



**DESIGN DESCRIPTION REPORT**

**PROPULSION SYSTEM ARRANGEMENT  
AND DESIGN EVALUATION**

Submitted to:

Office of Naval Research  
Ballston Tower One, 800 North Quincy Street  
Arlington, VA 22217-5660

Dr. Paul Rispin, Program Manager  
ONR Code 33X  
703.696.0339  
rispinp@onr.navy.mil

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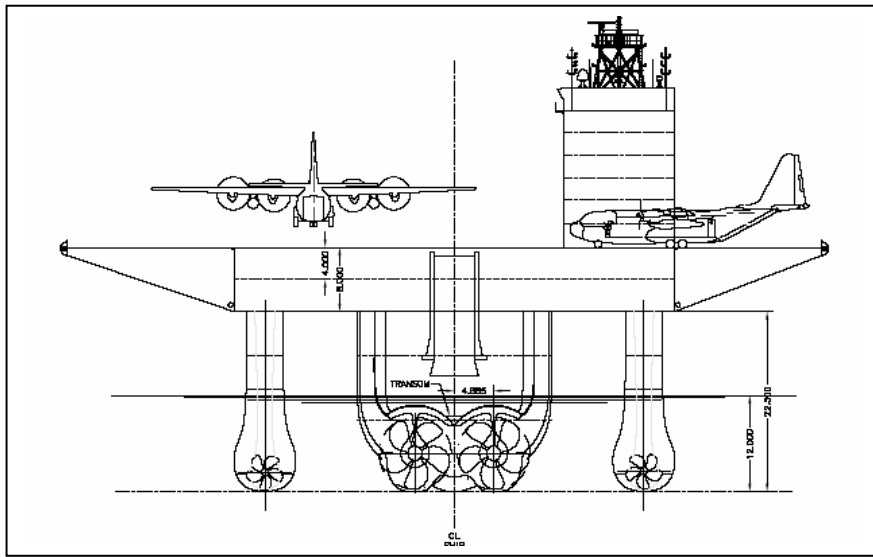
Center for the Commercial Deployment of Transportation Technologies  
California State University, Long Beach Foundation  
6300 State University Drive, Suite 220 • Long Beach, CA 90815 • 562.985.7394

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# High Speed Trimaran Technology Development

## Propulsion System Arrangement and Design Evaluation



Prepared by:  
Dr. Igor Mizine  
SAIC  
1710 SAIC Drive, MS 2-6-9  
McLean, VA 22102

Submitted to:  
Stan Wheatley  
CCDoTT  
6300 State University Drive, Suite 220  
Long Beach, CA 90815

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Center for the Commercial Deployment of Transportation Technologies (CCDoTT) at California State University, Long Beach.

## INTRODUCTION

This task focuses on innovative propulsion/hull arrangement and includes an evaluation of the waterjet propulsion and propeller propulsion systems well as trade-off analysis between these types of propulsion systems. Based on the previous CCDOTT projects with parametric design of the axial waterjets for large HST Sealift ships, the trade-offs between waterjet and propeller propulsion systems, sizing and performance evaluation is provided. For both types of propulsion systems the preliminary machinery arrangement is developed. Machinery arrangement and hull forms development performed in iterative design process: different propulsion options require special hull forms design solutions; and hull forms indicate powering requirements.

### 1. HALSS POWERING REQUIREMENTS

Based on HALSS hull forms the resistance curve is presented in Figure below.

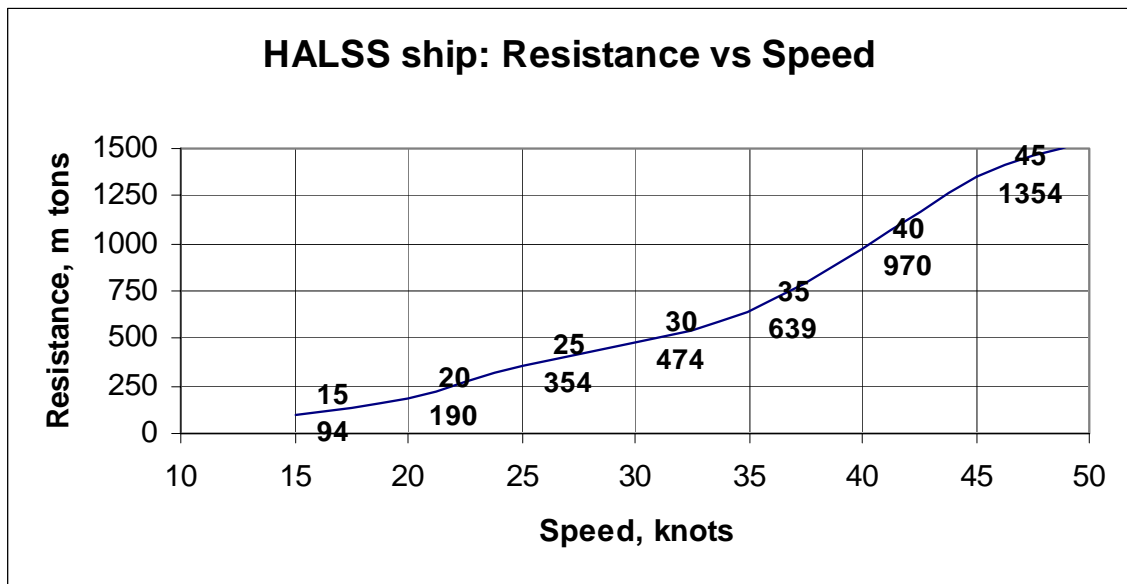


FIGURE: HALSS RESISTANCE VERSUS SPEED.

Resistance is calculated by MQLT method, described in previous Task 8.2 Report. Based on resistance, powering requirements are presented in following Figure.

