEM WITH FLUSH INLET ***

SHIP CHARACTERISTICS

	CRUISE	HUMP
VELOCITY, KNOTS	80.0	38.0
SHIP DRAG, LBS	246750.	278250.
ACCELERATION COEFFICIENT	1.00	1.20

LENGTH-TO-BEAM RATIO....................	3.00
DISPLACEMENT, LONG TONS................	2100.
ENDURANCE, NAUTICAL MILES..............	1000.
GAS TURBINE PLANT SELECTED............	FT 9D
REQUIRED NUMBER OF GAS TURBINES.......	4

INLET ASPECT RATIO................................	VARYING
HEIGHT OF DIFFUSER OUTLET ABOVE BASELINE.......	6.5 FEET
HEIGHT OF PUMP CENTERLINE ABOVE BASELINE.......	6.5 FEET
HEIGHT OF OUTSIDE WATERLINE ABOVE BASELINE.....	2.0 FEET

VELOCITY RATIO	WEIGHT RATIO	PROPULSIVE EFFICIENCY CRUISE (OVERALL)	PROPULSIVE EFFICIENCY CRUISE (NET)	PROPULSIVE EFFICIENCY HUMP (NET)	HORSEPOWER HUMP	HORSEPOWER CRUISE	SUCTION SPECIFIC SPEED HUMP
1.6855	0.1969	0.5111	0.4622	0.3168	25622.6	32792.0	13868.9
1.7255	0.1920	0.5128	0.4664	0.3131	25927.3	32495.1	13981.5
1.7655	0.1880	0.5133	0.4692	0.3068	26454.9	32300.6	14207.7
1.8055	0.1846	0.5130	0.4711	0.3008	26985.0	32172.5	14321.2
1.8455	0.1818	0.5120	0.4721	0.2950	27517.6	32099.6	14435.0
1.8855	0.1794	0.5105	0.4725	0.2894	28052.5	32073.5	14549.1
1.9255	0.1773	0.5086	0.4723	0.2839	28589.1	32087.0	14663.5
1.9655	0.1764	0.5062	0.4716	0.2787	29127.4	32134.9	14778.2
2.0055	0.1749	0.5036	0.4705	0.2736	29664.3	32208.7	14893.2
2.0455	0.1736	0.5007	0.4690	0.2687	30205.5	32311.7	15008.5
2.0855	0.1725	0.4975	0.4672	0.2640	30747.9	32437.1	15124.1
2.1255	0.1716	0.4942	0.4651	0.2594	31292.1	32582.3	15240.0
2.1655	0.1709	0.4907	0.4628	0.2550	31835.5	32744.8	15356.2
2.2055	0.1703	0.4871	0.4603	0.2507	32379.2	32921.6	15356.2
2.2455	0.1705	0.4834	0.4577	0.2466	32924.3	33112.8	15472.7
2.2855	0.1701	0.4796	0.4549	0.2425	33468.1	33314.0	15589.4
2.3255	0.1698	0.4758	0.4520	0.2387	34013.2	33527.6	15589.4
2.3655	0.1697	0.4720	0.4490	0.2349	34558.8	33750.9	15589.4
2.4055	0.1696	0.4681	0.4460	0.2312	35104.7	33983.3	15589.4

SYSTEM WEIGHTS AT MIN. TOTAL WEIGHT RATIO, VJVO = 2.406

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	13484.79	TRANSITION WATER ***=	0.00
FUEL ***********=	652150.63	PUMP-TO-NOZZLE PIPE =	2649.30
PUMP DRY *******=	20752.09	PUMP-TO-NOZZLE WATER=	8159.50
PUMP WATER *****=	4638.94	NOZZLE *************=	264.71
INLET SYSTEM ***=	41974.09	NOZZLE WATER *******=	621.43

TOTAL WEIGHT = 798295.25 LBS OR 356.38 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	4		
PUMP RPM-CRUISE **=	1354.85	PUMP RPM-HUMP ******=	1368.58
PUMP EFF.-CRUISE *=	91.1036	PUMP EFF.-HUMP *****=	91.1088
S. SPEC. SP.-CRUISE=	7306.86	S. SPEC. SP.-HUMP **=	15589.41
N.P.S.H.-CRUISE **=	189.92	N.P.S.H.-HUMP ******=	69.43
PUMP HEAD-CRUISE *=	1540.73	PUMP HEAD-HUMP *****=	1612.49
PUMP INLET DIA. **=	2.7910	PUMP LENGTH ********=	6.2239
FLOW COEF.-CRUISE =	0.1537	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	197.99	TIP VELO.-HUMP *****=	200.00
PUMP FLOW-CRUISE *=	169.39	PUMP FLOW-HUMP *****=	167.02

INLET DRAG-CRUISE = 12228.9   TOTAL RESIST.-CRUISE= 258978.9

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	3.1340	INLET AREA-HUMP *****=	6.5058
INLET HEIGHT-CRUISE=	0.9394	INLET HEIGHT-HUMP ***=	1.9502
INLET WIDTH *******=	3.3360	INLET DIFFUSION RATIO=	3.5511
VARIABLE AREA FACT.=	2.0759	REDUCTION GEAR RATIO =	2.6305

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	2.7755
NOZZLE INLET DIA. *=	1.3878	NOZZLE EXIT DIA. ****=	0.8146

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.3878
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************=	0.2953
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	38.7200

SYSTEM WEIGHTS AT MAX. NET PROPULSIVE EFF., VJVO = 1.886

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	16741.55	TRANSITION WATER ***=	0.00
FUEL ***********=	637755.38	PUMP-TO-NOZZLE PIPE =	3835.58
PUMP DRY *******=	28586.53	PUMP-TO-NOZZLE WATER=	12237.74
PUMP WATER *****=	7517.33	NOZZLE *************=	514.07
INLET SYSTEM ***=	86803.69	NOZZLE WATER *******=	1363.28

TOTAL WEIGHT = 848954.94 LBS OR 379.00 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	2		
PUMP RPM-CRUISE **=	1080.19	PUMP RPM-HUMP ******=	1028.72
PUMP EFF.-CRUISE *=	90.4830	PUMP EFF.-HUMP *****=	91.4458
S. SPEC. SP.-CRUISE=	7422.11	S. SPEC. SP.-HUMP **=	14434.97
N.P.S.H.-CRUISE **=	189.92	N.P.S.H.-HUMP ******=	69.43
PUMP HEAD-CRUISE *=	900.22	PUMP HEAD-HUMP *****=	845.38
PUMP INLET DIA. **=	3.5274	PUMP LENGTH ********=	6.3141
FLOW COEF.-CRUISE =	0.1550	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	199.51	TIP VELO.-HUMP *****=	190.00
PUMP FLOW-CRUISE *=	274.95	PUMP FLOW-HUMP *****=	253.45

INLET DRAG-CRUISE = 19850.0 TOTAL RESIST.-CRUISE= 266600.0

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	5.0871	INLET AREA-HUMP *****=	9.8724
INLET HEIGHT-CRUISE=	1.2065	INLET HEIGHT-HUMP ***=	2.3415
INLET WIDTH *******=	4.2163	INLET DIFFUSION RATIO=	3.4946
VARIABLE AREA FACT.=	1.9407	REDUCTION GEAR RATIO =	3.3327

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	3.3991
NOZZLE INLET DIA. *=	1.6995	NOZZLE EXIT DIA. ****=	1.1722

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.6995
PUMP-TO-NOZZLE PIPE THICKNESS - FEET ***************=	0.3493
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	38.8300

*** SES WATERJET PROPULSION SYSTEM WITH FLUSH INLET ***

SHIP CHARACTERISTICS

	CRUISE	HUMP
VELOCITY, KNOTS	80.0	30.0
SHIP DRAG, LBS	230000.	325000.
ACCELERATION COEFFICIENT	1.00	1.20

LENGTH-TO-BEAM RATIO....................	2.00
DISPLACEMENT, LONG TONS................	2000.
ENDURANCE, NAUTICAL MILES..............	1000.
GAS TURBINE PLANT SELECTED............	FT 9D
REQUIRED NUMBER OF GAS TURBINES.......	4

INLET ASPECT RATIO................................	VARYING
HEIGHT OF DIFFUSER OUTLET ABOVE BASELINE.......	6.5 FEET
HEIGHT OF PUMP CENTERLINE ABOVE BASELINE.......	6.5 FEET
HEIGHT OF OUTSIDE WATERLINE ABOVE BASELINE.....	2.0 FEET

VELOCITY RATIO	WEIGHT RATIO	PROPULSIVE EFFICIENCY CRUISE (OVERALL)	PROPULSIVE EFFICIENCY CRUISE (NET)	PROPULSIVE EFFICIENCY HUMP (NET)	HORSEPOWER HUMP	HORSEPOWER CRUISE	SUCTION SPECIFIC SPEED HUMP
1.6970	0.1929	0.5181	0.4686	0.2613	28645.6	30146.9	15875.0
1.7370	0.1888	0.5188	0.4718	0.2559	29250.6	29938.0	15875.1
1.7770	0.1854	0.5183	0.4738	0.2495	29999.0	29817.5	15875.1
1.8170	0.1838	0.5170	0.4747	0.2435	30745.7	29755.6	15875.1
1.8570	0.1814	0.5152	0.4750	0.2377	31486.8	29737.8	15875.1
1.8970	0.1794	0.5129	0.4746	0.2322	32230.6	29765.2	15875.1
1.937	0.1777	0.5101	0.4736	0.2270	32973.2	29827.4	15875.1
1.9770	0.1764	0.5069	0.4722	0.2220	33714.5	29918.8	15875.1
2.0170	0.1761	0.5035	0.4703	0.2173	34454.5	30035.6	15875.1
2.0570	0.1751	0.4999	0.4682	0.2127	35190.0	30171.1	15875.1

SYSTEM WEIGHTS AT MIN. TOTAL WEIGHT RATIO, VJVO = 2.057

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	18941.25	TRANSITION WATER ***=	0.00
FUEL ***********=	601769.94	PUMP-TO-NOZZLE PIPE =	2463.90
PUMP DRY *******=	31054.92	PUMP-TO-NOZZLE WATER=	10688.15
PUMP WATER *****=	7848.17	NOZZLE *************=	290.43
INLET SYSTEM ***=	57120.17	NOZZLE WATER *******=	990.58

TOTAL WEIGHT = 784767.50 LBS OR 350.43 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	4		
PUMP RPM-CRUISE **=	994.10	PUMP RPM-HUMP ******=	1045.19
PUMP EFF.-CRUISE *=	91.3071	PUMP EFF.-HUMP *****=	91.3623
S. SPEC. SP.-CRUISE=	6108.71	S. SPEC. SP.-HUMP **=	15875.05
N.P.S.H.-CRUISE **=	185.81	N.P.S.H.-HUMP ******=	56.12
PUMP HEAD-CRUISE *=	1091.69	PUMP HEAD-HUMP *****=	1254.67
PUMP INLET DIA. **=	3.3257	PUMP LENGTH ********=	7.4162
FLOW COEF.-CRUISE =	0.1555	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	173.10	TIP VELO.-HUMP *****=	182.00
PUMP FLOW-CRUISE *=	212.80	PUMP FLOW-HUMP *****=	215.80

INLET DRAG-CRUISE =	15592.6	TOTAL RESIST.-CRUISE=	245592.6

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	3.9373	INLET AREA-HUMP *****=	10.6473
INLET HEIGHT-CRUISE=	0.9905	INLET HEIGHT-HUMP ***=	2.6785
INLET WIDTH *******=	3.9751	INLET DIFFUSION RATIO=	4.0132
VARIABLE AREA FACT.=	2.7042	REDUCTION GEAR RATIO =	3.4444

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	3.1766
NOZZLE INLET DIA. *=	1.5883	NOZZLE EXIT DIA. ****=	0.9873

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.5883
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************=	0.2411
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	40.2100

