RECOMMENDED VEHICLE CONCEPTS FOR WATERJET PROPELLED HIGH-PERFORMANCE VEHICLES

L. T. Ravenscroft, Jr., et al

Naval Ship Research and Development Center
Bethesda, Maryland

December 1974
A rapid method is developed for providing first order estimates of the smooth water powering and weight characteristics of SES, hydrofoil, and planing craft concepts employing waterjet propulsors. A computer program utilizing this method and applicable to SES concepts is included.
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β  Ratio of $V_{k_t}$ to $V_{k_{max}}$

γ  Lift horsepower-to-propulsive horsepower ratio

η  Overall propulsive coefficient

$\eta_p$  Pump efficiency

$\eta_{p_{max}}$  Maximum pump efficiency

ρ  Fluid density, lb sec$^2$/ft$^4$

Δ  Vehicle gross weight, tons
INTRODUCTION

The project objective is to recommend "Reference Craft" for use in an exploratory development program of waterjet propulsion systems. The vehicle concepts recommended in this report are limited to 200 tons. However, other vehicle sizes may readily be examined by utilizing the method presented herein.

A rapid method is developed for estimating the overall propulsive coefficient and the drag of a vehicle concept over its operating speed range. Thus, an estimate of the shaft horsepower required as a function of speed may be obtained. Preliminary weight estimating relationships are also included so that predictions of fuel weight and payload weight may be made. A computer program utilizing this method and applicable to SES vehicle concepts is contained in Appendix A.

Some of the equations used in the method are presented without derivation. Future reports will cover the development of these relationships.

THE OVERALL PROPULSIVE COEFFICIENT
FOR WATERJET PROPELLED VEHICLES

The overall propulsive coefficient \( n \) is defined by,

\[
    n = \frac{D(1.6878V_K)}{550 P}
\]

where \( D \) is the total vehicle drag, exclusive of that drag induced by the inlet, in pounds, \( V_K \) is the speed of the vehicle in knots, and \( P \) is the shaft horsepower delivered to the pump at the vehicle speed \( V_K \). For purposes herein we assume a transmission efficiency of unity.
For parametric analysis of waterjet propelled high performance vehicle concepts operating in a patrol type mission, i.e., cruising at some specified speed (e.g., 20 knots) and having a specified maximum (dash) speed (e.g., 75 knots), it is necessary to be able to estimate the powering requirements at the specified cruising speed so that fuel weight requirements corresponding to the specified cruising range may be determined. When the desired cruising speed coincides with hull-borne or pre-hump operation, it will be assumed that the vehicle concept has a hull-borne waterjet propulsion system, in addition to the primary (high speed) system, which can be characterized by supposing that a small hull-borne inlet/pump/engine system is included as part of the propulsion system. The equation (to be developed) for \( \eta \) will, in addition to providing an estimate of \( \eta \) for the primary waterjet system, enable characterization of this "secondary" propulsion system efficiency over the hull-borne speed range.

An expression for the overall propulsive coefficient, as given in reference (1) [Equation 6], is

\[
\eta / \eta_p = 2\left((1 - k - \frac{2gh}{v^2} + \frac{2gH}{v^2})^{1/2} - 1\right)v^2/(2gH) \tag{1}
\]

where

- \( \eta_p \) is the pump efficiency
- \( k \) is the ratio of total inlet and internal energy losses (exclusive of elevation changes) to the vehicle velocity head \( (v^2/2g) \)
- \( h \) is the difference in elevation between the nozzle exit and the water surface, ft
- \( H \) is the head produced by the pump, ft-lb/lb
- \( g \) is the acceleration due to gravity, ft/sec^2
- \( v \) is the forward speed of the vehicle, ft/sec
As no attempt is made herein to estimate the inlet induced external drag, we account for this additive drag by penalizing the overall propulsive coefficient. This is done by replacing \( K = k + \frac{2gh}{v^2} \) (the magnitude of which, in reference (1), is taken to be fixed for a fixed geometry) by a waterjet system loss coefficient \( K_d \), which includes internal (inlet plus duct) and elevation losses plus an equivalent loss to account for the additive inlet induced external drag. Equation (1) then becomes

\[
\eta/\eta_p = \left((1 - K_d + \frac{2gh}{v^2})^{1/2} - 1\right)v^2/(gH)
\]

As pointed out in reference (1), this equation has a maximum value for a given value of \( K_d \) so that there is an optimum value for \( H \). This is found, as in reference (1), by differentiating Equation (2) with respect to \( H = \frac{2gh}{v^2} \) and solving for \( H \). The result is

\[
H_{opt} = \frac{v_d^2}{g} [K_d + \sqrt{K_d}]
\]

where \( v_d \) denotes the particular value of \( V \) for which \( H \) is optimum.

Reference (1) suggests that if the magnitudes of pump head and flow rate at cruise (design) speed are maintained at take-off speed, then the additional thrust required at take-off may be produced. Following this reasoning, we assume that the magnitude of \( H \) is a constant \( H = H_{opt} \), i.e.,

\[
H = \frac{v_d^2}{g} [K_d + \sqrt{K_d}]
\]

if \( 0 < V \leq V_d \)

Replacing \( H \) in Equation (2) by this relationship and setting \( V_d = \alpha v_{max} \), \( 0 < \alpha \leq 1 \), gives

\[
\eta/\eta_p = \left((1 - K_d + \frac{2(K_d + \sqrt{K_d})}{(v_K/\alpha v_{K_{max}})^2})^{1/2} - 1\right) \frac{(v_K/\alpha v_{K_{max}})^2}{(K_d + \sqrt{K_d})}
\]

if \( 0 < v_K \leq v_{K_d} \)

where the vehicle speeds are now given in units of knots.
An estimate for the pump efficiency $\eta_p$ is needed which has a specified maximum $\eta_p = \eta_p_{\text{max}}$ when $V_K = V_{K_d}$. Moreover, the effect of $K_d$ should be included since the magnitude of the total head above vapor pressure at the impeller, $H_{SV}$ (referred to as the net positive suction head), is given by

$$H_{SV} = (1 - k) \frac{V^2}{2g} + h_{SV} - h_{pi}$$

where $h_{SV}$ is the difference between atmospheric and vapor pressure expressed as a head in feet of water and $h_{pi}$ is the elevation of the pump inlet above the free water surface (if the pump inlet is below the free water surface, then $h_{pi}$ is a negative quantity). Referring to the equation for $H_{SV}$ it is seen that, for a fixed vehicle speed, the magnitude of $H_{SV}$ increases as $k$ (or $K_d$) decreases with a corresponding increase in the pump specific speed for a given pump.

Test results for the XR1-B and calculations were used to determine the variation of pump efficiency with vehicle speed. This variation can be characterized by a slowly increasing function of vehicle speed which reaches a maximum value at design speed. Such a function is

$$\eta_p = \eta_{p_{\text{max}}} [1 - C_1 (1 - \frac{V_K}{V_{K_d}})^2]$$

where $\eta_{p_{\text{max}}}$ is the maximum pump efficiency and $C_1$ is assumed to be a function of $K_d$.

We assume that the above functional relationship between pump efficiency and vehicle speed is generally true and that, as discussed previously, the propulsion system losses (as reflected by $K_d$) slightly affect the pump efficiency. To estimate this effect, the ratio
The constant $C_1$ is assumed for the constant $C_1$ as it provides small variations in the magnitude of $\eta_p$ for a considerable range of $K_d$ values. The validity of this assumption will have to be verified when more experience is gained in the application of waterjet propulsion systems to high-speed vehicles. The equation selected to estimate the pump efficiency is

$$\eta_p = \eta_p_{\text{max}} \left[ 1 - \frac{\sqrt{K_d}}{1 + \sqrt{K_d}} \left( 1 - \frac{V}{\alpha V_{K_{\text{max}}}} \right)^2 \right] \text{ if } 0 < V < V_{K_{\text{d}}} \quad [4]$$

Combining Equations [3] and [4] gives an estimate of the overall propulsive coefficient $\eta$ over the speed regime ($0 < V \leq V_{K_{\text{d}}}$) for a vehicle concept with a specified loss level ($K_d$) and a specified maximum pump efficiency, $\eta_{\text{p max}}$, i.e.,

$$\eta = \frac{\eta}{\eta_{\text{p max}}} \quad \eta_{\text{p max}} \text{ if } 0 < V \leq V_{K_{\text{d}}} \quad [5]$$

For high-speed operation, the design speed $V = \alpha V_{K_{\text{max}}}$ should be set equal to $V_{K_{\text{max}}}$, i.e., $\alpha = 1$. If a secondary propulsion system is assumed for purposes of cruise range specification at low speed, then a second set of values, $\alpha$, $K_d$, and $\eta_{\text{p max}}$, should be selected and used in Equation [5] to determine the $\eta_{\text{p max}}$ for this propulsion system.