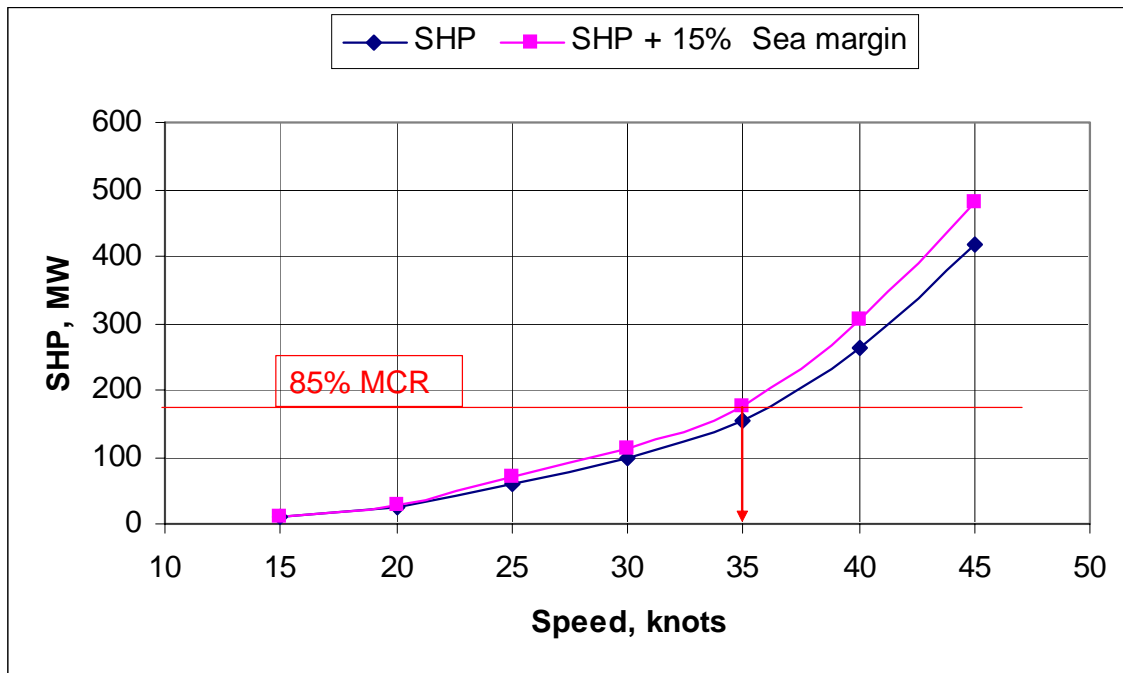


FIGURE: SPEED - POWER REQUIREMENT FOR HALSS WATERJET PROPULSION OPTION

For propeller propulsion option the powering requirements are approximately the same due to expected advantage in total propulsion efficiency. For waterjet propulsion the estimated propulsion efficiency coefficients is 0.65 and for propeller propulsion option it is estimated to be 0.7-0.72. From another point the resistance of propeller option due to skegged type of the stern and increased wetted surface is bigger, approximately for 10%. The increased wetted surface / resistance is compensated by improved propulsion efficiency of the propeller propulsion option.

## 2. TRADEOFFS AND PRELIMINARY PROPULSION DESIGN

### 2.1 OPTION 1 – WATERJETS WITH GAS TURBINES

Description: 5 \* LJ290E at 38MW, powered by LM6000 gas turbines with reduction gears.

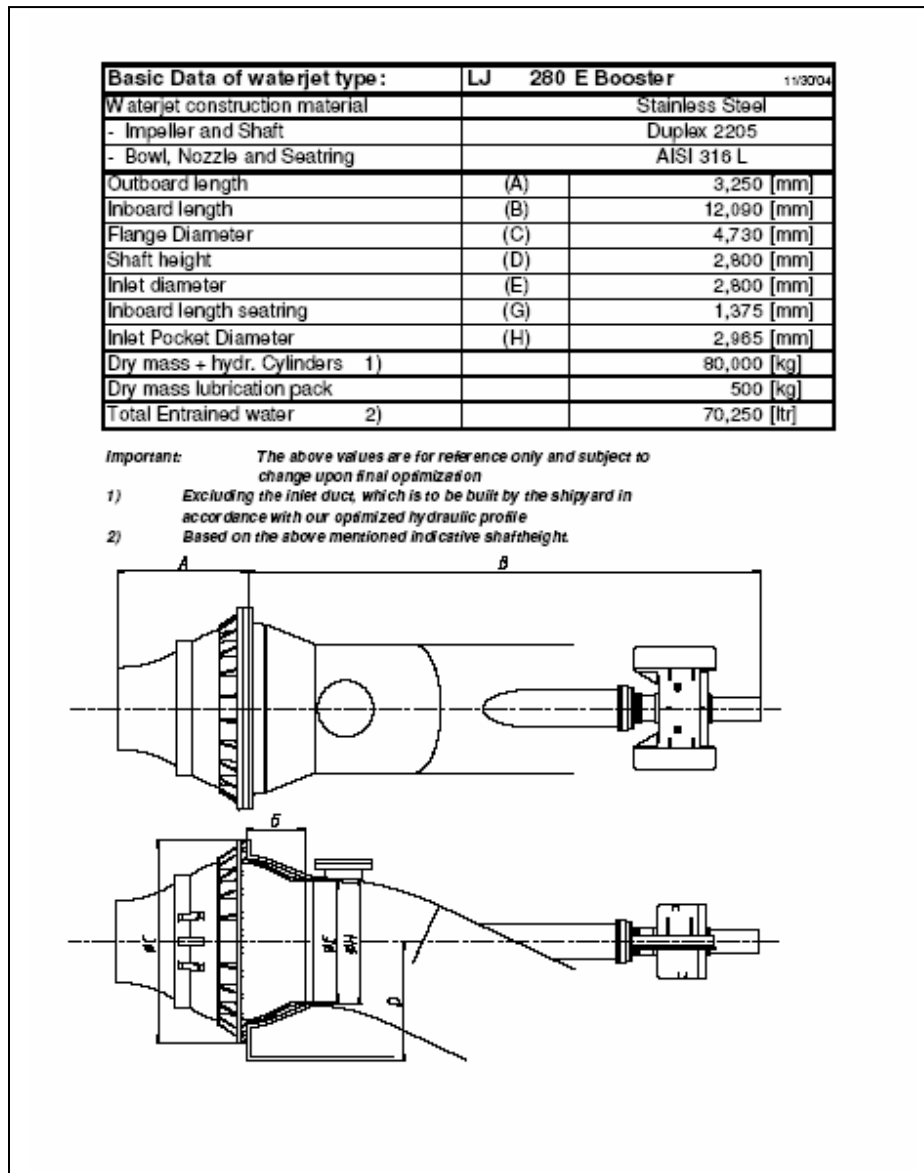
These will have to all be run at about 40% power to avoid cavitation at 25 knots. This is good for maintenance but will give a fuel rate of about 275g/KW-hr, which is very poor.