SYSTEM WEIGHTS AT MAX. NET PROPULSIVE EFF., VJVO = 1.857

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	19083.50	TRANSITION WATER ***=	0.00
FUEL ***********=	600454.69	PUMP-TO-NOZZLE PIPE =	2854.71
PUMP DRY *******=	34336.61	PUMP-TO-NOZZLE WATER=	12918.05
PUMP WATER *****=	9373.45	NOZZLE *************=	384.40
INLET SYSTEM ***=	79682.81	NOZZLE WATER *******=	1418.19

TOTAL WEIGHT = 814106.19 LBS OR 363.44 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	3		
PUMP RPM-CRUISE **=	940.48	PUMP RPM-HUMP ******=	954.73
PUMP EFF.-CRUISE *=	91.4244	PUMP EFF.-HUMP *****=	91.4904
S. SPEC. SP.-CRUISE=	6457.43	S. SPEC. SP.-HUMP **=	15875.09
N.P.S.H.-CRUISE **=	185.81	N.P.S.H.-HUMP ******=	56.12
PUMP HEAD-CRUISE *=	866.62	PUMP HEAD-HUMP *****=	934.88
PUMP INLET DIA. **=	3.6408	PUMP LENGTH ********=	7.3907
FLOW COEF.-CRUISE =	0.1564	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	179.28	TIP VELO.-HUMP *****=	182.00
PUMP FLOW-CRUISE *=	265.68	PUMP FLOW-HUMP *****=	258.63

INLET DRAG-CRUISE = 19467.1 TOTAL RESIST.-CRUISE= 249467.1

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	4.9157	INLET AREA-HUMP *****=	12.7604
INLET HEIGHT-CRUISE=	1.1296	INLET HEIGHT-HUMP ***=	2.9323
INLET WIDTH *******=	4.3517	INLET DIFFUSION RATIO=	3.8524
VARIABLE AREA FACT.=	2.5958	REDUCTION GEAR RATIO =	3.7707

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	3.4923
NOZZLE INLET DIA. *=	1.7461	NOZZLE EXIT DIA. ****=	1.1611

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.7461
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************=	0.2543
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	40.1800

*** SES WATERJET PROPULSION SYSTEM WITH FLUSH INLET ***

SHIP CHARACTERISTICS

	CRUISE	HUMP
VELOCITY, KNOTS	80.0	30.0
SHIP DRAG, LBS	230000.	325000.
ACCELERATION COEFFICIENT	1.00	1.20

LENGTH-TO-BEAM RATIO....................	2.00
DISPLACEMENT, LONG TONS................	2000.
ENDURANCE, NAUTICAL MILES.............	1000.
GAS TURBINE PLANT SELECTED............	LM 2500
REQUIRED NUMBER OF GAS TURBINES.......	6

INLET ASPECT RATIO................................	VARYING
HEIGHT OF DIFFUSER OUTLET ABOVE BASELINE.......	6.5 FEET
HEIGHT OF PUMP CENTERLINE ABOVE BASELINE.......	6.5 FEET
HEIGHT OF OUTSIDE WATERLINE ABOVE BASELINE.....	2.0 FEET

VELOCITY RATIO	WEIGHT RATIO	PROPULSIVE EFFICIENCY CRUISE (OVERALL)	PROPULSIVE EFFICIENCY CRUISE (NET)	PROPULSIVE EFFICIENCY HUMP (NET)	HORSEPOWER HUMP	HORSEPOWER CRUISE	SUCTION SPECIFIC SPEED HUMP
1.6904	0.1943	0.5186	0.4686	0.2627	18996.0	20098.4	15875.1
1.7304	0.1903	0.5194	0.4720	0.2571	19407.9	19951.9	15875.1
1.7704	0.1871	0.5190	0.4741	0.2507	19907.4	19865.8	15875.1
1.8104	0.1854	0.5178	0.4752	0.2446	20405.5	19819.7	15875.1
1.8504	0.1832	0.5161	0.4755	0.2388	20900.6	19804.5	15875.1
1.8904	0.1813	0.5138	0.4752	0.2332	21396.9	19819.6	15875.1
1.9304	0.1797	0.5110	0.4742	0.2279	21892.6	19858.4	15875.1
1.9704	0.1784	0.5079	0.4728	0.2229	22387.4	19917.5	15875.1

SYSTEM WEIGHTS AT MIN. TOTAL WEIGHT RATIO, VJVO = 1.970

ENGINE *********=	63000.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	14437.49	TRANSITION WATER ***=	0.00
FUEL ***********=	606390.25	PUMP-TO-NOZZLE PIPE =	4398.90
PUMP DRY *******=	28566.59	PUMP-TO-NOZZLE WATER=	21101.11
PUMP WATER *****=	6517.64	NOZZLE *************=	274.53
INLET SYSTEM ***=	53386.62	NOZZLE WATER *******=	1025.30

TOTAL WEIGHT = 799098.12 LBS OR 356.74 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	3		
PUMP RPM-CRUISE **=	1188.33	PUMP RPM-HUMP ******=	1233.62
PUMP EFF.-CRUISE *=	91.1260	PUMP EFF.-HUMP *****=	91.1228
S. SPEC. SP.-CRUISE=	6236.98	S. SPEC. SP.-HUMP **=	15875.07
N.P.S.H.-CRUISE **=	185.81	N.P.S.H.-HUMP ******=	56.12
PUMP HEAD-CRUISE *=	985.85	PUMP HEAD-HUMP *****=	1109.00
PUMP INLET DIA. **=	2.8177	PUMP LENGTH ********=	5.7199
FLOW COEF.-CRUISE =	0.1561	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	175.32	TIP VELO.-HUMP *****=	182.00
PUMP FLOW-CRUISE *=	155.24	PUMP FLOW-HUMP *****=	154.91
INLET DRAG-CRUISE =	17062.6	TOTAL RESIST.-CRUISE=	247062.6

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	4.3085	INLET AREA-HUMP *****=	11.4645
INLET HEIGHT-CRUISE=	1.0445	INLET HEIGHT-HUMP ***=	2.7794
INLET WIDTH *******=	4.1248	INLET DIFFUSION RATIO=	3.9490
VARIABLE AREA FACT.=	2.6609	REDUCTION GEAR RATIO =	2.7561
TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	2.8269
NOZZLE INLET DIA. *=	1.4135	NOZZLE EXIT DIA. ****=	0.8618

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.4135
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************=	0.1943
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	34.9600
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 3 - FEET *****=	69.9200

SYSTEM WEIGHTS AT MAX. NET PROPULSIVE EFF., VJVO = 1.850

ENGINE *********=	63000.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	14422.69	TRANSITION WATER ***=	0.00
FUEL ***********=	606904.63	PUMP-TO-NOZZLE PIPE =	4751.68
PUMP DRY *******=	32557.20	PUMP-TO-NOZZLE WATER=	23838.26
PUMP WATER *****=	7729.71	NOZZLE *************=	322.43
INLET SYSTEM ***=	65865.75	NOZZLE WATER *******=	1286.49

TOTAL WEIGHT = 820678.62 LBS OR 366.37 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	3		
PUMP RPM-CRUISE **=	1147.84	PUMP RPM-HUMP ******=	1165.44
PUMP EFF.-CRUISE *=	91.1287	PUMP EFF.-HUMP *****=	91.2057
S. SPEC. SP.-CRUISE=	6461.38	S. SPEC. SP.-HUMP **=	15875.06
N.P.S.H.-CRUISE **=	185.81	N.P.S.H.-HUMP ******=	56.12
PUMP HEAD-CRUISE *=	853.96	PUMP HEAD-HUMP *****=	923.48
PUMP INLET DIA. **=	2.9825	PUMP LENGTH ********=	6.0545
FLOW COEF.-CRUISE =	0.1567	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	179.25	TIP VELO.-HUMP *****=	182.00
PUMP FLOW-CRUISE *=	178.58	PUMP FLOW-HUMP *****=	173.56

INLET DRAG-CRUISE = 19627.4   TOTAL RESIST.-CRUISE = 249627.

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	4.9562	INLET AREA-HUMP *****=	12.8451
INLET HEIGHT-CRUISE=	1.1351	INLET HEIGHT-HUMP ***=	2.9420
INLET WIDTH *******=	4.3661	INLET DIFFUSION RATIO=	3.8464
VARIABLE AREA FACT.=	2.5917	REDUCTION GEAR RATIO =	2.9173

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	3.0047
NOZZLE INLET DIA. *=	1.5023	NOZZLE EXIT DIA. ****=	0.9536

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.5023
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************=	0.1976
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	35.3800
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 3 - FEET *****=	70.7600

*** SES WATERJET PROPULSION SYSTEM WITH FLUSH INLET ***

SHIP CHARACTERISTICS

	CRUISE	HUMP
VELOCITY, KNOTS	80.0	27.0
SHIP DRAG, LBS	223000.	440000.
ACCELERATION COEFFICIENT	1.00	1.20

LENGTH-TO-BEAM RATIO....................	1.50
DISPLACEMENT, LONG TONS.................	2000.
ENDURANCE, NAUTICAL MILES...............	1000.
GAS TURBINE PLANT SELECTED..............	FT 9D
REQUIRED NUMBER OF GAS TURBINES.......	6

INLET ASPECT RATIO...............................	VARYING
HEIGHT OF DIFFUSER OUTLET ABOVE BASELINE.......	6.5 FEET
HEIGHT OF PUMP CENTERLINE ABOVE BASELINE.......	6.5 FEET
HEIGHT OF OUTSIDE WATERLINE ABOVE BASELINE.....	2.0 FEET

VELOCITY RATIO	WEIGHT RATIO	PROPULSIVE EFFICIENCY CRUISE (OVERALL)	PROPULSIVE EFFICIENCY CRUISE (NET)	PROPULSIVE EFFICIENCY HUMP (NET)	HORSEPOWER HUMP	HORSEPOWER CRUISE	SUCTION SPECIFIC SPEED HUMP
1.7039	0.2649	0.5154	0.4663	0.2182	27861.7	19580.0	15990.9
1.7439	0.2616	0.5136	0.4673	0.2118	28712.6	19538.8	15991.0
1.7839	0.2603	0.5103	0.4666	0.2059	29535.3	19568.6	15991.0
1.8239	0.2580	0.5066	0.4653	0.2003	30350.4	19624.1	15991.0
1.8639	0.2560	0.5025	0.4633	0.1951	31166.3	19706.7	15991.0
1.9039	0.2555	0.4980	0.4609	0.1901	31979.4	19809.5	15991.0
1.9439	0.2540	0.4934	0.4582	0.1855	32785.9	19926.5	15991.0
1.9839	0.2527	0.4886	0.4552	0.1810	33593.7	20061.1	15991.0
2.0239	0.2515	0.4837	0.4518	0.1768	34399.4	20208.5	15991.0

SYSTEM WEIGHTS AT MIN. TOTAL WEIGHT RATIO, VJVO = 2.024

ENGINE *********=	80400.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	25180.83	TRANSITION WATER ***=	0.00
FUEL ***********=	895881.56	PUMP-TO-NOZZLE PIPE =	5242.38
PUMP DRY *******=	39466.41	PUMP-TO-NOZZLE WATER=	23546.81
PUMP WATER *****=	9102.52	NOZZLE *************=	259.08
INLET SYSTEM ***=	46238.93	NOZZLE WATER *******=	896.96

TOTAL WEIGHT = 1126215.00 LBS OR 502.77 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	5		
PUMP RPM-CRUISE **=	933.95	PUMP RPM-HUMP ******=	1126.75
PUMP EFF.-CRUISE *=	87.9944	PUMP EFF.-HUMP *****=	91.1978
S. SPEC. SP.-CRUISE=	4711.12	S. SPEC. SP.-HUMP ***=	15990.97
N.P.S.H.-CRUISE **=	184.86	N.P.S.H.-HUMP ******=	51.39
PUMP HEAD-CRUISE *=	1053.93	PUMP HEAD-HUMP *****=	1600.55
PUMP INLET DIA. **=	2.96630	PUMP LENGTH ********=	7.2080
FLOW COEF.-CRUISE =	0.1560	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	145.05	TIP VELO.-HUMP *****=	175.00
PUMP FLOW-CRUISE *=	142.30	PUMP FLOW-HUMP *****=	165.08

INLET DRAG-CRUISE = 15725.8 TOTAL RESIST.-CRUISE = 238725.