In using this method for estimating the overall propulsive coefficient of waterjet propelled vehicle concepts, the waterjet system loss coefficient $K_d$ may be treated as a parameter.
In this case the following tentative range of magnitudes for $K_d$ are recommended for preliminary performance estimates:

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<th>Recommended $K_d$ Values</th>
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<tr>
<td>Hydrofoil strut/pod ram inlet</td>
<td>0.65 - 0.75</td>
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<tr>
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<td>0.5 - 0.65</td>
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SES DRAG AND POWER ESTIMATES

The drag estimates for SES (rigid sidewall ACV's) are obtained by a summation of component drag relationships based essentially on the procedure given in references (2) and (3). As an approximation, it is assumed that the SES is fully cushion supported (i.e., $W = p_o S$, where $W$ is the gross weight in lbs, $p_o$ is the design cushion pressure in psf, and $S$ is the cushion platform area in $\text{ft}^2$), that the cushion platform is rectangular, that the sidewall length is equal to the cushion length ($L$), and that the daylight clearance is zero. Consistent with the latter assumption, the ram (or momentum) drag is taken to be zero.

The equations used to predict the component drag to weight ratios are as follows:

Wavemaking drag, $D_W$: From reference (2), this component is given by

$$D_W = \frac{L}{\rho g} \cdot \frac{p_o}{L} \cdot f_k$$  \[6\]

where $p_o / \rho g$ is the design pressure to cushion length ratio and $f_k$ is the wave drag parameter. A closed form analytical expression for $f_k$ has been developed, assuming a uniform pressure distribution acting over a rectangular region. It is
\[ f_L(F_L, \lambda) = \begin{cases} 
\frac{16\lambda}{\pi F_L H} \cdot \frac{F_L^2}{(1 + 1.6\lambda^{1/4})^2} \cdot \left\{ 3 - \gamma + \ln \frac{(1 + 1.6\lambda^{1/4})^2 F_L^2}{16\lambda} \right\} & \text{if } 0 < F_L \leq \frac{1}{2} F_L H \\
e^{-\sqrt{\frac{\pi}{F_L}} \sin^2 \left( \frac{\pi F_L^2}{2F_L^2} \right)} + \frac{\lambda}{\pi} \cdot \frac{2}{(F_L + 4/3\lambda^{1/4} F_L H)^2} \cdot \left\{ 3 - \gamma + \ln \frac{F_L^2 + 4/3\lambda^{1/4} F_L H^2}{4\lambda} \right\} & \text{if } \frac{1}{2} F_L H < F_L \leq \frac{4}{3} \lambda^{1/4} F_L H \\
e^{-\sqrt{\frac{\pi}{F_L}} \sin^2 \left( \frac{\pi F_L^2}{2F_L^2} \right)} + \frac{\lambda}{\pi} \cdot \frac{1}{F_L^2} \left\{ 3 - \gamma + \ln \left( \frac{F_L^2}{\lambda} \right) \right\} & \text{if } \frac{4}{3} \lambda^{1/4} F_L H < F_L 
\end{cases} \]

where
\[ \lambda = l/b \] is the length-beam ratio of the rectangular planform
\[ \gamma = .577... \] is Euler's constant
\[ F_L = V/\sqrt{gk} \] is the Froude number
\[ F_L H = V_H/\sqrt{gk} \] is the primary hump Froude number, which is estimated by
\[ F_L H = \sqrt{\frac{1}{\pi} + 0.01745 \lambda^2} \]

Sidewall frictional drag, \( D_{s,a} \):

For 2 sidewalls, this component is given in reference (2) by

\[ \frac{D_{s,a}}{w} = \frac{4}{w} \cdot C_f \cdot q_w \cdot \ell \cdot h_a \]  

\text{(7)}

where \( C_f \) is the friction coefficient, \( q_w \) is the water dynamic pressure \((2.835 V^2_K)\), and \( h_a \) is the fully wetted sidewall depth. The following estimate for \( h_a \) is used.

\[ h_a = \begin{cases} 
\frac{p_0}{2g} \left( 1 - \frac{(F_L H)^2}{F_L H \sqrt{\ell}} \right) & \text{if } 0 < F_L H \leq F_L H \\
\frac{.2}{2g} \left( 1 - \frac{(F_L H)^2}{F_L H \sqrt{\ell}} \right) & \text{if } F_L H < F_L H \leq F_L H \text{ max} 
\end{cases} \]  

Additional (external) sidewall frictional drag, \( D_{s,v} \), according to reference (2), this component is given as
Sidewall wavemaking drag, \( D_{s,w} \): This component, as given in reference (3), is

\[
\frac{D_{s,w}}{W} = C_f \cdot \frac{1}{b} \cdot \frac{q_w}{P_o} \cdot \frac{D_w}{W} \tag{8}
\]

Values of the wavemaking resistance coefficient, \( r \), for a full form, having \( B/L = .0265 \), \( B/H = .183 \), and \( L/H = 7 \), were taken from reference (4). For Froude numbers between 0 and 1.80, the magnitude of \( r \) is computed by interpolation of these stored values. For larger Froude numbers, the following approximation is used.

\[
r = 6.125 \cdot \frac{1}{F_k^2} \cdot \ln F_k \quad \text{if} \quad 1.80 < F_k
\]

The assumption is also made that \( H = h_a \).

External aerodynamic drag, \( D_e \): As given in reference (2), this component is

\[
\frac{D_e}{W} = \frac{2}{k/b} \cdot \frac{q_a}{P_o} \tag{10}
\]

where \( q_a \) is the air dynamic pressure \((.00339V_e^2)\). Here we have assumed the estimate of \( .2/(k/b) \) for the aerodynamic drag coefficient as given in reference (5).

Seal (or ski) drag, \( D_{sk} \): For this component, a flat planing surface is assumed. The average bottom planing speed is taken to be equal to the vehicle speed and the ski width is assumed equal to \( b \). The drag for two seals is then
\[ D_{SK} = 2 \cdot \frac{1}{2} \rho V^2 C_{f_g} \cdot l'b = 2q_w C_{f_g} \cdot l'b \]

where \( C_{f_g} \) is the flat plate skin friction coefficient and \( l' \) is the chord length of the ski. Assuming \( l' = 0.025t \) and \( C_{f_g} = 2C_f \) gives

\[ \frac{D_{SK}}{W} = 1 \cdot C_f \cdot \frac{q_w}{\rho_o} \quad [11] \]

Appendage drag, \( D_a \): Reference (6) gives an estimate for the drag coefficient of parabolic cross section appendages. If the values .01 and .1 are assumed for appendage area to cushion area ratio and thickness to chord ratio, respectively, then the drag coefficient given therein becomes

\[ C_{DA} = .0000393 + .02C_f \]

The appendage drag is then taken to be

\[ \frac{D_a}{W} = \frac{C_{DA}q_w}{\rho_o} \quad [12] \]

The total drag to weight ratio \((D/W)\) is obtained as the sum of Equations [6] through [12], i.e.,

\[ \frac{D}{W} = \frac{D_s}{W} + \frac{D_{a1a}}{W} + \frac{D_{a1v}}{W} + \frac{D_{a1w}}{W} + \frac{D_e}{W} + \frac{D_{SK}}{W} + \frac{D_a}{W} \quad [13] \]

from which we obtain the propulsive horsepower to weight ratio as,

\[ \frac{P_p}{W} = \frac{D}{W} \cdot \frac{V_K}{326n} \quad [14] \]

where \( V_K \) is the vehicle speed in knots and \( n \) is the overall propulsive coefficient.
It is assumed that the lift horsepower required \( (P_L) \) is proportional to propulsive power required, i.e.,

\[
\frac{P_L}{W} = \gamma \cdot \frac{P}{W}
\]

The smooth water shaft horsepower required is now given as

\[
P = \left( \frac{P_P}{W} + \frac{P_L}{W} \right) \cdot W
\]

where \( W \) is the gross weight of the SES in pounds.

HYDROFOIL DRAG AND POWER ESTIMATES

Smooth water drag estimates for hydrofoil vehicles are based on empirical relationships developed for estimating vehicle lift-drag ratios, \( L/D \), over the vehicle's speed regime for hydrofoils having either subcavitating or supercavitating lift systems.

For hydrofoil vehicles having subcavitating lift systems, the \( L/D \) curve (as a function of vehicle speed) decreases rapidly with increasing speed in the hullborne condition until take-off (where \( L/D \) is a minimum) after which the \( L/D \) curve increases to a maximum value (depending on cavitation conditions) and then decreases again as cavitation becomes more severe. To include the effect of various take-off speeds on \( L/D \), the take-off speed, \( V_{K_t} \) is defined by setting \( V_{K_t} = \beta V_{K_{max}} \), \( 0 < \beta < 1 \).

To provide the variation of \( L/D \) over the whole vehicle speed range, the following variation for subcavitating \( L/D \)'s is selected
\[
L/D = \begin{cases} 
\frac{550}{V_{K_{\max}}} \cdot \beta^{2.5} \cdot \frac{1}{(V_{K}/V_{K_{\max}})^2} & \text{if } 0 < V_{K} < V_{K_{t}} \\
\frac{550}{V_{K_{\max}}} \cdot \frac{1}{1.5} \cdot \left(\frac{V_{K}}{V_{K_{\max}}}\right)^2 & \text{if } V_{K_{t}} \leq V_{K} < \sqrt{\beta} \cdot V_{K_{\max}} \\
\frac{550}{V_{K_{\max}}} \cdot \frac{1}{(V_{K}/V_{K_{\max}})^{1/2}} & \text{if } \sqrt{\beta} \cdot V_{K_{\max}} \leq V_{K} \leq V_{K_{\max}}
\end{cases}
\]  

where the empirical constant is selected so that the L/D at 50 knots is 11. This is based on an average of L/D's attained by existing hydrofoils.