For Mid Term technology this option would be more attractive with axial-flow waterjets. In order to present axial pump option in HALSS it is necessary to make a

rough estimate of the size and performance characteristics of WJ required for an axial-flow design.

Proposed Solution:

Based on the preliminary performance characteristics of CDI’s axial pump design, we conclude that the inlet diameter of the axial pump will be the same as for our current E-type waterjets. The difference is that with an axial pump the impeller diameter is the same as the inlet diameter and is not 33% larger as with the E-type. We can thus expect an approx. 30+% reduction in transom flange diameter. According CDI, the transom flange is about 1.15 X inlet diameter. This is considered a bit lower than desirable 25% reduction of inlet diameter. The current transom flange of the 290E is 4900 mm. A 290 size in axial execution would thus have an approx. 3350 - 3600 mm transom flange diameter (290 X 1.15 (CDI) or 290 X 1.25 (our best guess)). The characteristics of A 280 WJ is shown in Figure 1.



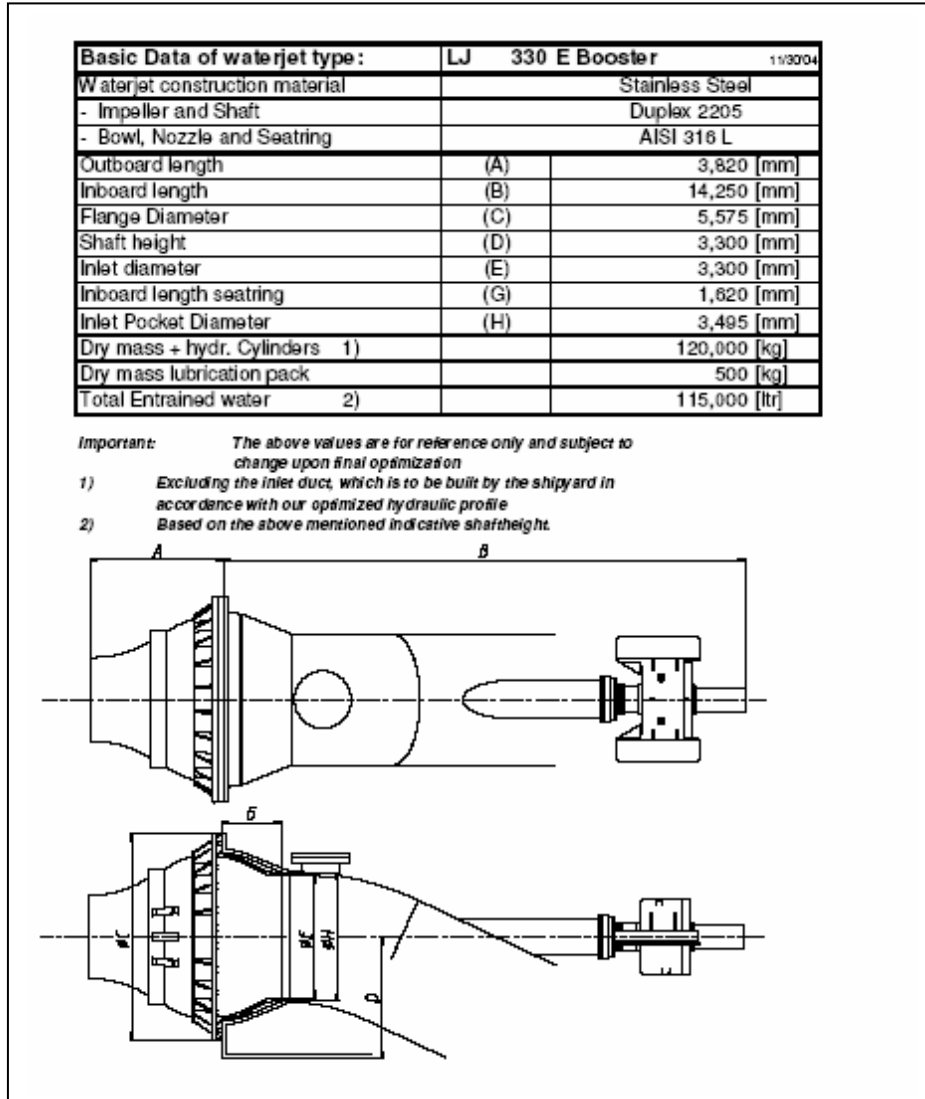


FIGURE 1 A 280 & 330 WJ CHARACTERISTICS FOR HALSS PROPULSION OPTION #1

If to enhance the CDI design for improvement of the cavitation margin of the axial pump, a further reduction in pump size may be achieved. For instance a 280 size instead of 290 with a flange of 3250 – 3500 mm can be used.