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	3.9492	INLET AREA-HUMP *****=	13.5744
INLET HEIGHT-CRUISE=	0.9095	INLET HEIGHT-HUMP ***=	3.1260
INLET WIDTH *******=	4.3424	INLET DIFFUSION RATIO=	4.7747
VARIABLE AREA FACT.=	3.4372	REDUCTION GEAR RATIO =	3.1950

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	2.7222
NOZZLE INLET DIA. *=	1.3611	NOZZLE EXIT DIA. ****=	0.8140

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.3611
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************=	0.1997
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	39.9500
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 3 - FEET *****=	79.9000

SYSTEM WEIGHTS AT MAX. NET PROPULSIVE EFF., VJVO = 1.744

ENGINE *********=	80400.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	24947.88	TRANSITION WATER ***=	0.00
FUEL ***********=	893486.69	PUMP-TO-NOZZLE PIPE =	6687.61
PUMP DRY *******=	43746.89	PUMP-TO-NOZZLE WATER=	31359.61
PUMP WATER *****=	11363.47	NOZZLE *************=	403.85
INLET SYSTEM ***=	77005.31	NOZZLE WATER *******=	1539.98

TOTAL WEIGHT = 1170941.00 LBS OR 522.74 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	3		
PUMP RPM-CRUISE **=	869.32	PUMP RPM-HUMP ******=	985.54
PUMP EFF.-CRUISE *=	90.4186	PUMP EFF.-HUMP *****=	91.3901
S. SPEC. SP.-CRUISE=	5197.81	S. SPEC. SP.-HUMP ***=	15990.96
N.P.S.H.-CRUISE **=	184.86	N.P.S.H.-HUMP ******=	51.39
PUMP HEAD-CRUISE *=	750.60	PUMP HEAD-HUMP *****=	1018.72
PUMP INLET DIA. **=	3.3913	PUMP LENGTH ********=	6.8843
FLOW COEF.-CRUISE =	0.1576	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	154.36	TIP VELO.-HUMP *****=	175.00
PUMP FLOW-CRUISE *=	199.93	PUMP FLOW-HUMP *****=	215.77

INLET DRAG-CRUISE = 22094.8   TOTAL RESIST.-CRUISE= 245094.8

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	5.5487	INLET AREA-HUMP *****=	17.7430
INLET HEIGHT-CRUISE=	1.1177	INLET HEIGHT-HUMP ***=	3.5739
INLET WIDTH *******=	4.9646	INLET DIFFUSION RATIO=	4.4419
VARIABLE AREA FACT.=	3.1977	REDUCTION GEAR RATIO =	3.6528

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	3.1415
NOZZLE INLET DIA. *=	1.5707	NOZZLE EXIT DIA. ****=	1.0394

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************= 1.5707
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************= 0.2208
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****= 0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****= 39.5400
PUMP TO NOZZLE PIPE LENGTH FOR SYSTEM 3 - FEET *****= 79.0900

*** SES WATERJET PROPULSION SYSTEM WITH FLUSH INLET ***

SHIP CHARACTERISTICS

	CRUISE	HUMP
VELOCITY, KNOTS	80.0	27.0
SHIP DRAG, LBS	178400.	352000.
ACCELERATION COEFFICIENT	1.00	1.20

LENGTH-TO-BEAM RATIO..................	1.50
DISPLACEMENT, LONG TONS...............	1600.
ENDURANCE, NAUTICAL MILES.............	1000.
GAS TURBINE PLANT SELECTED............	FT 9D
REQUIRED NUMBER OF GAS TURBINES.......	4

INLET ASPECT RATIO...............................	VARYING
HEIGHT OF DIFFUSER OUTLET ABOVE BASELINE.......	6.5 FEET
HEIGHT OF PUMP CENTERLINE ABOVE BASELINE.......	6.5 FEET
HEIGHT OF OUTSIDE WATERLINE ABOVE BASELINE.....	2.0 FEET

VELOCITY RATIO	WEIGHT RATIO	PROPULSIVE EFFICIENCY CRUISE (OVERALL)	PROPULSIVE EFFICIENCY CRUISE (NET)	PROPULSIVE EFFICIENCY HUMP (NET)	HORSEPOWER HUMP	HORSEPOWER CRUISE	SUCTION SPECIFIC SPEED HUMP
1.7020	0.2349	0.5166	0.4674	0.2190	33322.2	23444.4	15991.0
1.7420	0.2318	0.5146	0.4681	0.2124	34355.0	23407.6	15991.0

SYSTEM WEIGHTS AT MIN. TOTAL WEIGHT RATIO, VJVO = 1.742

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	22721.66	TRANSITION WATER ***=	0.00
FUEL ***********=	623358.63	PUMP TO NOZZLE PIPE =	2040.02
PUMP DRY *******=	36053.78	PUMP TO NOZZLE WATER=	12913.31
PUMP WATER *****=	9989.48	NOZZLE *************=	271.66
INLET SYSTEM ***=	67756.37	NOZZLE WATER *******=	1389.79

TOTAL WEIGHT = 830094.50 LBS OR 370.58 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	3		
PUMP RPM-CRUISE **=	790.19	PUMP RPM-HUMP ******=	898.74
PUMP EFF.-CRUISE *=	90.5610	PUMP EFF.-HUMP *****=	91.5201
S. SPEC. SP.-CRUISE=	5182.56	S. SPEC. SP.-HUMP **=	15990.97
N.P.S.H.-CRUISE **=	184.86	N.P.S.H.-HUMP ******=	51.39
PUMP HEAD-CRUISE *=	743.67	PUMP HEAD-HUMP *****=	1020.71
PUMP INLET DIA. **=	3.7188	PUMP LENGTH ********=	7.5492
FLOW COEF.-CRUISE =	0.1582	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	153.86	TIP VELO.-HUMP *****=	175.00
PUMP FLOW-CRUISE *=	240.56	PUMP FLOW-HUMP *****=	259.46

INLET DRAG-CRUISE =	17723.3	TOTAL RESIST.-CRUISE=	196123.3

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	4.4509	INLET AREA-HUMP *****=	14.2239
INLET HEIGHT-CRUISE=	1.0013	INLET HEIGHT-HUMP ***=	3.1999
INLET WIDTH *******=	4.4450	INLET DIFFUSION RATIO=	4.4392
VARIABLE AREA FACT.=	3.1958	REDUCTION GEAR RATIO =	4.0056

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH ****** =	3.4917
NOZZLE INLET DIA. *=	1.7468	NOZZLE EXIT DIA. *** =	1.1407

PUMP-TO-NOZZLE PIPE DIAMETER - FEET *************** =	1.7458
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES ************ =	0.1824
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET **** =	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET **** =	40.3700

SYSTEM WEIGHTS AT MAX. NET PROPULSIVE EFF., VJVO = 1.742

ENGINE *********=	53600.00	TRANSITION PIPE ****=	0.00
REDUCTION GEAR *=	22759.80	TRANSITION WATER ***=	0.00
FUEL ***********=	623272.38	PUMP-TO-NOZZLE PIPE =	1949.68
PUMP DRY *******=	36053.78	PUMP-TO-NOZZLE WATER=	13001.01
PUMP WATER *****=	9989.48	NOZZLE *************=	259.97
INLET SYSTEM ***=	67756.37	NOZZLE WATER *******=	1398.68

TOTAL WEIGHT = 830040.87 LBS OR 370.55 LONG TONS

PUMP DATA

NUMBER OF STAGES *=	3		
PUMP RPM-CRUISE **=	789.63	PUMP RPM-HUMP ******=	898.74
PUMP EFF.-CRUISE *=	90.5610	PUMP EFF.-HUMP *****=	91.5201
S. SPEC. SP.-CRUISE=	5178.90	S. SPEC. SP.-HUMP **=	15990.97
N.P.S.H.-CRUISE **=	184.86	N.P.S.H.-HUMP ******=	51.39
PUMP HEAD-CRUISE *=	743.22	PUMP HEAD-HUMP *****=	1022.43
PUMP INLET DIA. **=	3.7188	PUMP LENGTH ********=	7.5492
FLOW COEF.-CRUISE =	0.1583	FLOW COEF.-HUMP ****=	0.1500
TIP VELO.-CRUISE *=	153.75	TIP VELO.-HUMP *****=	175.00
PUMP FLOW-CRUISE *=	240.56	PUMP FLOW-HUMP *****=	259.46

INLET DRAG-CRUISE = 17723.3   TOTAL RESIST.-CRUISE= 196123.3

MISCELLANEOUS SYSTEM DATA

INLET AREA-CRUISE *=	4.4509	INLET AREA-HUMP *****=	14.2239
INLET HEIGHT CRUISE=	1.0013	INLET HEIGHT HUMP ***=	3.1999
INLET WIDTH *******=	4.4450	INLET DIFFUSION RATIO=	4.4392
VARIABLE AREA FACT.=	3.1958	REDUCTION GEAR RATIO =	4.0056

TRANS. PIPE LENGTH =	0.0000	NOZZLE LENGTH *******=	3.5035
NOZZLE INLET DIA. *=	1.7517	NOZZLE EXIT DIA. ****=	1.1407

PUMP-TO-NOZZLE PIPE DIAMETER - FEET ****************=	1.7517
PUMP-TO-NOZZLE PIPE THICKNESS - INCHES *************=	0.1738
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 1 - FEET *****=	0.0000
PUMP-TO-NOZZLE PIPE LENGTH FOR SYSTEM 2 - FEET *****=	40.3700

APPENDIX B

COMPUTER PROGRAM DESCRIPTION

This waterjet optimization computer program for surface effect ships is a modified and expanded version of the computer program presented in reference 6. This program optimizes the waterjet system on a basis of maximum net propulsive efficiency or minimum system weight ratio. It also is capable of optimizing the displacement of the ship for a given number of specified engines. The computer program consists of the main program and four subroutines. The characteristics of up to fifteen different engines can be stored in the main program.

After reading in the ship data and selecting the engines and inlet system, the main program call subroutine SESIN. This subroutine computes the inlet system internal efficiency, inlet drag coefficient and the ratio of entering water momentum velocity to ship speed at hump and cruise speeds. This subroutine is essentially a computerization of Figures 19 through 26.

The main program then computes the approximate jet velocity for maximum overall propulsive efficiency. Using this jet velocity ratio, an assumed efficiency (pump and reduction gear) of .865 and neglecting the pump-to-nozzle pipe, the program computes the number of engines required.

With the number of engines known, the flow rate per system is determined and subroutine PIPE is called. Subroutine PIPE returns the head loss due to the pump-to-nozzle piping. The main program then recomputes the number of engines required.

The jet velocity ratio is the only system variable. The velocity ratio is increased in steps and subroutines PIPE and PUMP are called respectively. Subroutine PIPE returns the optimum characteristics of the pump-to-nozzle pipe and the head losses due to the pipe at hump and cruise speeds. Subroutine PUMP returns all the system data. A summary of this data, including the system weight ratio and net propulsive efficiency, is stored in an array in the main program. The jet velocity ratio is increased until either the number of required pump stages exceeds six or the required power at hump or cruise speed exceeds the available power. The program then prints out a table of summary data for every jet velocity ratio. Finally, the program recalculates and prints out all the system data for the minimum weight ratio system and the system with the maximum net propulsive efficiency.

At this point, the program will either go to the next set of input data or it will optimize the displacement. This option is controlled by the variable KK.

If displacement optimization is desired, the program

will check the slope of the weight-to-drag ratio versus the jet velocity ratio curve at the point when a limiting constraint is reached. If the slope is positive the displacement will be increased and if the slope is negative the displacement will be decreased. New drags are then determined using a constant lift-to-drag ratio. The entire program is then repeated for the new displacement and drags. This process will continue until the minimum weight ratio is found.