The variation of L/D with vehicle speed for hydrofoil vehicles with supercavitating lift systems is assumed to be similar to the variation of L/D with vehicle speed for subcavitating lift systems throughout the hullborne speed range. After reaching a minimum at take-off, the L/D is assumed to slowly increase throughout the foilborne speed range. The following variation of L/D with vehicle speed reflects the above assumptions.

\[
L/D = \begin{cases} 
\frac{550}{V_{K_{\max}}} \cdot \beta^{2.5} \cdot \frac{1}{(V_{K}/V_{K_{\max}})^2} & \text{if } 0 < V_{K} < V_{K_{t}} \\
\frac{550}{V_{K_{\max}}} \cdot \left(\frac{V_{K}}{V_{K_{\max}}}\right)^{1/2} & \text{if } V_{K_{t}} \leq V_{K} < \sqrt{\beta} \cdot V_{K_{\max}} \\
\frac{550}{V_{K_{\max}}} \cdot \frac{1}{(V_{K}/V_{K_{\max}})^{1/2}} & \text{if } \sqrt{\beta} \cdot V_{K_{\max}} \leq V_{K} \leq V_{K_{\max}}
\end{cases}
\]  

The same empirical constant is selected as it gives L/D's of 7.33 and 5.5 at 75 and 100 knots, respectively. These magnitudes are considered to be attainable with careful design in the near future.

The smooth water shaft horsepower delivered to the pump is given as,

\[
P = \frac{6.87 \Delta V_{K}}{\eta(L/D)}
\]  

[19]
where \( \Delta = W/2240 \) is the gross weight of the hydrofoil in tons.

**PLANING CRAFT DRAG AND POWER ESTIMATES**

The smooth water drag estimates for planing craft are based on Series 62 data (reference (7)). For the planing craft considered herein, Figure 12(a) of reference (7) was used to determine the resistance to weight ratios \( D/W \), i.e., a length to beam ratio of 5.5 was selected and the 8% LCC curves were used.

The shaft horsepower required is given by

\[
P = \frac{D}{W} \cdot \frac{V}{W} \cdot \frac{P}{326 n}
\]  

**WEIGHT ESTIMATES, ALL VEHICLES**

In order to obtain first order payload weight estimates, it is necessary to estimate the component weights of the selected vehicle concepts. Ordinarily, one would specify payload weight and estimate the gross weight; however, in this case an iterative procedure is required to solve the weight equation for gross weight. By specifying a gross weight (\( \Delta \)) the payload weight may be calculated explicitly.

The following relationships were selected for use in estimating component weights.

**Hull Structure:** The hull structural weight group \( W_s \) includes the main body and hull structure, superstructure, and machinery foundations. A minimum structural weight envelope given in reference (R) was selected for hydrofoils based on the best currently available material technology and construction techniques. This was increased by approximately 28% for planing craft based on a recent planing craft design. A weight estimate for SES, as a function of \( l/b \) and \( P_o/l \), was developed based on the variations presented in both references (6) and (9).
The hull structural weights are given by

\[
W_s = \begin{cases} 
0.15 \Delta + 0.25 \Delta^7 & \text{HYDROFOILS} \\
0.19 \Delta + 0.32 \Delta^7 & \text{PLANING CRAFT} \\
\sqrt{\frac{\Delta}{P_{sf}}} \left[ \frac{1}{\Delta^{1/3}} + \frac{0.3}{(l/b)^{1/3}} \right] & \text{SES}
\end{cases}
\] ; TONS  [21]

**Lift Systems:** The lift systems weight group \( W_{g1} \), includes the foil system weight in the case of hydrofoils and the seal system weight in the case of SES's. The equation selected for estimating the weight of hydrofoil lift systems, whose form is taken from reference (6), is assumed to depend on gross weight and the design foil loading \( P_{sf} \) in lbs/ft\(^2\). The lift system weight for SES's is taken proportional to gross weight.

\[
W_{g1} = \begin{cases} 
\frac{84 \Delta}{P_{sf}} + 0.275 \Delta^{3/2} & \text{HYDROFOILS} \\
0.05 \Delta & \text{SES} \\
0 & \text{PLANING CRAFT}
\end{cases}
\] ; TONS  [22]

The magnitude selected for \( P_{sf} \) should not exceed 2100 PSF as the resulting weight estimate might be too low.

**Propulsion System:** This weight group includes the prime movers and the transmission and propulsor systems. Based on available data for two recent high-performance vehicles, SES 100A and PHM, a specific weight (lbs of propulsion system/maximum intermittent shaft horsepower) of 3 lb/h.p. is selected to provide an estimate of marine gas turbine/waterjet propulsor/light weight transmission propulsion systems. If a secondary propulsion system is required, then an additional .5 lb/h.p. is assumed. This gives
$W_m = \begin{cases} 
0.001339 \; P_{MI}; & \text{if 1 propulsion system} \\
0.001562 \; P_{MI}; & \text{if 2 propulsion systems} 
\end{cases} \text{TONS} \quad [23]

where $P_{MI}$ is the available maximum intermittent shaft horsepower ($80^\circ F$). The magnitude of $P_{MI}$ is selected such that it exceeds the larger of either 1.15 times the power required at $V_{K_{\text{max}}}$, $(P_{SH} = 1.15P(V_{K_{\text{max}}}))$, or the power required at hump, $P(V_{KH})$ or take-off, $P(V_{K_T})$. If existing (or planned) gas turbines are not considered, then the estimate

$$P_{MI} = \text{MAX}[P_{SH}, P(V_{KH})]$$

may be used.

**Electric System:** This group is a small percentage of gross weight, and for our purposes, the following equation is selected based on an approximate average of the SES 100A and PGH-2.

$$W_e = 0.03 \Delta; \text{TONS} \quad [24]$$

**Auxiliary Systems and Outfit and Furnishings:** This group comprises a larger percentage of gross weight than the electric plant, however, it is still comparatively small relative to the previous groups. The weight of this group is taken to be 10 percent of the gross weight on the basis of the SES 100A and a recent planing craft design, i.e.,

$$W_{\text{aux}} = 0.1 \Delta; \text{TONS} \quad [25]$$

**Complement, Personal Effects, and Stores:** This group consists of the accommodations dependent weight items, some of which may be a function of duration at sea measured in terms of dry stores duration in days. The complement and personal effects weight is estimated by
assuming 225 lbs/man. The stores weight per man is assumed to be proportional to the dry stores duration. Based on the PGH-2 and a recent planing craft design, we obtain the following equation

\[ W_{ces} = 0.1N_c + 0.015N_c D_s \text{ TONS}, \]  \[ \text{(26)} \]

where \( N_c \) is the number of accommodations and \( D_s \) is the dry stores duration in days.

**Fuel:** This weight group includes the fuel required to meet the range requirements specified for the mission. The fuel weight equation used is

\[ W_f = \Delta(1 - e^{-\frac{2240\Delta V}{V_e}}) \text{ TONS}, \]  \[ \text{(27)} \]

where sfc is the specific fuel consumption in lbs/h.p.-hr. and \( R \) is the specified range in miles. Estimates for sfc are made by using an equation developed by H. D. Marron, Naval Ship Research and Development Center, NSRDC, Annapolis, for sfc's corresponding to maximum continuous power ratings of second generation gas turbines; however, as an approximation we assume it valid for the power per engine \( P_{en} \) where \( P_e \) is the estimated power required at \( V_e \), \( P_{en} \), divided by the number of engines installed. The equation is \( sfc = 1.9 P_{en}^{-.15} \). For hydrofoil and SES concepts where hullborne range is specified, an sfc of .4 is assumed to reflect a small diesel installation.

The payload \( W_{p/L} \) is defined to consist of those items comprising NAVSHIPS weight groups 4 and 7 (communications and control and armament, respectively) all variable load payload and margins. The payload weight, given in terms of Equations [21] through [27] via the weight equation, is
\( W_{p/L} = \Delta - (W_s + W_{sl} + W_m + W_e + W_{aux} + W_{ces} + W_f); \text{ TONS.} \quad [28] \)

APPLICATION OF THE METHOD OF ESTIMATING THE PRIMARY
CHARACTERISTICS OF SES'S, HYDROFOILS, AND PLANING CRAFT

The equations presented for estimating the powering characteristics and weight characteristics of SES, hydrofoils, and planing craft may now be solved provided certain design parameters are known. In this section these parameters are discussed and defined.

Design Specifications Common to All Craft

These are essentially selected according to the mission requirements. They are:

- \( V_{p,max} \): Maximum speed, knots
- \( V_{k,d} \): Design speed (speed at which maximum propulsive coefficient is desired), knots*
- \( V_{k,e} \): Endurance speed (speed corresponding to range specification), knots
- \( R \): Range, miles
- \( N_C \): Number of accommodations
- \( D_S \): Dry stores duration, days
- \( W_{p/L} \): Payload weight, TONS. (In general this should be a specification resulting from mission requirements, in which case Equation [28] becomes an implicit equation in gross weight, \( \Delta \) which can only be solved by iteration. For purposes herein we chose to specify \( \Delta \) and compute \( W_{p/L} \) for ease in computation.)