To visualize the reduction with an axial pump a bit better, the LJ200E size has a transom flange of 3380mm. So with the axial pump it is possible to reduce a 290E size to roughly the same size as a 200 size jet. The main advantage is that the same performance and less transom occupation can be obtained.



## 2.2 OPTION 2 – WATERJETS IN CENTER HULL AND CPPS IN SIDE HULLS

Description: Same prime movers as Option 1 but with the side hull WJs replaced with CPPs.

For maneuverability there should rudder at each of the side hulls. These would provide most of the power, with the center hull waterjets being used only for speeds above 25kts. This is “mixed propeller-waterjet” variant, for which an industry (Wartsila Lips) has experience with CPP used only for low speeds.

### Assumptions:

The propeller self-propulsion coefficients are assumed as follows:

- Effective axial wake factor : 0.05
- Thrust deduction factor : 0.10
- Relative rotative efficiency : 1.00

The mechanical losses in the transmission system are assumed to be equal to 4% when a gearbox is involved and 2% otherwise. For option III, only the side hull CPP gas turbine option is considered at this stage, as this is the most pessimistic from a mechanical efficiency point of view.

The optimum propeller diameter for this application is 6000 mm (5-bladed propeller with a blade area ratio of 0.75).

### Proposed Solution:

Preliminary sizing of the waterjets for the center hull will be size 280E.

Figure 2 shows the CPP power absorption diagram when the jets are trailing.

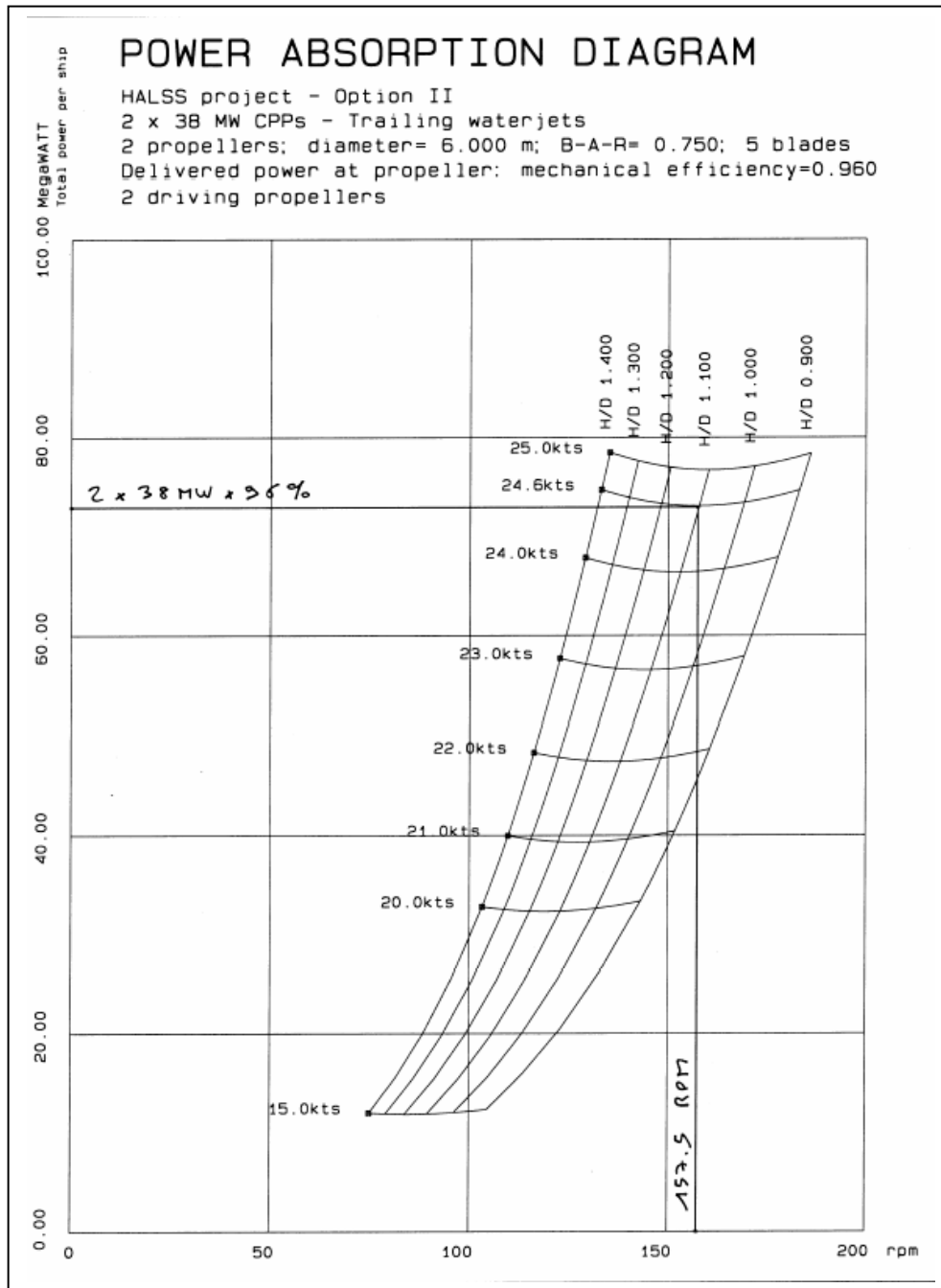


FIGURE 2. 6M PROPELLER DIAGRAM FOR HALSS PROPULSION OPTION #2.