Subroutine PUMP uses the equations developed in Chapters 2 and 3 to define the basic pump characteristics and performance. The subroutine designs the pump at hump speed to meet the constraints of blade tip velocity and suction specific speed. The pump efficiency is then determined by the pump diameter and a test is made to determine if sufficient power is available to accelerate through the hump region. Next, the cruise performance is calculated and the constraints of blade tip velocity, suction specific speed and available power are checked. If these constraints are not satisfied, the blade tip velocity at hump speed is decreased and entire pump design process is repeated.

Once the pump is determined, subroutine WEIGHT is called. Subroutine WEIGHT returns the system weights according to equations developed in Chapter 3.

APPENDIX C

COMPUTER PROGRAM USER'S GUIDE

This program has two arrays available for storing the characteristics of fifteen different engines. The characteristics are entered in two card groups, thus thirty cards are required. The characteristics of fourteen gas turbines are listed in Table 1. If fifteen engines are not required, blank cards can be used to fill the remainder of the thirty cards. The engine characteristics cards consist of fifteen groups of two cards containing:

Card 1 - Name of the engine
The format for this card is 3A4.

Card 2 - PERF(IENG, 1) - Normal SHP
PERF(IENG, 2) - Maximum SHP
PERF(IENG, 3) - SFC at normal SHP
PERF(IENG, 4) - RPM of engine
PERF(IENG, 5) - Weight of engine
PERF(IENG, 6) - Length of engine
The format for this card is 6F10.3.

Following the thirty engine characteristics cards, the user must input two cards to describe the inlet systems that can be used. In this program the inlet systems available are a 2.5 aspect ratio inlet and a varying aspect ratio inlet.

Card 31 - 2.5
Card 32 - VARYING
The format for cards 31 and 32 is 2A4.

Next the user must input three cards for each waterjet system. There is no limit to the number of different systems that can be designed in a single computer run as long as the engine characteristics are entered somewhere in cards 1 through 30.

Card 33 - IENG - The type of engine selected corresponding to its position among the fifteen engines described in cards 1 through 30.

IAR - The type of inlet system selected. 1 for a 2.5 aspect ratio inlet 2 for a varying aspect ratio inlet

NGT - The number of engines to be used. If this space is left blank, the program will determine the number of engines required.

KK - If KK = 2, the program will optimize the ship displacement. If KK $\neq$ 2, the program will optimize the waterjet design for the given displacement only.

KINCRE - The size of the displacement increment as a fraction of the total original displacement. This space may be left blank if KK $\neq$ 2.

The format for this card is 5I5.

Card 34 - HEP - The height of the pump above the inlet in feet.

HEW - The height of the outside waterline above the inlet in feet.

CAC - The acceleration coefficient required at hump speed.

XLENG(1) - The length of the pump-to-nozzle pipe for system 1.

The format for this card is 4F10.2.

Card 35 - VO(1) - Cruise speed in knots
VO(2) - Hump speed in knots
DRAG(1) - Hull drag at cruise speed
DRAG(2) - Hull drag at hump speed
DISP - Ship displacement in long tons
RANGE - Range in nautical miles
XLTOB - Length-to-beam ratio
The format of this card is 7F10.2.

Final Card - This card is left blank

A sample input data deck to optimize three different waterjet systems is shown on pages 158 and 159. This data deck will produce results for three 2,000 ton surface effect ships. A brief summary of the characteristics of the three ships are:

Ship	Length/ Beam Ratio	Type Engine	Optimize Displacement
1	4.0	FT9D	Yes
2	2.0	LM2500	Yes
3	1.5	FT9D	No

APPENDIX D

COMPUTER PROGRAM

LIST OF PROGRAM VARIABLES

A	The individual waterjet system for which the pump is designed	
AAJET	Jet area per pump	ft^2/pump
AD	Diffuser outlet area	ft^2
AINLET	Inlet area at cruise speed	ft^2
AJET	Total jet area	ft^2
APUP	Pump inlet area	ft^2
AR	Inlet aspect ratio	
ASPRT(I,J)	Variable used to print out type of inlet aspect ratio 1 for 2.5 aspect ratio inlets 2 for varying aspect ratio inlets	
C	The square of the ratio of the momentum velocity of entering water to the ship velocity (CU)	
CA	Coefficient used in determining RX	
CAC	Acceleration coefficient at hump speed	
CAC1	Acceleration coefficient at cruise speed	
CAL	Ratio of ship drag to displacement	
CB	Coefficient used in determining RX	
CDIN1	Inlet drag coefficient at cruise speed	
CDIN(I)	Inlet drag coefficient	
COR1	Correction factor for ETAOA(1)	
COR2	Correction factor for ETAOA(2)	

CORRD	Correction factor for CDIN(I)	
CORRN	Correction factor for ETAOA(1)	
CU	Ratio of momentum velocity of inlet water to ship velocity	
CW	Pump weight coefficient	
CWIN	Inlet system weight coefficient	
D1	Variable used to determine nozzle weights	
D2	Variable used to determine nozzle weights	
DCOF	Inlet drag coefficient (subroutine WEIGHT)	
DEL	Increment of change in jet velocity ratio (MAIN program)	
DEL	Increment of change in pump-to-nozzle pipe diameter (subroutine PIPE)	
DIS(1)	Displacement after removing fuel	lb
DISP	Displacement - entered in long tons converted to pounds	
DISPIN	Amount of change in ship displacement used in ship displacement optimization	tons
DISP1	New ship displacement used in ship displacement optimization	tons
DJET	Diameter of nozzle exit	ft
DPIPE	Diameter of pump-to-nozzle pipe	ft
DR	Diffusion ratio	
DRAG(I)	Ship drag	lb
DRAT	Ratio of pump inlet hub radius to blade tip radius	
EFFNOZ	Efficiency of nozzle	

ENGN(IJ,IENG)	Variable used to print out type of engine selected	
ETA1	η_{OA}, at cruise speed	
ETA2	η_{OA}, at hump speed	
ETAOA(I)	η_{OA}	
ETAP(I)	Pump efficiency	
ETAX	Ratio of off-design point pump efficiency to design point efficiency	
ETERM	Variable used in determining fuel weight	
FACT	Variable used in determining the jet velocity ratio at hump speed	
G	Acceleration due to gravity	ft/sec^2
GERAT	Reduction gear ratio	
H(I)	Head loss due to difference in height between pump inlet and diffuser exit	ft
HA	Atmospheric pressure head	ft
HE	Height of diffuser outlet above baseline	ft
HEP	Height of pump above baseline	ft
HEPHE	Length of transition pipe	ft
HEW	Height of outside waterline above baseline	ft
HIN	Inlet height at cruise speed	ft
HIN2	Inlet height at hump speed	ft
HPIPE(I)	Head loss in pump-to-nozzle pipe	ft
HPP(I)	Head across pump	ft
HSV(I)	Net positive suction head	ft

HX	Ratio of pump head at cruise to pump head at hump
(I)	Indicates ship velocity 1 for cruise speed 2 for hump speed
IAR	Input to program 1 for 2.5 aspect ratio inlets 2 for varying aspect ratio inlets
ICONT	Program control
IENGN	Type of gas turbine 1 - TF 35 2 - TF 40 3 - Proteus, 1,500 RPM 4 - Proteus, 1,000 RPM 5 - Tyne 1A 6 - Tyne 1C 7 - FT12A 8 - LM 1500 9 - LM 2500 10 - FT4A-2C 11 - FT4A-12 12 - FT4C-2 13 - FT9D 14 - GTPF 990 15 - Unused space
IMAX	Program control
INIT	Program control
IPRINT	Output device number
IREAD	Input device number
ISTEER	Program control
IWVJ	Program control
KK	Program control
KKK	Program control
KINCRE	The size of the displacement increment as a fraction of the total original ship displacement

KOUT	Program control	
LAST	Program control	
M	Program control	
MN	Program control	
NGT	Number of gas turbines	
NSTG	Number of pump stages	
PC(L,M)	Inducer stage characteristics	
PCA(L,M)	Axial stages characteristics	
PC1MAX	Maximum overall propulsive coefficient	
PC2MAX	Maximum net propulsive coefficient	
PC1VJ	Jet velocity ratio for PC1MAX	
PC2VJ	Jet velocity ratio for PC2MAX	
PCOEF(J,K)	Pump length and weight coefficients	
PERF(N,IENGN)	Engine data where N is:	
	1 - Normal SHP	HP
	2 - Maximum SHP	HP
	3 - SFC at normal SHP	lb/HP-hr
	4 - RPM	rpm
	5 - Weight of engine (dry)	lb
	6 - Engine length	ft
PHI	Pump flow coefficient at hump speed	
PHI1	Pump flow coefficient at cruise speed	
PI	Constant = 3.1415927	
PIDIA	Pump inlet diameter	ft
PLP	Pump length	ft
PRC(I)	Propulsive coefficient (overall)	
PRC1	Propulsive coefficient (overall) at cruise speed (MAIN program)	

PRNC1	Net propulsive coefficient at cruise speed	
PRNC2	Net propulsive coefficient at hump speed	
Q(I)	Flow rate through system	ft^3/sec
QQ(I)	Flow rate through each pump	ft^3/sec
QQ1PC2	Flow rate through each pump at the jet velocity ratio for the maximum net propulsive efficiency system	ft^3/sec
QQ1WVJ	Flow rate through each pump at the jet velocity ratio for the minimum weight ratio system	ft^3/sec
QX	Ratio of flow rate at cruise speed to the flow rate at hump speed	
RANGE	Ship range	nautical miles
RESIST	Total resistance of ship including inlet drag	lb
RHOT	Density of titanium	$slug/ft^3$
RHOW	Density of water	$slug/ft^3$
RNSTG	Variable used in determining the number of pump stages	
RPM(I)	Pump RPM	rpm
RPM2	Pump RPM at hump speed	rpm
RQ	Reduction gear Q-factor	
RTIP	Pump inlet tip radius	ft
RX	Ratio of pump RPM at cruise speed to RPM at hump speed	
SCONT	Variable used in determining fuel weight	
SFC	Specific fuel consumption	lb/HP-hr

SHI	Pump head coefficient	
SHNG	Shaft horsepower required after fuel is removed	HP
SHP(I)	Shaft horsepower	HP
SSS1	Suction specific speed at cruise speed	
SSS2	Suction specific speed at hump speed	
STRESS	Maximum allowable normal stress in pump-to-nozzle pipe	lb/in^2
THICK	Thickness of pump-to-nozzle pipe	in
TI	Time interval for fuel consumption calculation	
VAF	Variable area factor (ratio of inlet area at hump speed to inlet area at cruise speed)	
VISC	Viscosity of water	ft^2/hr
VJ	Jet velocity	ft/sec
VJVO(I)	Jet velocity ratio	
VO(I)	Ship velocity	
	Input and subroutine SESIN	knots
	Remainder of program	ft/sec
VOTERM	Variable used in determining fuel weight	
VTIP(I)	Pump blade tip velocity	ft/sec
WIDTH	Width of inlet opening	ft
WT(K)	Weight of fuel required for one time period	lb
WTMIN	Minimum weight ratio	
WTOT	Total system weight	lb

WTOTLT	Total system weight	long tons
WTRAT	Weight ratio	
WVJ	Jet velocity ratio for minimum weight ratio	
XDRAG	Inlet system drag	lb
XK	Reduction gear K-factor	
XLBSHP	Ratio of waterjet system weight to shaft horsepower required	
XLENG(II)	Pump-to-nozzle pipe length for system II	ft
XLENGP	Estimated pump-to-nozzle length used in determining number of gas turbines required	ft
XLN	Nozzle length	ft
XLTOB	Ship length-to-beam ratio	
XN	Factor for SFC versus power curve	
XNGT	Number of gas turbines	
XWD	Pump dry weight	lb
XWENG	Weight of engines	lb
XWF	Total fuel weight	lb
XWGR	Weight of reduction gears	lb
XWIN	Weight of inlet systems	lb
XWPIP	Weight of transition pipes	lb
XWPIW	Weight of water in transition pipes	lb
XWPN(II)	Weight of pump-to-nozzle pipe for system II	lb
XWPNO	Total weight of pump-to-nozzle pipe	lb
XWW	Weight of water in pumps	lb