*Two values are required for this specification if the endurance speed specification is less than hump or take-off speed.
### SES Design Parameters

The following parameters are required for determining characteristics of SES:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Specification</th>
<th>Units</th>
<th>Procedure for Determining</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta)</td>
<td>gross weight</td>
<td>tons</td>
<td>specify</td>
</tr>
<tr>
<td>(\ell/b)</td>
<td>cushion length to beam ratio</td>
<td>non-dim</td>
<td>specify</td>
</tr>
<tr>
<td>(P_0/\ell)</td>
<td>design pressure to length ratio</td>
<td>non-dim</td>
<td>(P_0/\ell = 2/\sqrt{\ell/b})</td>
</tr>
<tr>
<td>(F_{\ell_{\text{max}}}^2)</td>
<td>square of maximum Froude no.</td>
<td>non-dim</td>
<td>(F_{\ell_{\text{max}}}^2 = \frac{0.00678(P_0/\ell)^{1/3} V_K}{\Delta^{1/3}(\ell/b)^{1/3}})</td>
</tr>
<tr>
<td>(\ell)</td>
<td>cushion length</td>
<td>feet</td>
<td>(\ell = 0.08254(V_{K_{\text{max}}}/F_{\ell_{\text{max}}})^2)</td>
</tr>
<tr>
<td>(P_0)</td>
<td>design cushion pressure</td>
<td>lbs/ft(^2)</td>
<td>(P_0 = (P_0/\ell) \cdot \ell)</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>ratio of (V_{K_{\text{d}}}) to (V_{K_{\text{max}}})</td>
<td>non-dim</td>
<td>specify</td>
</tr>
<tr>
<td>(K_d)</td>
<td>waterjet system loss coefficient*</td>
<td>non-dim</td>
<td>specify</td>
</tr>
<tr>
<td>(\eta_{\text{p}})</td>
<td>maximum pump efficiency*</td>
<td>non-dim</td>
<td>specify</td>
</tr>
</tbody>
</table>

With the above now known, Equations [6] through [13] are used to determine the drag/weight ratio at any desired Froude number; \(0 < F_{\ell} < F_{\ell_{\text{max}}}\). Next corresponding magnitudes of \(V_K/V_{K_{\text{max}}}\) are determined via

\[
\frac{V_K}{V_{K_{\text{max}}}} = \frac{\sqrt{\ell} \cdot F_{\ell_{\text{max}}}}{1.6878 V_{K_{\text{max}}}}
\]

and then Equations [14] through [16] are used to determine the smooth water shaft horsepower required at each speed, \(0 < V_K < V_{K_{\text{max}}}\). The magnitudes of the component weight groups are then found using Equations [21] through [27]. The payload weight then follows from Equation [28]. If the payload weight is insufficient, then the procedure should be repeated using a new gross weight.

*If secondary propulsion system is assumed, then two values may be required.
Hydrofoil Design Parameters

The following parameters are required for determining the characteristics of hydrofoils:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Specification</th>
<th>Units</th>
<th>Procedure for Determining</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta )</td>
<td>gross weight</td>
<td>tons</td>
<td>specify</td>
</tr>
<tr>
<td>( \beta )</td>
<td>ratio of ( V_{K_t} ) to ( V_{K_{max}} )</td>
<td>non-dim</td>
<td>specify (( V_{K_t} \leq 35 ))</td>
</tr>
</tbody>
</table>
| \( P_{sf} \) | design foil loading | lbs/ft\(^2\) | recommend  
| &nbsp; | &nbsp; | &nbsp; | 1200 if \( 0 < V_{K_{max}} < 55 \)  
| &nbsp; | &nbsp; | &nbsp; | \( P_{sf} = 1600 \) if \( 55 < V_{K_{max}} < 70 \)  
| &nbsp; | &nbsp; | &nbsp; | 2100 if \( 70 \leq V_{K_{max}} < 100 \) |
| \( a \) | ratio of \( V_{K_t} \) to \( V_{K_{max}} \) | non-dim | specify |
| \( K_d \) | waterjet system loss coefficient* | non-dim | specify |
| \( \eta_{p_{max}} \) | maximum pump efficiency* | non-dim | specify |

If \( 0 < V_{K_{max}} \leq 55 \), then subcavitating lift systems should be assumed and L/D estimates for the desired speeds, \( 0 < V_{K} \leq 55 \) may be computed using Equation [17]. For these cases, it is recommended that \( \beta = .5 \), i.e., assume that the take-off speed is 1/2 of maximum speed.

If \( V_{K_{max}} > 55 \), then Equation [18] should be used to reflect the lower L/D's obtained with supercavitating lift systems. If \( V_{K_{max}} < 70 \), then take-off speed may be assumed to be 1/2 of maximum speed, i.e., \( \beta = .5 \); however, for \( V_{K_{max}} > 70 \), one should select \( V_{K_{c}} = 35 \) and determine the appropriate value for \( \beta \).

*If secondary propulsion system is assumed, then two values may be required.
Smooth water shaft horsepower magnitudes for each $V_K$ are given by Equation [19], and the payload weight is determined by use of Equations [21] through [28].

**Planing Craft Design Parameters**

The parameters needed for determining the characteristics of planing craft are:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Specification</th>
<th>Units</th>
<th>Procedure for Determining</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta$</td>
<td>gross weight</td>
<td>tons</td>
<td>specify</td>
</tr>
<tr>
<td>$L_p/B_{PX}$</td>
<td>length-beam ratio</td>
<td>non-dim</td>
<td>specify</td>
</tr>
<tr>
<td>$L_p$</td>
<td>projected chine length</td>
<td>ft.</td>
<td>specify</td>
</tr>
<tr>
<td>$B_{PX}$</td>
<td>maximum beam at chine</td>
<td>ft.</td>
<td>specify</td>
</tr>
<tr>
<td>$A_p/(35\Delta)^{2/3}$</td>
<td>bottom loading coefficient</td>
<td>non-dim</td>
<td>specify</td>
</tr>
<tr>
<td>$\beta_d$</td>
<td>deadrise angle</td>
<td>degrees</td>
<td>12.5</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>ratio of $V_K$ to $V_{K_{\text{max}}}$</td>
<td>non-dim</td>
<td>specify</td>
</tr>
<tr>
<td>$K_d$</td>
<td>waterjet system loss coefficient</td>
<td>non-dim</td>
<td>specify</td>
</tr>
<tr>
<td>$n_{p_{\text{max}}}$</td>
<td>maximum pump efficiency</td>
<td>non-dim</td>
<td>specify</td>
</tr>
</tbody>
</table>

Magnitudes of resistance to weight ratios, $D/W$, should be obtained from reference (7) after having selected an LCG location given therein. The procedure may then be completed by use of Equations [20] through [28].
Vehicle concepts considered for purposes of providing a reference vehicle for the selection of specifications for a developmental waterjet propulsion system are categorized according to a desired maximum smooth water speed capability as follows:

<table>
<thead>
<tr>
<th>$V_{K_{\text{max}}}$</th>
<th>Vehicle Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Planing Craft</td>
</tr>
<tr>
<td></td>
<td>Hydrofoil</td>
</tr>
<tr>
<td></td>
<td>SES</td>
</tr>
<tr>
<td>75</td>
<td>Hydrofoil</td>
</tr>
<tr>
<td></td>
<td>SES</td>
</tr>
<tr>
<td>100</td>
<td>SES</td>
</tr>
</tbody>
</table>

Design parameters and primary characteristics for the planing craft concepts are shown in Table 1. The selected design parameters have previously been defined. Two particular sets of design specifications, both of which require 50 knot maximum smooth water speed capability, are selected. One is for a vehicle concept having a 50 knot design speed $V_{K_d}$ and a 500-mile range $R$ at that speed $V_{K_c}$; while the other reflects a concept designed to be most efficient at 25 knots and to have a 500-mile range at 25 knots. For this patrol mission, however, only one propulsion system is assumed. In each case, the number of accommodations $N_c$ and the dry stores duration $D_s$ are assumed to be 12 and 7, respectively.