As can be seen on this Figure 2, the optimum propeller speed at 38 MW is 157.5 RPM, giving a pitch ratio equal to 1.10 (at 0.7 R, R being the propeller radius) i.e. a pitch equal to 26.6 degrees.

The maximum ship speed achievable on propellers only is 24.6 knots.



At 35 knots, when the 3 jets are in operation, each propeller will virtually decrease the ship resistance by 150.6 metric tons. In these conditions, the propeller pitch ratio will be equal to 1.337, giving a pitch equal to 31.3 degrees, meaning an increase of 4.7 degrees between the configuration without jets and the configuration with jets. This configuration is qualitatively similar to that of the SAN MEKO 200 corvettes.

### **2.3 OPTION 3 – FPPs IN THE CENTER HULL AND CPPs IN THE SIDE HULLS**

Description: 2x 80MW large slow-speed diesel engines, Sulzer 14 RTA 96, at 102 RPM in the center hulls driving fixed-pitch propellers.

For side hulls there are two variants for consideration:

- 2\*LM2500+ driving CPPs
- 2\*20MW electric motors driving CPPs. The electric motors would be driven by diesel-generator sets located in the center hull.

This is most attractive with superconducting motors.

#### Assumptions:

The propeller self-propulsion coefficients are assumed as follows:

- Effective axial wake factor : 0.05
- Thrust deduction factor : 0.10
- Relative rotative efficiency : 1.00

The mechanical losses in the transmission system are assumed to be equal to 4% when a gearbox is involved and 2% otherwise. For option III, only the side hull CPP gas turbine option is considered at this stage, as this is the most pessimistic from a mechanical efficiency point of view.

#### Proposed Solutions:

##### **80 MW PROPELLERS**

Considering the maximum engine speed of 102 RPM, the optimum diameter for this application is 9000 mm (5 blade propeller with a blade area ratio of 0.80).

Using these propellers only (the side hull CPPs being windmilling), the maximum ship speed is 33.6 knots, the pitch ratio at 0.7 R being equal to 1.335, giving a pitch equal to 31.3 degrees. This can be seen in attached Figure 3.

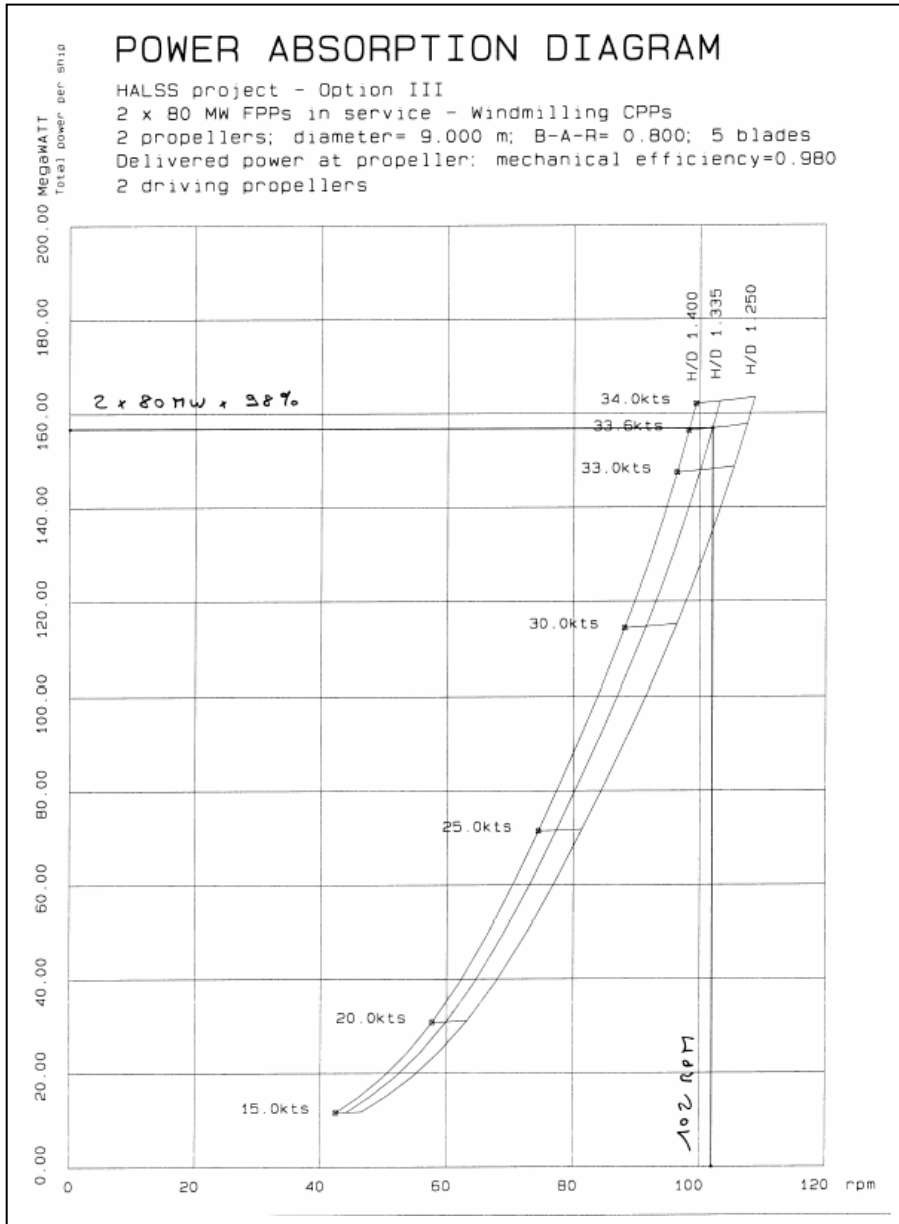


FIGURE 3 9M DIAMETER PROPELLER DIAGRAM FOR HALSS PROPULSION OPTION # 3.