XWWN(II)	Weight of water in pump-to-nozzle piping for system II	lb
XWWNO	Total weight of water in pump-to-nozzle piping	lb
XWNOZ	Total weight of nozzles	lb
XWNOW	Total weight of water in nozzles	lb
XX(J,K)	Main program outputs	
	1 - Jet velocity ratio	
	2 - Weight ratio	
	3 - Overall propulsive efficiency	
	4 - Net propulsive efficiency at cruise speed	
	5 - Net propulsive efficiency at hump speed	
	6 - Shaft horsepower at hump speed	HP
	7 - Shaft horsepower at cruise speed	HP
	8 - Suction specific speed at hump speed	
	9 - Pump RPM at hump speed	rpm
	10 - Number of pump stages	
XXLP	Pump length coefficient	
ZERO	Variable used to iterant the final pump-to-nozzle pipe diameter	

```
C     MAIN PROGRAM
      COMMON/PIP/DPIPE,THICK,HPIPE(2),QQ1WVJ,XLENG(5),QQ1PC2
      COMMON/COEF/DCOF,ENETA,AJET,DJET
      COMMON/POUT/PRC1,SSS2,RPM2,SSS1
      COMMON/INDEX/IAR,IPRINT,IREAD,IENGN,NSTG,LAST,INIT
      COMMON/PARIN/ETA1,ETA2,CU,CORRN,CORRD,CDIN1
      COMMON/VELOC/VO(2),VJVO(2)
      COMMON CWIN
      COMMON/HEAD/HA,HEW,HEP,Q(2),QQ(2),HE,H(2)
      COMMON/PUM/RTIP,RPM(2),ETAP(2),DRAT,HSV(2),HPP(2)
      COMMON/XNOZ/XLENGP,PLP,XLN,EFFNOZ
      COMMON/PERFO/PERF(6,15),WTRAT,XNGT,ENGN(3,15),ASPRT(2,2)
      COMMON/CONST/PI,G,RHOW,RHOT,XK,VISC,XLBSHP
      COMMON/PUMA/CAC,COR1,COR2
      COMMON/SHIP/DISP,RANGE,DRAG(2)
      COMMON/WEMA/APUP,GERAT,SHP(2)
      DIMENSION ETAOA(2),CDIN(2),XX(25,10),PRC(2)
C
      IREAD=8
      IPRINT=5
C
      DO 2 K=1,15
      READ(IREAD,1005)(ENGN(I,K),I=1,3)
      READ(IREAD,1004)(PERF(I,K),I=1,6)
 1004 FORMAT(6F10.3)
 1005 FORMAT(3A4)
    2 CONTINUE
      READ(IREAD,1006)(ASPRT(I,1),I=1,2)
      READ(IREAD,1006)(ASPRT(I,2),I=1,2)
 1006 FORMAT(2A4)
C     READ IN INPUT DATA
    1 READ(IREAD,1001) IENGN,IAR,NGT,KK,KINCRE
 1001 FORMAT(5I5)
```

```
      IF(IENGN.EQ.0) STOP                                               MA 034
      READ(IREAD,1002) HEP,HEW,CAC,XLENG(1)                             MA 035
 1002 FORMAT(4F10.2)                                                    MA 036
      READ(IREAD,1003) VO(1),VO(2),DRAG(1),DRAG(2),DISP,RANGE,XLTOB     MA 037
 1003 FORMAT(7F10.2)                                                    MA 038
C                                                                       MA 039
C     CALCULATION OF DIFFUSION RATIO AND HEIGHT OF DIFFUSER EXIT        MA 040
      DR=VO(1)/20.0                                                     MA 041
      HE=(DR-1.0)/.39238-1.15                                           MA 042
      IF(HEP-HE.LE.0.2) HE=HEP                                          MA 043
C                                                                       MA 044
C     IENGN CONTAINS CODING OF GAS TURBINE MODEL                        MA 045
C                                                                       MA 046
C      IENGN          GAS TURBINE                                       MA 047
C        1            TF35                                              MA 048
C        2            TF40                                              MA 049
C        3            PROTEUS 1500 RPM                                  MA 050
C        4            PROTEUS 1000 RPM                                  MA 051
C        5            TYNE 1A                                           MA 052
C        6            TYNE 1C                                           MA 053
C        7            FT12A                                             MA 054
C        8            LM1500                                            MA 055
C        9            LM2500                                            MA 056
C       10            FT4A-2C                                           MA 057
C       11            FT4A-12                                           MA 058
C       12            FT4C-2                                            MA 059
C       13            FT9D                                              MA 060
C       14            GTPF 990                                          MA 061
C       15            UNUSED SPACE                                      MA 062
C                                                                       MA 063
C     ACCELERATION COEFFICIENT IS ONE AT CRUISE SPEED                   MA 064
      CAC1=1.0                                                          MA 065
      KKK=1                                                             MA 066
```

```
      IF(KK.EQ.2) DISPIN=DISP/FLOAT(KINCRE)
      WTMIN1=DISP
   21 CONTINUE
C
C     PRINT OUT INPUT DATA
      WRITE(IPRINT,2000)
 2000 FORMAT('1',////////////////,1X,'*** SES WATERJET PROPULSION SYSTEM
     1WITH FLUSH INLET ***',////////,13X,'SHIP CHARACTERISTICS',/////)
      WRITE(IPRINT,2001)
 2001 FORMAT(30X,'CRUISE',17X,'HUMP')
      WRITE(IPRINT,2002) VO(1),VO(2)
 2002 FORMAT(1X,'VELOCITY, KNOTS',14X,F5.1,17X,F5.1)
      WRITE(IPRINT,2003) DRAG(1),DRAG(2)
 2003 FORMAT(1X,'SHIP DRAG, LBS',14X,F7.0,15X,F7.0)
      WRITE(IPRINT,2004) CAC1,CAC
 2004 FORMAT(1X,'ACCELERATION COEFFICIENT',6X,F4.2,18X,F4.2///)
      WRITE(IPRINT,2005) XLTOB,DISP,RANGE,(ENGN(N,IENGN),N=1,3)
 2005 FORMAT(1X,'LENGTH TO BEAM RATIO.................',F7.2/1X,'DISPLAC
     1EMENT, LONG TONS..............',F7.0/1X,'ENDURANCE, NAUTICAL MILES
     2............',F7.0/1X,'GAS TURBINE PLANT SELECTED..........',2X,3
     3A4)
      DISP=DISP*2240.
      PI=3.1415927
      HA=33.0
      G=32.174
      RHOW=1.99
      RHOT=8.9513
      XK=500.
      VISC=.044
      XLBSHP=2.13
      MN=1
      INIT=1
      CALL SESIN
```

```
C     CONVERT VELOCITY IN KNOTS TO VELOCITY IN FEET/SECOND
C
      DO 3 I=1,2
      VO(I)=VO(I)*1.689
    3 CONTINUE
      COR1=(HE-HEW)*2.*G/(VO(1)**2*CU**2)
      COR2=(HE-HEW)*2.*G/(VO(2)**2)
C
C     COMPUTE NUMBER OF GAS TURBINES (NGT) REQUIRED, ASSUMING THE
C     PRODUCT OF THE NOZZLE, GEAR AND PUMP EFFICIENCIES=.865
      ETAOA(1)=ETA1-COR1
      CDIN(1)=CDIN1
      H(1)=HEP-HE
      M=1
   38 VJVO(1)=CU+SQRT(CU**2*(1.-ETAOA(1))+2.*G*H(1)/(VO(1)**2))
      HPP(1)=(VJVO(1)**2-CU**2*ETAOA(1))*VO(1)**2/2./G+H(1)
      PRC(1)=1.73*(VJVO(1)-CU)/(VJVO(1)**2-ETAOA(1)*CU**2+2.*G*H(1)/(VO(
     11)**2))
      IF(NGT.GT.0) GO TO 40
      NGT=2
   40 XNGT=FLOAT(NGT)
      IF(VO(1)*DRAG(1)*(1.+CDIN(1)*.5/(VJVO(1)-CU-CDIN(1)/2.)).LE.PERF(1
     1,IENGN)*PRC(1)*XNGT*550.) GO TO 44
      NGT=NGT+2
      GO TO 40
   44 CONTINUE
      IF(M.GT.1) GO TO 45
      IF(NGT.LT.11) A=2.
      IF(NGT.LT.7) A=1.
      IF(NGT.LT.3) A=0.
      XLENGP=1.25*(PERF(6,IENGN)+PERF(2,IENGN)/3910.)*A
      QQ(1)=DRAG(1)/(RHOW*VO(1)*(VJVO(1)-CU-CDIN(1)/2.))/XNGT
      QQ(2)=QQ(1)
```

```
      CALL PIPE
      H(1)=HEP-HE+HPIPE(1)
      M=M+1
      GO TO 38
   45 CONTINUE
      WRITE(IPRINT,2007) NGT
 2007 FORMAT(1X,'REQUIRED NUMBER OF GAS TURBINES......',I4///)
      WRITE(IPRINT,2050) (ASPRT(N,IAR),N=1,2),HE,HEP,HEW
 2050 FORMAT(48H INLET ASPECT RATIO..............................,2X,2A4,
     * /,48H HEIGHT OF DIFFUSER OUTLET ABOVE BASELINE.......,F5.1,2X,
     1 4HFEET,/,
     2 48H HEIGHT OF PUMP CENTERLINE ABOVE BASELINE.......,F5.1,2X,
     3 4HFEET,/,
     4 48H HEIGHT OF OUTSIDE WATERLINE ABOVE BASELINE.....,F5.1,2X,
     5 4HFEET,///)
      WRITE(IPRINT,2009)
 2009 FORMAT('1',3X,'    ',//)
      IF(MN.GT.1) XLENGP=1.25*(PERF(6,IENGN)+PLP)*A
      I=0
      IJ=0
      PC1MAX=0.0
      PC2MAX=0.0
      WTMIN=1.0
      DEL=0.04
      VJVO(1)=CU+SQRT(CU**2*(1.-ETAOA(1))+2.*G*H(1)/VO(1)**2)
   50 CONTINUE
      CALL PIPE
      H(1)=HEP-HE+HPIPE(1)
      H(2)=HEP-HE+HPIPE(2)
   49 CONTINUE
      CALL PUMP
      MN=2
      IJ=IJ+1
```

```
      IF(IJ.GT.10) GO TO 42
      GO TO 43
   42 IF(I.EQ.0) GO TO 86