For each set, gross weights $\Delta$ of 50, 100, 150, and 200 tons are selected. For reference, the planing craft PTF has a gross weight of approximately 85 tons and the displacement ship PG has a gross weight of about 225 tons. The geometry selected is the same for both sets. The loss coefficient $K_d$ specified for each set is .5, which is assumed to be representative of waterjet systems having flush (or semi-flush) inlets. Maximum pump efficiencies $\eta_{p_{\text{max}}}$ of 90% are assumed. The
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{K_{max}}$</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>$V_{K_d}$</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
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<tr>
<td>$V_{K_e}$</td>
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<td>50</td>
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<td>25</td>
<td>25</td>
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</tr>
<tr>
<td>$R$</td>
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<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>$N_C$</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
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</tr>
<tr>
<td>$D_S$</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
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<td>7</td>
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</tr>
<tr>
<td>$\Delta$</td>
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<td>150</td>
<td>200</td>
<td>50</td>
<td>100</td>
<td>150</td>
<td>200</td>
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<tr>
<td>$L_p/B_{PX}$</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
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<tr>
<td>$L_p$</td>
<td>68</td>
<td>85</td>
<td>98</td>
<td>108</td>
<td>68</td>
<td>85</td>
<td>98</td>
<td>108</td>
</tr>
<tr>
<td>$B_{PX}$</td>
<td>12.4</td>
<td>15.4</td>
<td>17.8</td>
<td>19.6</td>
<td>12.4</td>
<td>15.4</td>
<td>17.8</td>
<td>19.6</td>
</tr>
<tr>
<td>$A_p/(35\alpha)^{2/3}$</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>$\beta_d$</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
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<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>$K_d$</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>$n_{P_{max}}$</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>No. &amp; Model</td>
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<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
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<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>P_{MI}</td>
<td>5000</td>
<td>10000</td>
<td>14,920</td>
<td>22400*</td>
<td>5000</td>
<td>11200*</td>
<td>16000</td>
<td>22400*</td>
</tr>
<tr>
<td>P_{MC}</td>
<td>4400</td>
<td>8800</td>
<td>13,600</td>
<td>20000</td>
<td>4400</td>
<td>10000</td>
<td>14000</td>
<td>20000</td>
</tr>
</tbody>
</table>

*at 100°F
resultant overall propulsive coefficient $\eta$ at maximum speed is .527, while at 25 knots it is .365.

The estimated characteristics, powering and weights, are presented next. The shaft horsepower required by the pump is given at two speeds, i.e., $P(V_{K_d})$ and $P(V_{K_{max}})$. The magnitude of $P_{SH}$ is also given.

The number and model of possible gas turbine installations along with the total maximum intermittent $P_{MI}$ and maximum continuous $P_{MC}$ power rating (at 80°F unless otherwise noted) are shown for each concept.

Tables 2 and 3 present selected design parameters and resultant characteristics for the 50 and 75 knot hydrofoil concepts, respectively. In each case, two "mission profiles" are assumed; the first specifies that $V_{K_d} = V_{K_{max}}$ and that the range at $V_{K_e} = V_{K_{max}}$ be 500 miles, while the second represents a hull-borne cruise capability of 2750 miles for the 50 knot hydrofoils (2000 miles for the 75 knot hydrofoils) at $V_{K_d} = .2V_{K_{max}} = V_{K_{e}}$ with a dash capability of $V_{K_{max}}$. For this patrol mission, a secondary propulsion system is assumed.* Parameter values characterizing it are given in parentheses next to the selected parameters for the primary propulsion system. For all cases, the number of accommodations $N_c$ and the dry store duration $D_s$ are taken to be 12 and 7, respectively.

For each set, gross weights $\Delta$ of 50, 100, 150, and 200 tons are selected. The PCH-2 has a gross weight of 58 tons and the PHM is approximately 224 tons gross weight. The design loading $P_{ef}$ selected for the 50 knot subcavitating hydrofoil concepts is 1200 psf, while for the 75 knot supercavitating hydrofoil concepts it is 2100 psf. The loss coefficient $K_d$, taken to be .75 for the primary waterjet system, is

*A small diesel installation is assumed but not identified.
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<p>| \Delta | 50 | 100 | 150 | 200 | 50 | 100 | 150 | 200 |
| \beta | .5 | .5 | .5 | .5 | .5 | .5 | .5 | .5 |
| P_{\text{sf}} | 1200 | 1200 | 1200 | 1200 | 1200 | 1200 | 1200 | 1200 |
| \alpha | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| K_{d} | .75 | .75 | .75 | .75 | .75 | .75 | .75 | .75 |</p>
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^*at 100°F
assumed to be representative of waterjet systems having hydrofoil strut/pod ram-type inlets. For the secondary system, assumed to be of the flush type, \( K_d \) is taken to be .5. Both primary and secondary systems are assumed to have a maximum pump efficiency of 90%. This leads to an overall propulsive coefficient of .482 at maximum speed, and an overall propulsive coefficient of .527 at the hullborne endurance speed.

The estimated characteristics include, in addition to those presented in table 1, the shaft horsepower required by the pump at take-off speed, \( H V_k \).

Design parameters and resultant characteristics for the 50, 75, and 100 knt SES ship concepts are shown in Tables 4, 5, and 6, respectively. For the "transport" mission, i.e., \( V_k = V_{k_{\text{max}}} = V_k \), a range of 500 miles at \( V_k \) is selected. For the "patrol mission", the endurance requirements are specified as 2500 miles at 12 knots for the 50 knot SES concepts and 1500 miles at 18 knots for the 75 and 100 knot SES concepts and a secondary propulsion system is assumed. For all cases, the number of accommodations \( N_c \) and the dry stores duration \( D_s \) are assumed to be 12 and 7, respectively.

The gross weights considered for all SES concepts are again taken as 50, 100, 150, and 200 tons. Cushion length-beam, \( l/b \), ratios for the SES transport concepts are selected to be 2. However, for the SES patrol concepts, the \( l/b \) is selected to be 4 except for the 100 knot, 200 ton concept. The loss coefficient \( K_d \) is taken to be .5 for both propulsion systems and the maximum pump efficiency \( \eta_p \) for both systems is assumed to be .9. This gives an overall propulsive coefficient at maximum speed of .527, which may be somewhat optimistic. At the pre-hump endurance speeds, the overall propulsive coefficient is also .527.

* A small diesel installation is assumed, but not identified.
### TABLE 4 - 50 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS

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TABLE 4 - 50 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS, CON'T.

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TABLE 6 - 100 KNOT SES CONCEPTS - DESIGN PARAMETERS AND CHARACTERISTICS

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No. & Model of Gas Turbines

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The estimated characteristics presented in Tables 4, 5, and 6 are the same as those given in Table 1, except that the shaft horsepower required by the pump at primary hump speed \( P(V_H) \) is also included.

RECOMMENDED VEHICLE CONCEPTS

For each of the 3 maximum smooth water speeds considered - 50, 75, and 100 knots - and for each of the 2 mission type profiles considered - transport and patrol - a vehicle concept is recommended for use as reference craft for waterjet propulsion systems. They are described below.

50 Knot Vehicle Concepts

The payload weight characteristics for all the 50 knot vehicle concepts, given in Tables 1, 2, and 4 are considered acceptable. In fact, the payload weight fractions \( (W_P/L) \) for all these concepts are between .08 and .34. Since the transport mission requires a continuous sustained speed of 50 knots, the hydrofoil concept is recommended for this mission profile as its performance in a seaway is superior to the other two type concepts. However, for the patrol mission profile, the planing craft concept is recommended as it will be cruising at a moderate speed (25 knots or less) most of the time. Moreover, it represents the least complex concept in terms of vehicle technology and cost. Table 7 presents the recommended vehicle concepts.

75 Knot Vehicle Concepts

The 75 knot hydrofoil and SES vehicle concepts are presented in Tables 3 and 5. Insufficient payload capability is indicated for the 50 ton transport vehicle concepts and the 50 ton SES patrol concept, i.e., the payload weight is less than 5% of the gross weight. For both missions, the hydrofoil of larger gross weight is again recommended, even though its payload capability appears to be somewhat less than that of the SES. The selections are presented in Table 7.
<table>
<thead>
<tr>
<th>$V_{K_{\text{max}}}$</th>
<th>50</th>
<th>50</th>
<th>75</th>
<th>75</th>
<th>100</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission Profile</td>
<td>Transport</td>
<td>Patrol</td>
<td>Transport</td>
<td>Patrol</td>
<td>Transport</td>
<td>Patrol</td>
</tr>
<tr>
<td>Recommended Concept</td>
<td>Hydrofoil</td>
<td>Planing Craft</td>
<td>Hydrofoil</td>
<td>Hydrofoil</td>
<td>SES</td>
<td>SES</td>
</tr>
<tr>
<td>Gross Weight, tons</td>
<td>50–200</td>
<td>50–200</td>
<td>100–200</td>
<td>100–200</td>
<td>&gt; 200</td>
<td>&gt; 200</td>
</tr>
</tbody>
</table>
100 Knot Vehicle Concepts

In this case, the only concept considered was the SES. The characteristics obtained for the 50 and 100 ton SES concepts (Table 6) indicate that these craft would have no fuel or payload capability. Furthermore, the payload weight for the 150 and 200 ton SES concepts is less than 5% of its gross weight. Thus, all of these concepts are considered infeasible. Viable SES concepts for these missions would have to be larger in gross weight. Table 7 presents the recommendations.

REFERENCES


37
APPENDIX A: Computerized Method for Waterjet Propelled SES Vehicle Concepts

The computer program "RAVSES" utilizes the method derived herein to estimate the overall propulsive coefficient and the drag of an SES vehicle concept over its operating speed range, and preliminary vehicle and component weights. The program operates in either of two modes; one being specification of payload weight; the second being specification of gross vehicle weight. When payload is specified, gross weight is derived by iteration until the specified payload is satisfied. When gross vehicle weight is specified, the payload weight is calculated directly. If the resulting payload is less than 5 percent of the gross weight, the gross weight is increased iteratively until the 5 percent minimum payload is satisfied. The program will also calculate the predicted drag of the vehicle over a specified speed range.