If the Navy accepts this top speed, these 9000 mm propellers can be FPPs. If a minimum top speed of 35 knots is mandatory, the side hull CPPs will have to be used as boosters to give the additional required thrust. The 9000 mm propellers should, in this case, probably be CPPs in order to comply with the two operating modes “with or without side hull CPPs”. We would have to do some additional software development to fully analyze this mixed configuration.

**20 MW SIDE HULL PROPELLERS**

The optimum propeller diameter for this application is 4600 mm (5-bladed propeller with a blade area ratio of 0.75).

Figure 4 shows the power absorption diagram when the 9000 mm diameter propellers are trailing.

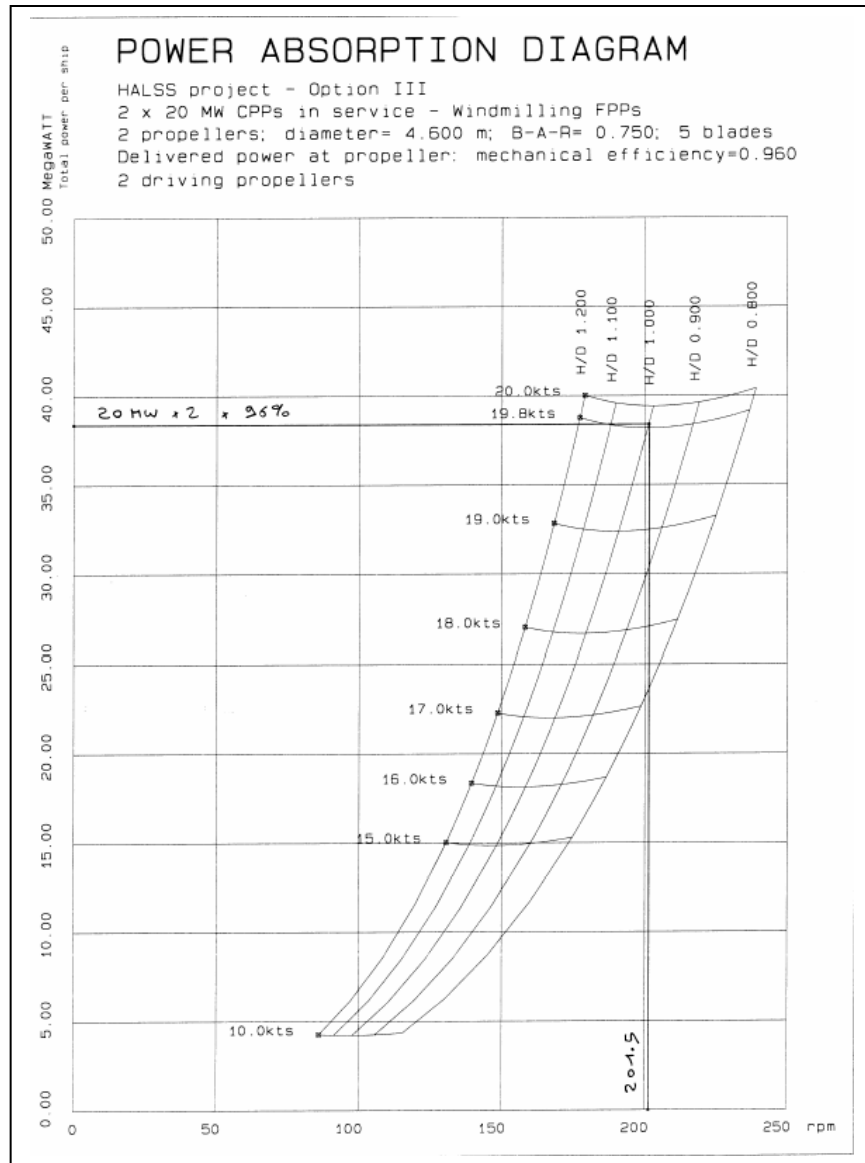
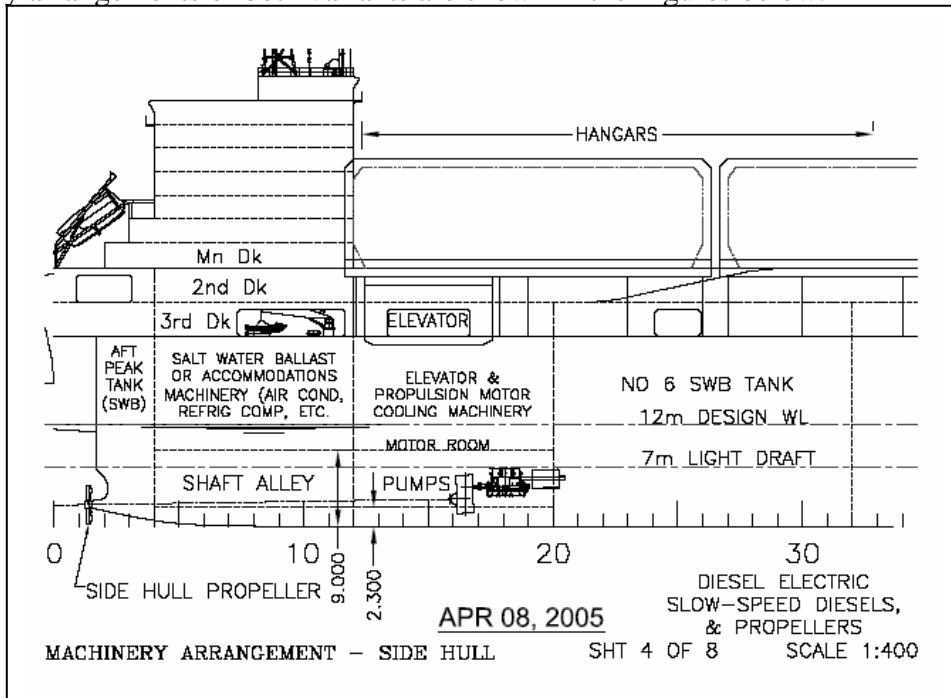


FIGURE 4 4.6 M DIAMETER CPP PROPELLER DIAGRAM FOR HALSS PROPULSION OPTION # 3.