   43 CONTINUE
      IF(WTRAT.GE.1.0) GO TO 57
      PRNC1=DRAG(1)*VO(1)/(XNGT*SHP(1)*550.)
      PRNC2=DRAG(2)*VO(2)/(XNGT*SHP(2)*550.)
      IF(WTMIN.LT.WTRAT) GO TO 51
      WTMIN=WTRAT
      WVJ=VJVO(1)
      QQ1WVJ=QQ(1)
   51 CONTINUE
      IF(PC1MAX.GT.PRC1) GO TO 52
      PC1MAX=PRC1
      PC1VJ=VJVO(1)
   52 CONTINUE
      IF(PC2MAX.GT.PRNC1) GO TO 53
      PC2MAX=PRNC1
      PC2VJ=VJVO(1)
      QQ1PC2=QQ(1)
   53 CONTINUE
      GO TO 54
   57 CONTINUE
      IF(I.GT.0) GO TO 60
      VJVO(1)=VJVO(1)+DEL
      GO TO 50
   54 CONTINUE
      IF(INIT.GE.2) GO TO 73
      I=I+1
      IF(ABS(WVJ-VJVO(1)).LE.0.01) IWVJ=I
      IMAX=I
      IF(I.GT.35) GO TO 60
      XX(I,1)=VJVO(1)
```

```
      XX(I,2)=WTRAT
      XX(I,3)=PRC1
      XX(I,4)=PRNC1
      XX(I,5)=PRNC2
      XX(I,6)=SHP(2)
      XX(I,7)=SHP(1)
      XX(I,8)=SSS2
      XX(I,9)=RPM2
      XX(I,10)=FLOAT(NSTG)
   73 AINLET=Q(1)/(VO(1)*.8*2.)
      AD=APUP*XNGT/2.
      DR=AD/AINLET
      VAF=Q(2)/(VO(2)*.8*AINLET*2.)
      IF(IAR.EQ.2) GO TO 75
      AR=2.5
   74 CONTINUE
      HIN=SQRT(AINLET/AR)
      WIDTH=AR*HIN
      GO TO 76
   75 AR=DR
      GO TO 74
   76 CONTINUE
      HEPHE=(HEP-HE)/.707
      AIN2=VAF*AINLET
      HIN2=VAF*HIN
      IF(INIT.EQ.1) GO TO 89
      WRITE(IPRINT,4050)
 4050 FORMAT(38X,'MISCELLANEOUS SYSTEM DATA'/)
      WRITE(IPRINT,4100) AINLET,AIN2,HIN,HIN2,WIDTH,DR,VAF,GERAT
 4100 FORMAT(5X,'INLET AREA-CRUISE ***********=',F10.4,10X,'INLET AREA-H
     1UMP ***************=',F10.4/5X,'INLET HEIGHT-CRUISE *********=',F10
     2.4,10X,'INLET HEIGHT-HUMP ************=',F10.4/5X,'INLET WIDTH ***
     3**************=',F10.4,10X,'INLET DIFFUSION RATIO ********=',F10.4
```

```
     4/5X,'VARIABLE AREA FACTOR ********=',F10.4,10X,'REDUCTION GEAR RAT
     5IO *********=',F10.4///)
      WRITE(IPRINT,4150) HEPHE,XLN,DPIPE,DJET,DPIPE,THICK
 4150 FORMAT(5X,'TRANSITION PIPE LENGTH ******=',F10.4,10X,'NOZZLE LENGT
     1H-FT ************=',F10.4/5X,'NOZZLE INLET DIAMETER-FT ****=',F10
     2.4,10X,'NOZZLE EXIT DIAMETER-FT ******=',F10.4/5X,'PUMP TO NOZZLE
     3PIPE DIA.-FT *=',F10.4,10X,'PUMP TO NOZZLE PIPE THICK.-IN =',F10.4
     4)
      WRITE(IPRINT,4170) XLENG(1)
 4170 FORMAT(//,5X,'PUMP TO NOZZLE PIPE LENGTH FOR SYSTEM   1 PORT OR ST
     1ARBOARD-FT *****************=',F10.2)
      ILA=NGT/2
      IF(ILA.EQ.1) GO TO 89
      DO 80 IL=2,ILA
      XLENG(IL)=FLOAT(IL-1)*1.25*(PERF(6,IENGN)+PLP)+XLENG(1)
      WRITE(IPRINT,4175) IL,XLENG(IL)
 4175 FORMAT(5X,'PUMP TO NOZZLE PIPE LENGTH FOR SYSTEM',I4,' PORT OR STA
     1RBOARD-FT *****************=',F10.2)
   80 CONTINUE
   89 CONTINUE
      IF(INIT.EQ.2) GO TO 81
      IF(INIT.EQ.3) GO TO 87
      VJVO(1)=VJVO(1)+DEL
      GO TO 50
   60 CONTINUE
      WRITE(IPRINT,4200) PC1MAX,PC1VJ,PC2MAX,PC2VJ,WTMIN,WVJ
 4200 FORMAT(5X,'MAXIMUM OVERALL PROPULSIVE COEFFICIENT ***=',F10.6,' AT
     1 A JET VELOCITY RATIO =',F10.4//5X,'MAXIMUM NORMAL PROPULSIVE COEF
     2FICIENT ****=',F10.6,' AT A JET VELOCITY RATIO =',F10.4//5X,'MINIM
     3UM TOTAL WEIGHT RATIO ***************=',F10.6,' AT A JET VELOCITY
     4RATIO =',F10.4)
      WRITE(IPRINT,4300)
 4300 FORMAT('1',3X,'VELOCITY',3X,'WEIGHT',4X,'PROPULSIVE',5X,'PROPULSIV
```

```
     1E',5X,'PROPULSIVE',4X,'HORSEPOWER',3X,'HORSEPOWER',4X,'SUCTION',4X
     2,'PUMP',4X,'NUMBER')
      WRITE(IPRINT,4310)
 4310 FORMAT(4X,'RATIO',6X,'RATIO',4X,'COEFFICIENT',4X,'COEFFICIENT',4X,
     1'COEFFICIENT',6X,'HUMP',8X,'CRUISE',6X,'SPECIFIC',4X,'RPM',7X,'OF'
     2/27X,'CRUISE',8X,'CRUISE',9X,'HUMP',36X,'SPEED',6X,'HUMP',4X,'STAG
     3ES'/25X,'(OVERALL)',7X,'(NET)',10X,'(NET)',35X,'HUMP'//)
      WRITE(IPRINT,4400)((XX(L,K),K=1,10),L=1,I)
 4400 FORMAT(//  20(4X,F6.4,4X,F6.4,7X,F6.4,9X,F6.4,9X,F6.4,8X,F7.1,6X,F
     17.1,5X,F7.1,3X,F6.1,5X,F3.1//))
      INIT=INIT+1
      VJVO(1)=WVJ
      GO TO 50
   81 CONTINUE
      INIT=INIT+1
      VJVO(1)=PC2VJ
      GO TO 50
   87 CONTINUE
      IF(KK-2) 82,83,82
   82 CONTINUE
      GO TO 78
   83 CONTINUE
      GO TO 86
   86 CONTINUE
      IF(WTRAT.GE.1.) GO TO 85
      IF(IMAX-IWVJ) 84,85,84
   85 IF(KKK.GT.1) GO TO 78
      IF(WTMIN1.LT.WTMIN) GO TO 78
      DISP1=DISP-DISPIN*2240.
   92 DRAG(1)=DRAG(1)/DISP*DISP1
      DRAG(2)=DRAG(2)/DISP*DISP1
      XNGT=2.
      DISP=DISP1/2240.
```

```
      VO(1)=VO(1)/1.689
      VO(2)=VO(2)/1.689
      KOUT=4
      WTMIN1=WTMIN
      GO TO 21
   84 KKK=KKK+1
      IF(WTMIN1.LE.WTMIN) GO TO 78
      DISP1=DISP+DISPIN*2240.
      DRAG(1)=DRAG(1)/DISP*DISP1
      DRAG(2)=DRAG(2)/DISP*DISP1
      XNGT=2.
      DISP=DISP+DISPIN*2240.*.5
      IF(KOUT.EQ.4) GO TO 92
      DISP=DISP1/2240.
      VO(1)=VO(1)/1.689
      VO(2)=VO(2)/1.689
      WTMIN1=WTMIN
      GO TO 21
   78 CONTINUE
      WRITE(IPRINT,4500)
 4500 FORMAT(1H1)
      GO TO 1
      END
```

```
      SUBROUTINE SESIN
      COMMON/PARIN/ETA1,ETA2,CU,CORRN,CORRD,CDIN1
      COMMON/INDEX/IAR,IPRINT,IREAD,IENGN,NSTG,LAST,INIT
      COMMON/VELOC/VO(2),VJVO(2)
      COMMON CWIN
C
C     CALCULATION OF OVERALL INTERNAL EFFICIENCY
C     FOR 2.5 ASPECT RATIO INLETS
      IF (IAR.EQ.2) GO TO 10
      D=.603+.0001*(VO(2)-15.0)
      E=.5835+.000075*(VO(2)-15.0)
      F=.00015*VO(2)**2-.0056*VO(2)+.59025
      A=(D+F-2.0*E)/800.0
      B=(E-F)/20.0-140.0*A
      C=10.0*F-15.0*E+6.0*D
      ETA1=A*VO(1)**2+B*VO(1)+C
      CU=0.988-.00005*(VO(1)-60.0)
      D=-.00014*VO(2)**2+.00315*VO(2)+.70125
      E=-.000145*VO(2)**2+.0025*VO(2)+.730125
      F=.76-.0036*(VO(2)-15.0)
      A=(D+F-2.0*E)/800.0
      B=(E-F)/20.0-140.0*A
      C=10.0*F-15.0*E+6.0*D
      ETA2=A*VO(1)**2+B*VO(1)+C
C     CALCULATION OF INLET DRAG COEFFICIENT FOR
C     2.5 ASPECT RATIO INLETS
      D=.0000575*VO(2)**2-.00235*VO(2)+.1298125
      E=.08+.0001*(VO(2)-15.0)
      F=.00004*VO(2)**2-.0012*VO(2)+.1
      A=(D+F-2.0*E)/800.0
      B=(E-F)/20.0-140.0*A
      C=10.0*F-15.0*E+6.0*D
      CDIN1=A*VO(1)**2+B*VO(1)+C
```

```
C     CALCULATION OF INLET WEIGHT COEFFICIENT FOR
C     2.5 ASPECT RATIO INLETS
      IF(VO(1).GT.80.0) GO TO 5
      CWIN=-.00625*VO(1)**2+.9875*VO(1)-32.5
      GO TO 6
    5 CWIN=-.00075*VO(1)**2+.1525*VO(1)-.9
    6 CONTINUE
      CORRN=0.0
      CORRD=0.0
      RETURN
C     CALCULATION OF OVERALL INTERNAL EFFICIENCY
C     FOR VARYING ASPECT RATIO INLETS
   10 CONTINUE
      D=.5925+.000125*(VO(2)-15.0)
      E=.000065*VO(2)**2-.00255*VO(2)+.590625
      F=.000235*VO(2)**2-.0089*VO(2)+.612625
      IF(VO(2).LT.23.0) F=.532
      A=(D+F-2.0*E)/800.0
      B=(E-F)/20.0-140.0*A
      C=10.0*F-15.0*E+6.0*D
      ETA1=A*VO(1)**2+B*VO(1)+C
      CU=.987-.00015*(VO(1)-60.0)
      D=-.0001675*VO(2)**2+.0052*VO(2)+.6946875
      E=-.00012*VO(2)**2+.00155*VO(2)+.75375
      F=.00002*VO(2)**2-.0042*VO(2)+.8025
      A=(D+F-2.0*E)/800.0
      B=(E-F)/20.0-140.0*A
      C=10.0*F-15.0*E+6.0*D
      ETA2=A*VO(1)**2+B*VO(1)+C
C     CALCULATION OF INLET DRAG COEFFICIENT FOR
C     VARYING ASPECT RATIO INLETS
      D=.22-.00015*(VO(2)-15.0)
      E=.14-.00025*(VO(2)-15.0)
```

```
      F=.00006*VO(2)**2-.0017*VO(2)+.107
      IF(VO(2).LT.25.0) F=.102+.0003*(VO(2)-15.0)
      A=(D+F-2.0*E)/800.0
      B=(E-F)/20.0-140.0*A
      C=10.0*F-15.0*E+6.0*D
      CDIN1=A*VO(1)**2+B*VO(1)+C
C     CALCULATION OF INLET WEIGHT COEFFICIENT FOR
C     VARYING ASPECT RATIO INLETS
      CWIN=4.3+.02*(VO(2)-15.0)
      CORRD=0.0
      CORRN=0.0
      RETURN
      END
```

```
      SUBROUTINE PIPE
      COMMON/VELOC/VO(2),VJVO(2)
      COMMON/SHIP/DISP,RANGE,DRAG(2)
      COMMON/INDEX/IAR,IPRINT,IREAD,IENGN,NSTG,LAST,INIT
      COMMON/HEAD/HA,HEW,HEP,Q(2),QQ(2),HE,H(2)
      COMMON/PUM/RTIP,RPM(2),ETAP(2),DRAT,HSV(2),HPP(2)
      COMMON/XNOZ/XLENGP,PLP,XLN