A description of the input to program "RAVSES", a sample output, and a program listing follow. The headings on the output follow the notation used in the derivation of the method.
**INPUT FOR “RAVSES”**

<table>
<thead>
<tr>
<th>Card</th>
<th>Columns</th>
<th>Format</th>
<th>Designation</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-80</td>
<td>A</td>
<td>TITLE</td>
<td>Any identification to be printed at top of each page of output.</td>
</tr>
<tr>
<td>2</td>
<td>1-10</td>
<td>F10.0</td>
<td>LOB</td>
<td>Cushion length-to-beam ratio.</td>
</tr>
<tr>
<td></td>
<td>11-20</td>
<td>F10.0</td>
<td>LOBSW</td>
<td>Sidewall length-to-beam ratio.</td>
</tr>
<tr>
<td></td>
<td>21-30</td>
<td>F10.0</td>
<td>WPL</td>
<td>Payload weight, tons. If WPL=0.0 and DELO is non-zero, payload weight is calculated from DELO and other weight requirements.</td>
</tr>
<tr>
<td>3</td>
<td>31-40</td>
<td>F10.0</td>
<td>DELO</td>
<td>Vehicle gross weight, tons. If DELO=0.0 and WPL is non-zero, gross vehicle weight is calculated from WPL and other weight requirements by an iterative procedure.</td>
</tr>
<tr>
<td></td>
<td>41-50</td>
<td>F10.0</td>
<td>VKMAX</td>
<td>Maximum vehicle speed in smooth water, knots.</td>
</tr>
<tr>
<td></td>
<td>51-60</td>
<td>F10.0</td>
<td>VKD</td>
<td>Vehicle design speed, knots.</td>
</tr>
<tr>
<td></td>
<td>61-70</td>
<td>F10.0</td>
<td>VKE</td>
<td>Vehicle endurance speed, knots.</td>
</tr>
<tr>
<td></td>
<td>71-80</td>
<td>F10.0</td>
<td>R</td>
<td>Vehicle range, miles.</td>
</tr>
<tr>
<td>3</td>
<td>1-10</td>
<td>F10.0</td>
<td>NC</td>
<td>Number of accommodations.</td>
</tr>
<tr>
<td></td>
<td>11-20</td>
<td>F10.0</td>
<td>DS</td>
<td>Dry stores duration, days.</td>
</tr>
<tr>
<td></td>
<td>21-30</td>
<td>F10.0</td>
<td>KD</td>
<td>Waterjet system loss coefficient.</td>
</tr>
<tr>
<td></td>
<td>31-40</td>
<td>F10.0</td>
<td>ETAPM</td>
<td>Maximum pump efficiency.</td>
</tr>
<tr>
<td></td>
<td>41-50</td>
<td>F10.0</td>
<td>PLOPP</td>
<td>Lift horsepower-to-propulsive horsepower ratio.</td>
</tr>
<tr>
<td></td>
<td>51-60</td>
<td>F10.0</td>
<td>EPS</td>
<td>Governs accuracy of gross weight calculation when DELO=0.0 is entered. If the difference between the initial gross weight estimate and the calculated gross weight is greater than EPS tons, another iteration is made.</td>
</tr>
<tr>
<td>Card</td>
<td>Columns</td>
<td>Format</td>
<td>FORTRAN Designation</td>
<td>Explanation</td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
<td>--------</td>
<td>---------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>3</td>
<td>61-70</td>
<td>F10.0</td>
<td>SYST</td>
<td>Use 1 for a single gas turbine. Use 2 for a gas turbine primary system plus a secondary system for low speed operation. If the endurance horsepower is greater than 3000, the secondary system is assumed to be gas turbine; otherwise it is assumed to be diesel.</td>
</tr>
<tr>
<td></td>
<td>71-80</td>
<td>F10.0</td>
<td>PRNT</td>
<td>Use 0 if each iteration is not to be printed. Use 1 if each iteration is to be printed.</td>
</tr>
<tr>
<td>4</td>
<td>1-5</td>
<td>I5</td>
<td>NVK</td>
<td>Number of speeds through speed range for which drag prediction are to be made. If NVK = 0, omit cards 4 and 5 through T.</td>
</tr>
<tr>
<td>5</td>
<td>1-10</td>
<td>F10.0</td>
<td>VK(1)</td>
<td>Speeds in knots for which drag predictions are to be made. Enter up to 8 speeds per card to a maximum of 60 speeds.</td>
</tr>
<tr>
<td>:</td>
<td>11-20</td>
<td>F10.0</td>
<td>VK(2)</td>
<td></td>
</tr>
<tr>
<td>:</td>
<td>:</td>
<td>:</td>
<td>:</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td></td>
<td></td>
<td>VK(NVK)</td>
<td></td>
</tr>
<tr>
<td>T+1</td>
<td>1-5</td>
<td>I5</td>
<td>MORE</td>
<td>Use 0 if another case follows. Use -1 if no more input follows.</td>
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</table>
### 50 Knot SES Concepts - Design Parameters and Characteristics

#### Ravenwood Method for Waterjet Propelled SES Conceptual Design

<table>
<thead>
<tr>
<th>VKMAX</th>
<th>VK0</th>
<th>VKE</th>
<th>RANGE</th>
<th>ACCUM.</th>
<th>UNIV ST.</th>
<th>L/R</th>
<th>P/L</th>
<th>PD</th>
<th>LENGTH</th>
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<td>12</td>
<td>2500</td>
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<table>
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<tr>
<th>NO. ENG.</th>
<th>MODEL</th>
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<th>PML</th>
<th>FHF</th>
<th>PJE</th>
<th>FMAX</th>
<th>DURMAX</th>
<th>DURHUNP</th>
<th>DURHM</th>
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<th>ETA MAX</th>
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<td>2440</td>
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<td>.49</td>
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<td>2.02</td>
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<td>.62</td>
<td>1550</td>
<td>.50</td>
<td>.53</td>
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<thead>
<tr>
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<th>DEL1</th>
<th>W5</th>
<th>WSL</th>
<th>WM</th>
<th>WE</th>
<th>WAUX</th>
<th>WCFS</th>
<th>WF</th>
<th>WPL</th>
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<td>2.8</td>
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<td>2.8</td>
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#### RVKMAX Method for Waterjet Propelled SES Conceptual Design

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<th>RANGE</th>
<th>ACCUM.</th>
<th>UNIV ST.</th>
<th>L/R</th>
<th>P/L</th>
<th>PD</th>
<th>LENGTH</th>
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<td>2500</td>
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<tr>
<th>NO. ENG.</th>
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<th>PMO</th>
<th>PML</th>
<th>FHF</th>
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<th>FMAX</th>
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<th>DURHUNP</th>
<th>DURHM</th>
<th>NO</th>
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<th>ETA MAX</th>
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<td>2</td>
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<td>2440</td>
<td>.49</td>
<td>.49</td>
<td>315</td>
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<td>.53</td>
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<table>
<thead>
<tr>
<th>DELO</th>
<th>DEL1</th>
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<th>WSL</th>
<th>WM</th>
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<th>WCFS</th>
<th>WF</th>
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</thead>
<tbody>
<tr>
<td>50</td>
<td>47</td>
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</table>

<table>
<thead>
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</thead>
<tbody>
<tr>
<td>50.00</td>
<td>3.112E+03</td>
<td>2.17</td>
<td>.53</td>
<td>2.026E+03</td>
<td>5.457E-02</td>
<td>1.115E-02</td>
<td>5.711E-03</td>
<td>3.603E-03</td>
<td>2.965E-06</td>
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<td>1.616E-02</td>
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<tr>
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<td>3.961E-03</td>
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<td>.51</td>
<td>2.054E+02</td>
<td>7.537E-02</td>
<td>3.147E-02</td>
<td>1.027E-03</td>
<td>7.106E-04</td>
<td>2.094E-05</td>
<td>6.380E-04</td>
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<tr>
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<td>.53</td>
<td>2.046E+02</td>
<td>7.537E-02</td>
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<td>1.027E-03</td>
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<td>2.094E-05</td>
<td>6.380E-04</td>
<td>1.130E-03</td>
<td>4.357E-04</td>
</tr>
</tbody>
</table>
PROGRAM RAVSES(INP,TAP,INPUT,TAP6=OUTPUT)

DIMENSION VK(60)

LOGICAL MET

REAL K0, L0, LBS, NC, NU

COMMON /DRAG/DAW*DEW+DOW*DSAOW+DSKOW+DSVOW+DSWOW+DSW

COMMON /PHYS/GRAY+NU*PI*RHD*RHO

COMMON /PWR/ALFA*ENG*ETA*ETAP=MU*NOEN*PLOPP*PLO*PWC*PM*PPW

COMMON /SES/BSW,DS,FRHUMP,FRMAX,LOB,LOBSW,NC,POL,POLE,R,SYST, 

TITLE (S) VKD, VKE, VKMAX

COMMON /WGT/DL, DEL, WAUX, WCES, WE, W, WM, WPL, WS, WSL 

MAXI=5

DOPL=2.0

GRAY=32.174

NU=1.2817E-5

PI=3.1415926535898

RHO=0.9905

RHOA=0.00238

Q1=2.0

Q2=1.6878*1.6AR7/GRAY

Q3=Q2/2240.**(1.0/3.)