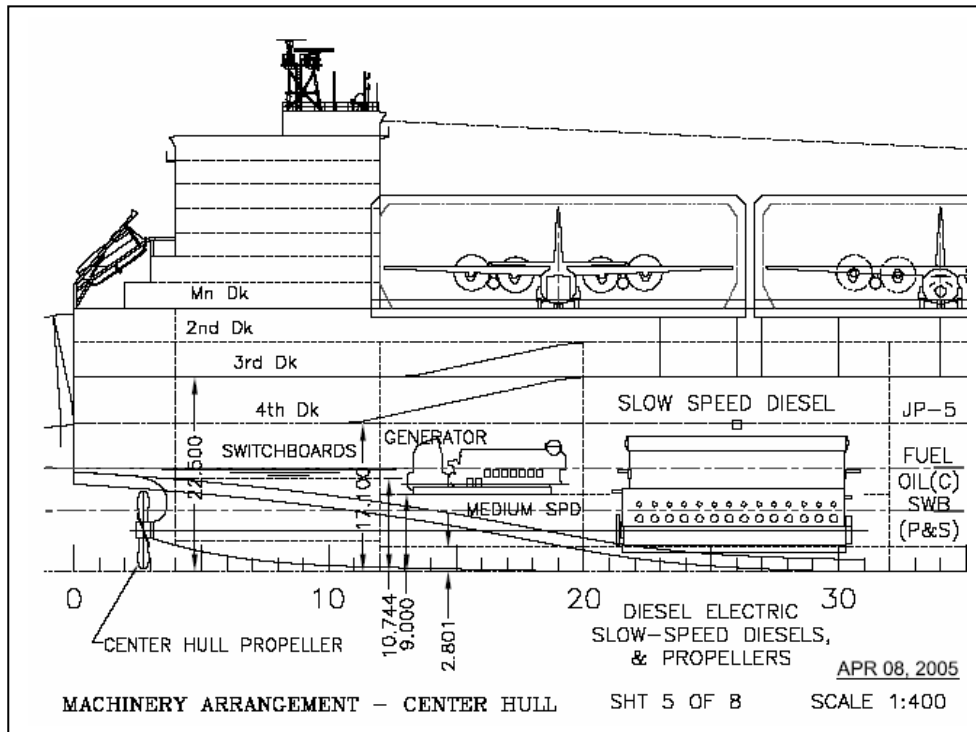
As can be seen on this Figure 4, the optimum propeller speed at 20 MW is 201.5 RPM, giving a pitch ratio equal to 1.00 at 0.7 R, i.e. a pitch equal to 24.5 degrees. The maximum ship speed achievable on side hull propellers only is 19.8 knots. As mentioned above, these side hull propellers could also be used as boosters in order to improve the ship top speed (above 33.6 knots).

### 3. MACHINERY ARRANGEMENT

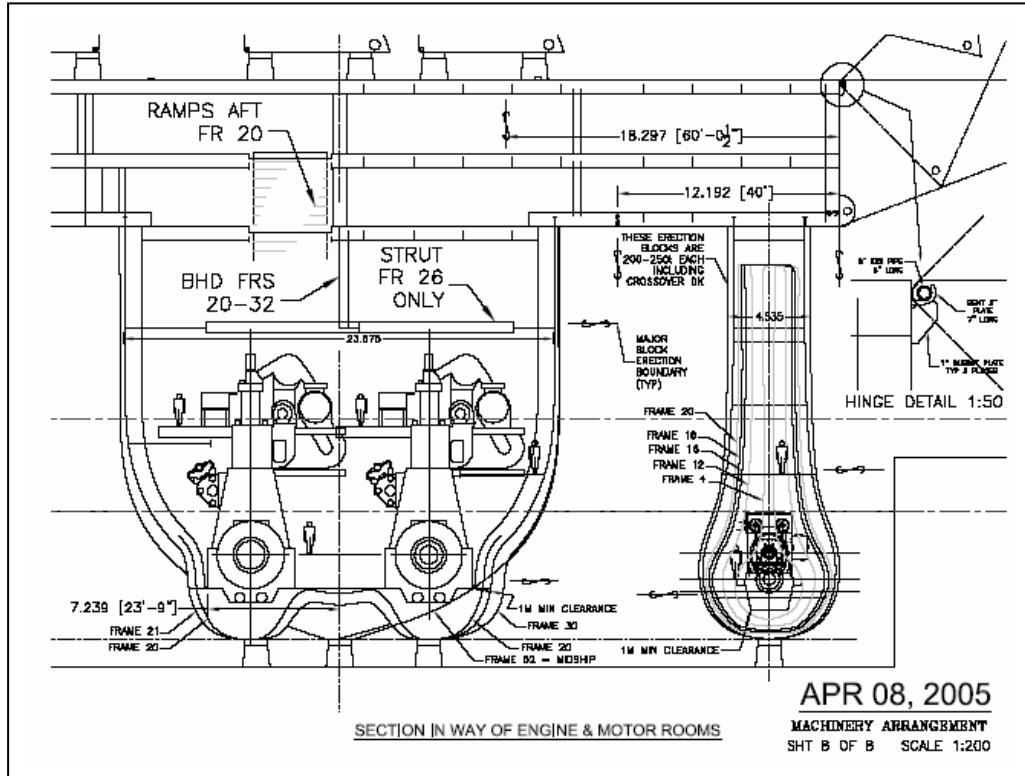
Machinery arrangements of both variants are shown in the Figures below.