      COMMON/PERFO/PERF(6,15),WTRAT,XNGT,ENGN(3,15),ASPRT(2,2)
      COMMON/CONST/PI,G,RHOW,RHOT,XK,VISC,XLBSHP
      COMMON/PIP/DPIPE,THICK,HPIPE(2),QQ1WVJ,XLENG(5),QQ1PC2
      ZERO=0.0
      DEL=.02
      STRESS=20000.
      IF(INIT.EQ.2) QQ(1)=QQ1WVJ
      IF(INIT.EQ.3) QQ(1)=QQ1PC2
      DPIPE=(.0007897*(VISC/3600.)**.2*QQ(1)**2.8*(PERF(3,IENGN)*RANGE*1
     1.689/VO(1)+XLBSHP)/G)**(1./6.8)
  100 DPIPE1=DPIPE
      ZERO1=ZERO
      DPIPE=DPIPE-DEL
      THICK=HPP(1)*RHOW*G*DPIPE/(2.*12.*STRESS)
      ZERO=RHOT*THICK/RHOW+DPIPE/2.-.0003949*(VISC/3600.)**.2*QQ(1)**2.8
     1*(PERF(3,IENGN)*RANGE*1.689/VO(1)+XLBSHP)/(G*DPIPE**5.8)
      IF(ZERO.GT.0.0) GO TO 100
      DPIPE=DPIPE1-(ZERO1/(ZERO1-ZERO)*(DPIPE1-DPIPE))
      THICK=HPP(1)*RHOW*G*DPIPE/(2.*12.*STRESS)
      IF(THICK.LE.0.1) THICK=0.1
      DO 120 I=1,2
      HPIPE(I)=.092*(VISC/3600.)**.2*XLENGP*(4./PI*QQ(I)/DPIPE**2)**1.8/
     1DPIPE**1.2/G
  120 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PUMP
      COMMON/POUT/PRC1,SSS2,RPM2,SSS1
      COMMON/INDEX/IAR,IPRINT,IREAD,IENGN,NSTG,LAST,INIT
      COMMON/PARIN/ETA1,ETA2,CU,CORRN,CORRD,CDIN1
      COMMON/VELOC/VO(2),VJVO(2)
      COMMON/PUMA/CAC,COR1,COR2
      COMMON/SHIP/DISP,RANGE,DRAG(2)
      COMMON/COEF/DCOF,ENETA,AJET,DJET
      COMMON/HEAD/HA,HEW,HEP,Q(2),QQ(2),HE,H(2)
      COMMON/XNOZ/XLENGP,PLP,XLN,EFFNOZ
      COMMON/PUM/RTIP,RPM(2),ETAP(2),DRAT,HSV(2),HPP(2)
      COMMON/PERFO/PERF(6,15),WTRAT,XNGT,ENGN(3,15),ASPRT(2,2)
      COMMON/CONST/PI,G,RHOW,RHOT,XK,VISC,XLBSHP
      COMMON/PIP/DPIPE,THICK,HPIPE(2),QQ1WVJ,XLENG(5),QQ1PC2
      DIMENSION QQ(2),ETAOA(2),CDIN(2),PC(2,3),PCA(2,3),VTIP(2),PRC(2)
      DATA PC/-3.0,-1.7,4.8,3.42,-0.8,-0.72/
      DATA PCA/-1.0,-1.7,1.0,3.42,1.0,-0.72/
      ETAP(1)=0.0
      ETAP(2)=0.0
C     CORRECT OVERALL INTERNAL EFFICIENCY AND DRAG COEFFICIENT
C     FOR EFFECTS OF HEIGHT AND VELOCITY RATIO
      ETAOA(1)=ETA1-(VJVO(1)-1.8)*CORRN-COR1
      ETAOA(2)=ETA2-COR2
      CDIN(1)=CDIN1+(VJVO(1)-1.8)*CORRD
      CDIN(2)=CDIN(1)
      ENETA=ETAOA(1)*CU**2
      DCOF=CDIN(1)
C     COMPUTE REQUIRED FLOW AND HEAD AND NPSH AT TAKEOFF(2)
C     AND CRUISE(1)
      Q(1)=DRAG(1)/(RHOW*VO(1)*VJVO(1)-CU-CDIN(1)/2.))
      AJET=Q(1)/(VJVO(1)*VO(1))
      FACT=.5+CAC*CDIN(2)/4.
      VJVO(2)=FACT+SQRT(FACT**2+CAC*DRAG(2)/(RHOW*AJET*VO(2)**2))
```

```
      Q(2)=AJET*VJVO(2)*VO(2)
      AAJET=AJET/XNGT
      DJET=SQRT(4.*AAJET/PI)
      EFFNOZ=-.0375*(DJET/DPIPE)**2+.0275*DJET/DPIPE+.988
      DO 2 I=1,2
      DCU=CU
      IF(I.EQ.2) DCU=1.0
      QQ(I)=Q(I)/XNGT
      HPP(I)=(VJVO(I)**2/EFFNOZ-DCU**2*ETAOA(I))*VO(I)**2/(2.*G)+HPIPE(I
     1)+HEP-HE
      HSV(I)=HA-HEP+HE+(DCU**2*ETAOA(I)*VO(I)**2)/(2.*G)
    2 CONTINUE
      LAST=1
      DRAT=.3
      PHI=.15
      QX=QQ(1)/QQ(2)
      HX=HPP(1)/HPP(2)
      VTIP(2)=200.
      XKEEP=10.
      ISTEER=0
      ICONT=0
   40 CONTINUE
      RTIP=SQRT(QQ(2)/(PI*VTIP(2)*PHI*(1.-DRAT*DRAT)))
      RPM(2)=VTIP(2)*60./(RTIP(2.*PI)
      SSS2=RPM(2)*QQ(2)**.5/HSV(2)**.75
      IF(ISTEER.GT.0) GO TO 51
      IF(SSS2.LT.755.) GO TO 50
      VTIP(2)=VTIP(2)-1.0
      GO TO 40
   50 CONTINUE
      ISTEER=10
   51 CONTINUE
      SSS2=SSS2*21.2
```

```
      SHI=G*HPP(2)/(VTIP(2)*VTIP(2))
C
C     COMPUTE NUMBER OF PUMP STAGES (NSTG)
   52 RNSTG=(SHI-0.41)/.3+1.
      IF(RNSTG.GT.6.3) GO TO 73
      INSTG=IFIX(RNSTG)
      DNSTG=RNSTG-FLOAT(INSTG)
      IF(DNSTG.LE.0.3) GO TO 55
      NSTG=INSTG+1
      GO TO 56
   55 NSTG=INSTG
   56 CONTINUE
      IF(NSTG.EQ.0) NSTG=1
      IF(NSTG-2) 60,72,72
   60 IF(ICONT-10) 61,65,61
   61 ICONT=10
      CA=PC(1,2)/PC(1,3)*.5
      CB=PC(1,1)/PC(1,3)
      RX=-CA*QX-SQRT(QX**2*(CA**2-CB)+HX/PC(1,3))
   65 CONTINUE
      ETAP(2)=1.0-((3.666/(2.*RTIP))**.165*(1.-.915))
      PRC(2)=2.*.98*ETAP(2)*(VJVO(2)-CU)/(VJVO(2)**2/EFFNOZ-CU**2*ETAOA(
     12)+2.*G*(HEP-HE+HPIPE(2))/VO(2)**2)
      IF(VO(2)*DRAG(2)*CAC*(1.+.5*CDIN(2)/(VJVO(2)-1.-CAC*CDIN(2)/2.)).L
     1E.550.*PRC(2)*PERF(2,IENGN)*XNGT) GO TO 70
      VTIP(2)=VTIP(2)-1.
      GO TO 40
   70 CONTINUE
      IF(ICONT.GT.11) GO TO 74
      ETAX=PC(2,1)*QX**2+PC(2,2)*QX+PC(2,3)
      IF(ETAX.LE.0.0) ETAX=.001
      ETAP(1)=ETAP(2)*ETAX
   71 CONTINUE
```

```
      PRC(1)=2.*.98*ETAP(1)*(VJVO(1)-CU)/(VJVO(1)**2/EFFNOZ-CU**2*ETAOA(   PU 100
     11)+2.*G*(HEP-HE+HPIPE(1))/VO(1)**2)                                  PU 101
      IF(DRAG(1)*VO(1)*(1.+.5*CDIN(1)/(VJVO(1)-CU-CDIN(1)/2.)).LE.PERF(1   PU 102
     1,IENGN)*PRC(1)*XNGT*550.) GO TO 75                                   PU 103
      VTIP(2)=VTIP(2)-1.                                                   PU 104
      GO TO 40                                                             PU 105
   72 CONTINUE                                                             PU 106
      IF(ICONT.GT.11) GO TO 65                                             PU 107
      ICONT=20                                                             PU 108
      CA=PCA(1,2)/PCA(1,3)*.5                                              PU 109
      CB=PCA(1,1)/PCA(1,3)                                                 PU 110
      RX=-CA*QX+SQRT(QX**2*(CA**2-CB)+HX/PCA(1,3))*(CA/ABS(CA))            PU 111
      GO TO 65                                                             PU 112
   73 IF(LAST-2) 79,77,52                                                  PU 113
   74 CONTINUE                                                             PU 114
      ETAX=PCA(2,1)*QX**2+PCA(2,2)*QX+PCA(2,3)                             PU 115
      IF(ETAX.LE.0.0) ETAX=.001                                            PU 116
      ETAP(1)=ETAP(2)*ETAX                                                 PU 117
      GO TO 71                                                             PU 118
   75 CONTINUE                                                             PU 119
      RPM(1)=RPM(2)*RX                                                     PU 120
      VTIP(1)=RPM(1)*2.*PI*RTIP/60.                                        PU 121
      IF(VTIP(1).LE.200.) GO TO 76                                         PU 122
      VTIP(2)=VTIP(2)-1.0                                                  PU 123
      GO TO 40                                                             PU 124
   76 CONTINUE                                                             PU 125
      SSS1=RPM(1)*(Q(1)/XNGT)**.5/HSV(1)**.75                              PU 126
      IF(SSS1.LE.755.) GO TO 82                                            PU 127
      VTIP(2)=VTIP(2)-1.                                                   PU 128
      GO TO 40                                                             PU 129
   82 CONTINUE                                                             PU 130
      SSS1=21.2*SSS1                                                       PU 131
      CALL WEIGHT                                                          PU 132
```

```
      IF(LAST.EQ.3) GO TO 78
      IF(XKEEP.LT.WTRAT) GO TO 77
      XKEEP=WTRAT
      LAST=2
      VTIP(2)=VTIP(2)-1.
      GO TO 40
   77 CONTINUE
      LAST=3
      VTIP(2)=VTIP(2)+1.0
      GO TO 40
   78 CONTINUE
      GO TO 80
   79 WRITE(IPRINT,2012) VJVO(1)
 2012 FORMAT(5X,'THERE IS NO SOLUTION AT VJVO(1)=',F10.4//)
      WTRAT=1.0
      WTMIN=1.0
      RETURN
   80 CONTINUE
      PRC1=PRC(1)
      PHI1=QQ(1)*VTIP(2)*PHI/(VTIP(1)*QQ(2))
      RPM2=RPM(2)
      XDRAG=CDIN(1)*RHOW*Q(1)*VO(1)/2.
      RESIST=DRAG(1)+XDRAG
      IF(INIT.EQ.1) GO TO 3112
      WRITE(IPRINT,3100) PHI1,PHI,VTIP(1),VTIP(2),QQ(1),QQ(2)
 3100 FORMAT(5X,'FLOW COEFFICIENT-CRUISE *****=',F10.4,10X,'FLOW COEFFIC
     1IENT-HUMP *******=',F10.4/5X,'TIP VELOCITY-CRUISE *********=',F10.