1 READ (5,500) (TITLE(I),I=1,8)

500 FORMAT (8A10)

READ (5,502) LOR, LORSW, WPL, DEL, VKM, VKMAX, VKD, VKE, R, NC, DS, KD, ETAP

*PLDSP, EPS, SYST, PRNT

502 FORMAT (AF10.0)

WRITE (6,600)

600 FORMAT (1H1)

IF (DELO LE 0.) MET=TRUE.

IF (WPL LE 0.) MET=FALSE.

IF (MET) DEL=1.0

FRHUMP=2270.*VKMAX

PO=POL/L

BSW=L/LOBSW

Q4=1.6878/SQRT(GRAY)

ALFA=1.0

IF (Syst.EQ.2.) ALFA=VKD/VKMAX

CALL RSACV(VKE*Q4+PVKE)

PMC=PVKE

IF (FRHUMP.GE.VK) ALFA=1.0

IF (FRHUMP.GE.FRMAX) CALL RSACV(FRMAX,PVKH)

ALFA=1.0

CALL RSACV(FRMAX,PVKH)

IF (FRHUMP.GE.FRMAX) PVK=PVKM

PM=PVKM*1.15

IF (PVKM.GE.PMI) PNI=PVKM

CALL ENGENG(ENG,PI,PWC,NOEN)

IF (MI) GO TO 7

42
WPL=DELO-DELI
IF(NSTEP.EQ.1.OR.PRNT.NE.0.) CALL OUT(1,NSTEP)
IF(WPL.GE.0.05*DELO) GO TO 4
DELO=1.15*DELI-WPL
IF(NSTEP.LE.MAXIT) WPL=0.0
IF(NSTEP.GT.MAXIT) 4,2,3
3 IF(PRNT.NE.0.) CALL OUT(1,NSTEP)
IF(ABS(DELI-DELO).*LE.*EPS) GO TO 4
DELO=DELI
IF(NSTEP.LE.MAXIT) GO TO 2
4 CALL OUT(2,NSTEP)
WRITE(6,602)
602 FORMAT(1MO*V(KTS) DRAG(LBS) FN ETA POWER DOW
+ DVOW DSAOW USVOW DSWOW DEOW DSKOW
* DOW**/**)
ALFA=1.0
CALL RSACV(FRMAX,P)
CALL LINE (FRMAX*P*L*GRAV*ETA)
IF(SYST.EQ.2.) ALFA=VKD/VKMAX
CALL RSACV(VKDO*P*P)
CALL LINE (VKDO*P*L*GRAV*ETA)
CALL RSACV(VKED*P*P)
CALL LINE (VKED*P*L*GRAV*ETA)
READ (5,504) NVK
504 FORMAT(15)
IF(NVK) 931,5
5 READ (5,502) (VK(I),I=1,NVK)
DO 6 I=1,NVK
FR=VK(I)*04
ALFA=1.0
IF(SYST.EQ.2.) AND.VK(I).LE.VKD) ALFA=VKD/VKMAX
CALL RSACV(FR*P)
CALL LINE (FR*P*L*GRAV*ETA)
6 CONTINUE
READ (5,504) MORE
IF(MORE) 99,1,1
99 STOP
END
SUBROUTINE RSACV(FR,P)
DIMENSION TABFR(42),TABR(42)
REAL K0,L,LOB,L0BSWNC,NU
COMMON /DRAG/DAW,DOW,DSNOW,DSNOW+DSNOW+DOW+DMOW+DMOW+DMOW+W
COMMON /PHYS/AVG,NU,PPI,PHI,PHU
COMMON /WAV/ALFA,ENG,ETA,TAPM,KU,NOEN,PL0PP,PL0W,PMC,PMI,PPW,
*PVKE,PVKE,PVKE
COMMON /SW,BW,DS,FRHUMP,FRMAX,L,LOB,L0BSWNC,PO,POL,R,SYST,
*TITLE(A),VK0,VKF,VKMAX
DATA TABFR/0.0,1.,1.5,2.,2.25,2.5,2.75,3.0,3.25,3.5,3.75,4.0,4.25,4.5,4.75,5.0,
+5.5,6.0,6.5,7.0,7.5,8.0,8.5,9.0,10.1,10.2,
+13.1,14.1,15.1,16.1,17.1,18.1,
DATA TABR/0.006,0.017,0.04,0.077,0.147,0.2,0.282,0.413,0.622,0.8,1.0,1.22,
+1.44,1.7,1.93,2.18,2.35,2.52,2.7,2.9,3.12,3.25,3.40,3.53,3.67,3.82,3.96,
+4.11,4.26,4.42,4.58,4.75,5.0,
EULER=0.577215664917
EOEP=(SORT(1.*KD)+2.*KD/SORT(KD))/(FR/ALFA/FRMAX)**2-1.
*E=FR/ALFA/FRMAX)**2/(KD)**2/SORT(KD))
ETA=EOEP*TAPM*(1.+SORT(KD))/(1.+SORT(KD))*(1.+FR/ALFA/FRMAX)**2)
IF (FR.GE.0.0 AND FR.LT.0.5*FRHUMP)
1 WAVEPAR=16.*LOR*FR/P1*FRHUMP**2,*(1.+1.5*LOR**25)**2
2*EULER*ALOG((1.+1.5*LOR**25)**2/(1.0*LOR))
IF (FR.GE.0.5*FRHUMP AND FR.LE.0.8*LOR**25*FRHUMP)
1 WAVEPAR=EXP(-SORT(LOR)**2/FR**25*FRHUMP)**2/(4.*LOR)**2
2*LOR/(P1*FRHUMP**2 / (2.*FR**2))**2
3*EULER*ALOG((FR**2*ALFA**25*FRHUMP)**2/(4.*LOR)**2)

IF (FR.GT.0.8*LOR**25*FRHUMP)
1 WAVEPAR=EXP(-SORT(LOR)**2/FR**25*FRHUMP)**2/(4.*LOR)**2
2*LOR/SORT(LOR)**2 / (3.*EULER + ALOG(FR**2/LOR))
DOW=4.*WAVEPAR*POL/RHO/GRV
VFS=FR*SORT(GRAV)*L
Q=RHO*VFS**2/2.
IF (FR.LT.FR HUMP) HA=PO*(1.0-0.8*(FR/FRHUMP/FRHUMP)) /RHO/GRV
IF (FR.GE.FR HUMP) HA=0.2*PO/RHO/GRV
RE=VFS*L/NU
CF=FRICL(1,PO)
DSNOW=0.0*Q*CF*L*HA/W
DSNOW=0.0*CF*L*HA/W
Q=0.0*RHO*GRV/SORT
IF (FR.LE.1.0) CALL NISCOT(FR,FR,TABFR,TABR,FR,-120.0,42.0,1)
IF (FR.GT.1.0) R1=6.125*ALUG/FR)**2/FRFR
DSNOW=Q1*RI+BSW*BSW*HA/W/L
Q=RHOA*VFS**2/2.
DEW=0.2*Q*LOR/PO
DSNOW=0.0*CF*GW/PO
CDA=0.393*4.-0.02*CF
DAOW=CDA*Q/PO
DOW=DOW+DSNOW-DSNOW+DEW+DSNOW+DAOW
PPW=1.0+DSNOW+DSNOW+DEW+DSNOW+DAOW
PLOW=1.0+PL0PP+PPW
P=P*PPW*PL0W+W
RETURN
END
SUBROUTINE ENGE

DIMENSION TAREN(3,N1),NMAX(10),PMCN(11),PMIN(11)
COMMON /WGHT/DEL0,DFL1,WAUX,WC5,WF,W,WPL,WS,LS

DATA TAREG/10H1,GNOME/825,970,10H1,LM10011150,1220,1,
*10H1,TF14135,1550,10H1,TF25A,2200,2500,10H1,TF35,1,
*2750,3150,10H1,501-K14,7400,13730,10H1,TPF-490,500,5600,1,
*10H1,501-M62,7000,19000,10H1,912-C1I3000,15000,1,
*10H1,LM2500,24050,25600,10H1,FT9A-2,36000,42500,1/

DATA NMAX/6*2)3*3,5/

DO 1 I=1,11
NE(I)=ROUND((PM/1TAREN(I)*3)+0.5,1,1)
IF(NE(I),LT,2) NE(I)=2
PMCN(I)=TAREN(I)*NE(I)
1 PMIN(I)=TAREN(I)*NE(I)
IMIN=1

CALL WEIGHT(NE(I),PMCN(I),PMIN(I))