     22,10X,'TIP VELOCITY-HUMP ***********=',F10.2/5X,'PUMP FLOW-CRUISE
     3************=',F10.2,10X,'PUMP FLOW-HUMP **************=',F10.2///
     4)
      WRITE(IPRINT,3111) XDRAG,RESIST
 3111 FORMAT(5X,'INLET DRAG-CRUISE ***********=',F10.1,10X,'TOTAL RESIST
     1ANCE-CRUISE *****=',F10.1///)
```

```
3112 CONTINUE                                                   PU 166
     RETURN                                                     PU 167
     END                                                        PU 168
```

```
      SUBROUTINE WEIGHT
      COMMON/INDEX/IAR,IPRINT,IREAD,IENGN,NSTG,LAST,INIT
      COMMON/PIP/DPIPE,THICK,HPIPE(2),QQ1WVJ,XLENG(5),QQ1PC2
      COMMON/VELOC/VO(2),VJVO(2)
      COMMON/COEF/DCOF,ENETA,AJET,DJET
      COMMON/POUT/PRC1,SSS2,RPM2,SSS1
      COMMON CWIN
      COMMON/SHIP/DISP,RANGE,DRAG(2)
      COMMON/HEAD/HA,HEW,HEP,Q(2),QQ(2),HE,H(2)
      COMMON/XNOZ/XLENGP,PLP,XLN,EFFNOZ
      COMMON/PUM/RTIP,RPM(2),ETAP(2),DRAT,HSV(2),HPP(2)
      COMMON/PERFO/PERF(6,15),WTRAT,XNGT,ENGN(3,15),ASPRT(2,2)
      COMMON/CONST/PI,G,RHOW,RHOT,XK,VISC,XLBSHP
      COMMON/WEMA/APUP,GERAT,SHP(2)
      COMMON/COUNT/ICOUNT
      DIMENSION PCOEF(6,2),WT(21),DIS(21),XWPN(6),XWWN(6)
      DATA PCOEF/ 1.71,1.79,2.03,2.23,2.43,2.63,347.0,393.5,439.5,489.5,
     *539.5,589.5/
   40 XXLP=PCOEF(NSTG,1)
      CW=PCOEF(NSTG,2)
      PIDIA=2.*RTIP
      XWD=CW*PIDIA**2.3*XNGT
      PLP=PIDIA*XXLP
      APUP=.785*PIDIA**2*(1.-DRAT**2)
      XWW=.523*APUP*PLP*RHOW*G*XNGT
      XWIN=CWIN*QQ(1)**1.5*XNGT
      XWPIW=RHOW*G*(HEP-HE)*APUP/.707*XNGT
      XWPIP=RHOT*G*PI*(SQRT(4.*APUP/PI)*THICK/12.+(THICK/12.)**2)*(HEP-H
     1E)/.707*XNGT
      XWENG=PERF(5,IENGN)*XNGT
      XWPN(1)=2.*RHOT*G*PI*(DPIPE*THICK/12.+(THICK/12.)**2)*XLENG(1)
      XWPNO=XWPN(1)
      MM=IFIX(XNGT/2.)
```

```
      IF(MM.EQ.1) GO TO 11
      DO 10 I=2,MM
      XWPN(I)=2.*RHOT*G*PI*(DPIPE*THICK/12.+(THICK/12.)**2)*(FLOAT(I-1)*
     1XLENGP+XLENG(1))
      XWPNO=XWPNO+XWPN(I)
   10 CONTINUE
   11 CONTINUE
      XWWN(1)=2.*RHOW*G*PI*.25*DPIPE**2*XLENG(1)
      XWWNO=XWWN(1)
      IF(MM.EQ.1) GO TO 9
      DO 20 II=2,MM
      XWWN(II)=2.*RHOW*G*PI*.25*DPIPE**2*(FLOAT(II-1)*XLENGP+XLENG(1))
      XWWNO=XWWNO+XWWN(II)
   20 CONTINUE
    9 CONTINUE
      XLN=2.*DPIPE
      D1=(DPIPE+1.1*DJET)/2.
      D2=1.05*DJET
      XWNOZ=RHOT*G*PI*((D1*THICK/12.+(THICK/12.)**2)*2.*XLN/3.+(D2*THICK
     1/12.+(THICK/12.)**2)*XLN/3.)*XNGT
      XWNOW=RHOW*G*PI*.25*((D1**2*2.*XLN/3.)+(D2**2*XLN/3.))*XNGT
      DO 1 I=1,2
    1 SHP(I)=RHOW*G*Q(I)*HPP(I)/(550.*XNGT*ETAP(I)*.98)
      GERAT=PERF(4,IENGN)/RPM(2)
      IF(SHP(1).GT.SHP(2)) GERAT=PERF(4,IENGN)/RPM(1)
      RQ=SHP(2)/PERF(4,IENGN)*(GERAT+1.)**3./GERAT
      IF(SHP(1).GT.SHP(2)) RQ=SHP(1)/PERF(4,IENGN)*(GERAT+1.)**3/GERAT
      XWGR=9500.*RQ/XK*XNGT
      CAL=DRAG(1)/DISP
      XWF=0.0
      WT(1)=0.0
      VOTERM=VO(1)+VO(1)*DCOF/2.
      ETERM=ENETA*VO(1)**2/2./G-HEP+HE-HPIPE(1)
```

```
      DIS(1)=DISP
      SCONT=RHOW*G*AJET/(550.*ETAP(1)*.98)
      N=21
      TI=RANGE*1.689/(VO(1)*20.)
      DO 2 I=2,N
      VJ=VOTERM/2.+SQRT(VOTERM**2/4.+CAL*DIS(I-1)/(RHOW*AJET))
      SHNG=SCONT*VJ*(VJ**2/(EFFNOZ*2.*G)-ETERM)/XNGT
      XN=0.25
      IF(SHNG.LT.0.7*PERF(1,IENGN)) XN=0.75
      SFC=PERF(3,IENGN)/((SHNG/PERF(1,IENGN))**XN)
      WT(I)=SFC*SHNG*TI*XNGT
      XWF=WT(I)+XWF
      DIS(I)=DIS(I-1)-WT(I)
    2 CONTINUE
      IF(XNGT.LE.2.) GO TO 13
      NGT=IFIX(XNGT)
      IF(NGT-NGT/4*4) 13,12,13
   12 XWF=XWF-2.*RHOW*G*HPIPE(1)*QQ(1)/550.*(PERF(3,IENGN)+SFC)/2.
   13 CONTINUE
      WTRAT=(XWD+XWW+XWIN+XWPIW+XWPIP+XWENG+XWPNO+XWWNO+XWNOZ+XWNOW+XWGR
     1+XWF)/DISP
      WTOT=WTRAT*DISP
      WTOTLT=WTOT/2240.
      XLBSHP=(WTOT-XWF)/(SHP(1)*XNGT)
      IF(WTRAT.GT.1.0) GO TO 7
      IF(LAST.EQ.3) GO TO 4
      RETURN
    4 CONTINUE
      ETAP(1)=ETAP(1)*100.
      ETAP(2)=ETAP(2)*100.
      IF(INIT.EQ.1) GO TO 2655
      IF(INIT.EQ.2) GO TO 3000
      WRITE(IPRINT,2110) VJVO(1)
```

```
2110 FORMAT('1',/////6X,'**   SYSTEM WEIGHTS AT MAXIMUM NET PROPULSIVE
    1COEFFICIENT, VELOCITY RATIO =',F6.3,'   **')
     GO TO 4000
3000 WRITE(IPRINT,2100) VJVO(1)
2100 FORMAT('1',/////9X,'**   SYSTEM WEIGHTS AT MINIMUM TOTAL WEIGHT RA
    1TIO, VELOCITY RATIO =',F6.3,'   **')
4000 CONTINUE
     WRITE(IPRINT,2200) XWENG,XWPIP,XWGR,XWPIW,XWF,XWPNO
2200 FORMAT(/5X,'ENGINE ***********************=',F10.2,10X,'TRANSITION
    1PIPE *************=',F10.2/5X,'REDUCTION GEAR **************=',F10
    2.2,10X,'TRANSITION WATER ************=',F10.2/5X,'FUEL ***********
    3*************=',F10.2,10X,'PUMP TO NOZZLE PIPE *********=',F10.2)
     WRITE(IPRINT,2300) XWD,XWWNO,XWW,XWNOZ,XWIN,XWNOW
2300 FORMAT(5X,'PUMP DRY ********************=',F10.2,10X,'PUMP TO NOZZ
    1LE WATER ********=',F10.2/5X,'PUMP WATER ******************=',F10.
    22,10X,'NOZZLE ***********************=',F10.2/5X,'INLET SYSTEM ****
    3************=',F10.2,10X,'NOZZLE WATER ****************=',F10.2)
     WRITE(IPRINT,2400) WTOT,WTOTLT
2400 FORMAT(/5X,'TOTAL WEIGHT =',F10.2,' LBS OR ',F10.2,' LONG TONS',//
    1/)
     WRITE(IPRINT,2500)
2500 FORMAT(46X,'PUMP DATA')
     WRITE(IPRINT,2600) NSTG,RPM(1),RPM(2),ETAP(1),ETAP(2),SSS1,SSS2
2600 FORMAT(5X,'NUMBER OF STAGES ************=',I10/5X,'PUMP RPM-CRUISE
    1 *************=',F10.2,10X,'PUMP RPM-HUMP ***************=',F10.2/
    25X,'PUMP EFFICIENCY-CRUISE ******=',F10.4,10X,'PUMP EFFICIENCY-HUM
    3P ********=',F10.4/5X,'SUCTION SPE., SPEED-CRUISE **=',F10.2,10X,'
    4SUCTION SPEC. SPEED-HUMP ****=',F10.2)
     WRITE(IPRINT,2650) HSV(1),HSV(2),HPP(1),HPP(2),PIDIA,PLP
2650 FORMAT(5X,'NET POS. SUCT. HEAD-CRUISE **=',F10.2,10X,'NET POS. SUC
    1T. HEAD-HUMP ****=',F10.2/5X,'PUMP HEAD-CRUISE ************=',F10.
    22,10X,'PUMP HEAD-HUMP **************=',F10.2/5X,'PUMP INLET DIAMET
    3ER *********=',F10.4,10X,'PUMP LENGTH *****************=',F10.4)
```

```
2655 CONTINUE
     RETURN
   7 WTRAT=1.0
     LAST=3
     WRITE(IPRINT,2700) VJVO(1),WTOT
2700 FORMAT(5X,'SYSTEM TOO HEAVY VJVO=',F5.3,5X,'WEIGHT=',F10.1)
     RETURN
     END
```

```
TF 35
 2220.      2840.    .59      14500.     1050.     4.083
TF 40
 2850.      3060.    .55      14500.     1050.     4.083
PROTEUS 1500
 2800.      3510.    .63       1500.     3200.     8.333
PROTEUS 1000
 2800.      3510.    .63       1000.     3300.     8.333
TYNE 1A
 3320.      4250.    .49       3110.     2800.     8.667
TYNE 1C
 4160.      5300.    .47       3110.     2800.     8.667
FT12A
 2220.      2840.    .79       9000.     1010.     8.250
LM 1500
12500.     14000.    .575      5500.     7500.    18.667
LM 2500
22200.     22500.    .41       3400.    10500.    22.250
FT4A-2C
19150.     24200.    .52       3600.    14200.    26.000
FT4A-12
21750.     26950.    .52       3600.    14200.    26.000
FT4C-2
27600.     34400.    .48       3600.    14200.    26.000
FT9D
35000.     35000.    .40       3600.    13400.    24.750
GTPF 990
 5000.      5000.    .48      16500.     4600.    10.200

  2.5
VARYING
```

SAMPLE INPUT DECK

```
      13     2     4     2   40
  6.5          2.0         1.2        0.0
  80.          45.         241000.    210000.    2000.     1000.     4.
       9     2     6     2   40
  6.5          2.0         1.2        0.0
  80.          30.         230000.    325000.    2000.     1000.     2.
      13     2     6
  6.5          2.0         1.2        0.0
  80.          27.         223000.    440000.    2000.     1000.     1.5
```

SAMPLE INPUT DECK CONTINUED

Thesis
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Waterjet propulsion
system optimization
for surface effect
ships.