DEL=DEL1

DO 2 I=1,10
IF(NF(I),GT,NMAX(I)) GO TO 2
CALL WEIGHT(NE(I),PMCN(I),PMIN(I))
IF(DEL,LT,DEL1) GO TO 2
IMIN=I

DEL=DFL1

2 CONTINUE

N=NE(IMIN)
EN=ATREN(I+IMIN)
PM=ATREN(I+IMIN)*N
PMN=ATREN(I+IMIN)+N
CALL WEIGHT(N,PMN,PM)
RETURN
END
SUBROUTINE WEIGHT(ME,MCN,MIN)
REAL LOB,LOBSW,NC
COMMON /PMR/ALPHA,ENG,ETA,ETAPH,KO,NOEN,PLOPP,PLPH,PMC,PML,POW,
+PYKE,PYKH,PYKM
COMMON /SCS/BSW,DS,FRHUMP,FRMAX,L,LOB,LOBSW,NC,PU,POL,R,SYST,
+TITLE(R),VKV,VEK,VEKMAX
COMMON /WHT/DLO,DFL,VAUX,VCES,WE,WF,WM,WPL,WS,WSL
IF (PYKE GT 3000.0) OR (SYST.EQ.1) GO TO 1
SFC=0.4
WM=0.001562*MIN
GO TO 2
1 N=ROUND((-PYKE/PMCN*NE+0.5)+1)
   PEN=PYKE/N
   SFC=1.9*PEN**(-0.15)
   WM=0.001339*MIN
2 WS=DEL0/SORT(POL)*(DEL0**(-1.0/3.0)+0.3/LOB**-(1/3.0))
   WSL=0.05*DEL0
   WE=0.03*DEL0
   VAUX=0.1*DEL0
   VCES=0.1*NC*0.015*NC*DS
   WF=DEL0*(1.-EXP(-1.*SFC*PYKE/(2240.*DEL0*VEK)))
   DFL=WPL+WS+WSL+WM+WE+VAUX+VCES+WF
RETURN
END
SURROUTINF OUT(1PAGE,NSTEP)
REAL K0,LOR,LOBSW,NC
COMMON /PWR//ALFA,ENGETA,LTAPM,KU,NOEN,PLOPP,PLOW,PMPC,PMI,PMW
+PVKE,PVCM,PVDM
COMMON /SES/ASW,DS,FRHUMP,FRMAX,L,LOB,LOBSW,NC,POL,POL,POE,SYS,
+TITLE(A),VKD,VKE,VKMAX
COMMON /WGHT/DELO,DEL1,WAX,WCES,WE,WF,WM,WPL,WWS
GO TO (1,2) PAGE
1 WRITE(6,600) (TITLE(I),I=1,8)
600 FORMAT(/28X,RA10)
GO TO 3
2 WRITE(6,602) (TITLE(I),I=1,8)
602 FORMAT(/1H1,27X,RA10)
3 WRITE(6,604) NSWP
604 FORMAT(1H0,25X,RAVENSCROT METHOD FOR WAGETJET PRUPELLED SES CONC
+EPICAL DESIGN*10X*ITERATION = 11)
WRITE(6,606) VKMAX,VKO,VKE,R,NC,US,LOB,PO,POL
606 FORMAT(1H0,* VKMAX VKO VKE RANGE, ACCOM,
+ DRY ST. , F/L P/L PO LENGTH/1X,7F10.0,F10.3,
+10.0,F10.1)
FRE=VKE*FRMAX/VKMAX
WRITE(6,608) NOEN,ENG,PMC,PMI,FRE,PVKE,FRMAX,PVCM,FRHUMP
608 FORMAT(1H0, NO ENG, MODEL, PMC, PMI, FRE
+ PVKE, FRMAX, PVCM, FRHUMP, KD ETA
+ ETAPMAX/111*10.0,2F10.0,3(F10.2,F10.0))
IF(FRHUMP.LT.FRMAX) WRITE(6,610) PVKM
610 FORMAT(1H0,90X,F10.0)
IF(FRHUMP.GT.FRMAX) WRITE(6,612)
612 FORMAT(1H0,90X,*)
WRITE(6,614) KD,ETA,ETAPM
614 FORMAT(1H0,100X,3F10.2)
WRITE(6,616) DELO,DEL1,WS,WSL,WM,WE,WEX,WCES,WF,WPL
616 FORMAT(1H0,DELO,DEL1,WS,WSL,WM
+WF,WEX,WCES,WF,WPL,1X,2F10.0,8F10.1)
RETURN
END
SUBROUTINE LINFRPLGETA
REAL L
COMMON /DAG/DAOW*DOW*DOW+DSAOW+DSKOW+DSVOW+DSWOW+DSWOW+DSWOW+DSWOW*DAOW
WRITE(6,600) VK*DSQRT(GL/I+AA7A
600 FORMAT(1X,F6.2,1PE11.3,0PF7.2,1PE11.3)
RETURN
END

SUBROUTINE DISCOT (XA, TABX, TABY, TABZ, NC, NY, NZ, ANS)
DIMENSION TABX(10), TABY(440), TABZ(144), NPX(8), NPY(8), YY(N)
CALL UNS (NC, 1, 10, 10, 1, IMS)
IF (NZ = 1) 5, 5, 10
5 CALL DISPER (XA, TABX, 1, NY, IDX, NN)
NNN=IDX+1
CALL LAGRAN (XA, TABX(10), TABY(10), NNN, ANS)
GOTO 70
10 ZARG=ZA
IPX=IDX+1
IPZ=IDX+1
IF (IA) 15, 25, 15
15 IF (ZARG-TABZ(NZ)) 25, 25, 20
20 ZARG=TABZ(NZ)
25 CALL DISPER (ZARG, TABZ, 1, NZ, 10, NPZ)
NX=NY/NZ
NPZL=NPZ+1
NX=NPZL
I=1
IF (IMS) 30, 30, 40
30 J=NPZ+1
NPY(1) = (J*1)*NX+NPX(1)
NPX(I) = NPX(I)
GOTO 50
35 I=I+1
GOTO 50
40 DO 45 J=NPZ+1
IS = (J*1)*NX+1
CALL DISPER (XA, TABX, IS, NX, IDX, NPX)
NPY(I) = NPX(I)
45 I=I+1
50 DO 55 I=1, IPZ
NLOC=NPX(I)
NLOC+NPY(I)
55 CALL LAGRAN (XA, TABX(NLOC), TABY(NLOC), 1, IPX, YY(I))
CALL LAGRAN (ZARG, TABZ(NPZ), YY, IPZ, ANS)
70 RETURN
END
S U R R O U T I N E  L A G R A N  ( X A , X * Y * N + A N S )

D I M E N S I O N  X ( 1 0 ) , Y ( 1 4 0 )

S U M = 0 , 0

D O 3  I = 1 , N

P R O D = Y ( I )

D O 2  J = 1 , N

A = X ( I ) * X ( J )

I F ( A ) 1 * 2 * 1

1 R = ( X A - X ( J ) ) / A

P R O D = P R O D * R

2 C O N T I N U E

3 S U M = S U M + P R O D

A N S = S U M

R E T U R N

E N D


D I M E N S I O N  T A B ( 1 0 )

N P T = I D + 1

N P R = N P T / 2

N P U = N P T - N P B

I F ( N X - N P T ) 1 0 * 5 * 1 0

6 N P X * 1

R E T U R N

1 0 N L O W = 1 * N P R

N U P P = I * N X * ( N P U + 1 )

D O 1 5  I I = N L O W + N U P P

N L O C = I I

I F ( T A R ( I I ) = X A ) 1 5 * 2 0 * 2 0

1 5 C O N T I N U E

N P X = N U P P - N P B + 1

R E T U R N

2 0 N L = N L O C - N P B

N U = N L + 1 0

D O 2 5  J J = N L + N U

N D I S = J J

I F ( T A R ( J J ) = T A B ( J J + 1 ) ) 2 5 * 3 0 * 2 5

2 5 C O N T I N U E

N P X = N L

R E T U R N

3 0 I F ( T A B ( N D I S ) = X A ) 4 0 * 3 5 * 3 5

3 5 N P X = N D I S - I D

R E T U R N

4 0 N P X = N D I S * 1

R E T U R N

E N D
SUBROUTINE UNS (IC, IA, IDX, IDZ, IMS)
   IF (IC) 5,5,10
5 IMS=1
   NC=IC
   GOTO 15
10 IMS=0
   NC=IC
15 NC=(NC-100) 20,25,25
20 IA=0
   GOTO 30
25 IA=1
   NC=NC-100
30 IDX=NC/10
   IDZ=NC-IDX*10
   RETURN
END

FUNCTION FRICT(IFRICT, RE)
   GO TO (*,2) IFRICT
2 FRICT=-0.75/(ALOG10(RE/100.1))**2 $GO TO 99
4 FRICT=(1.64*ALOG10(RE)-5.6)**2
6 FRICT=(.242/ALOG10(RE**1))**2
   IF(Abs(FRICT-X) .LT.5.E-07) GO TO 99
   X=FRICT*X/2.
   GO TO 6
99 RETURN
END

FUNCTION ROUND(X*V)
C X IS VARIABLE TO BE Rounded
C V IS THE VALUE TO WHICH X IS TO BE Rounded
   X=X/V $STX=NX=X $SDX=X-TX $STDX=NX=2.0*D $ROUND=(TX+TDX)*V
   RETURN
END