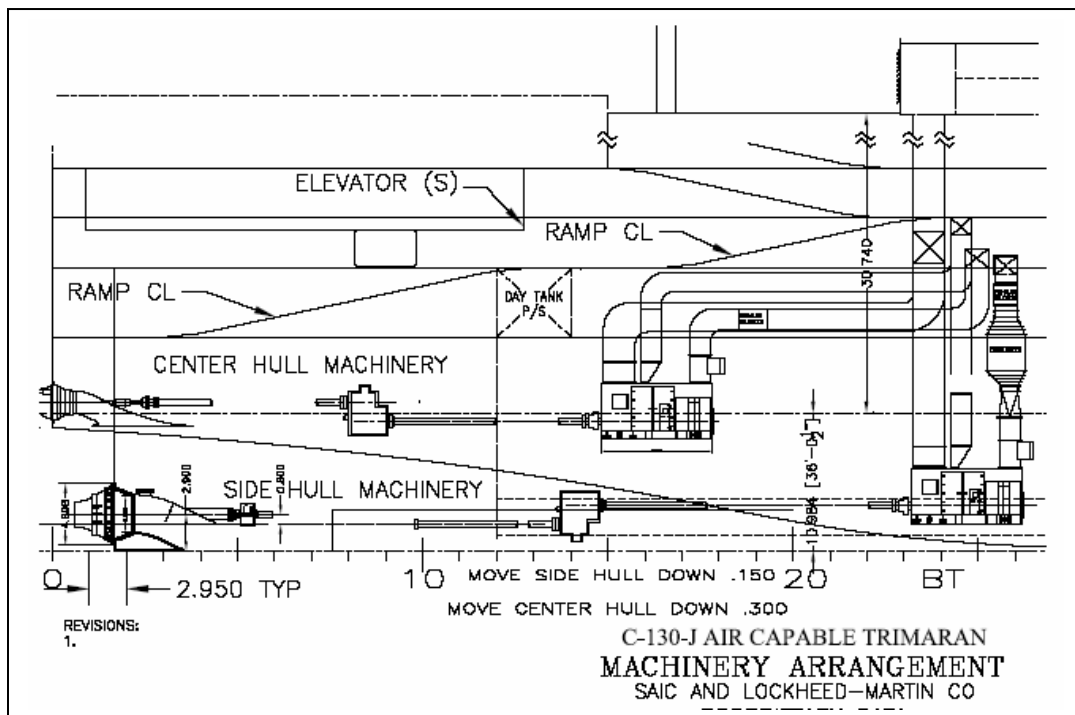
HALSS SIDE HULL PROPELLER PROPULSION MACHINERY ARRANGEMENT



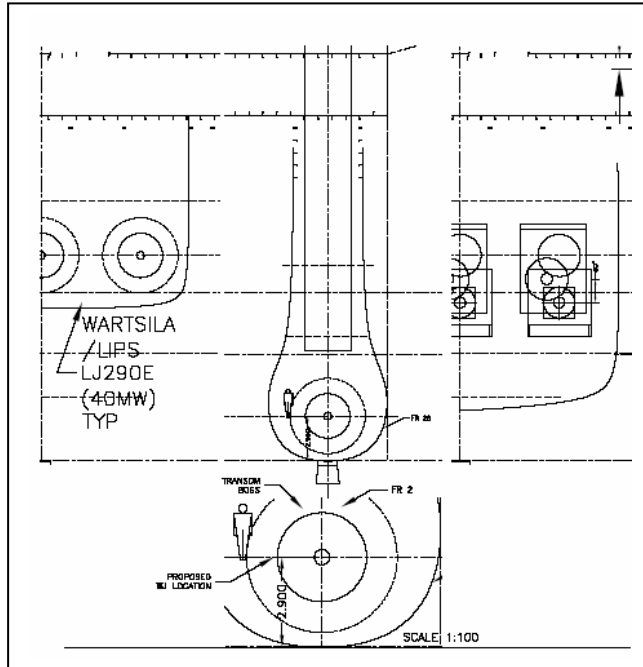
HALSS CENTER HULL PROPELLER PROPULSION MACHINERY ARRANGEMENT



HALSS PROPELLER PROPULSION ARRANGEMENT



HALSS WATERJET PROPULSION ARRANGEMENT



Section view of HALSS WATERJET PROPULSION ARRANGEMENT

#### 4. LESSONS LEARNED AND FURTHER R&D FOR HALSS PROPULSION DESIGN

HALSS power prediction was provided by calculating wave resistance, viscous-inviscid interaction, which results in transom drag and dynamic trim, and scaling correlation factor by MQLT CFD codes, which were verified with previous trimaran model tests.

Total propulsion efficiency coefficient is assumed to be 0.65 for waterjet propulsion option and 0.7 for propeller option.

35 knots are achieved at 85% MCR and at 15% Sea Margin, which is enough to cover drag increase at Sea State 5 due to the excellent seaworthiness of the Large Trimaran ship configuration.

At 200 MW shaft power the HALSS speed would increase to 36-37 knots.

For advanced HALSS version, where the waterjet propulsion option is considered as the basic, results of machinery and propulsion system concept evaluation showed substantially large sizes of the water jets of the mixed-flow type, which are currently produced by Rolls Royce Kamewa and LIPS. If for side hulls water jets these sizes are the result of performance requirements at low speeds, the installation sizes of the waterjets in the center hull can be substantially reduced if to use the axial-type waterjets.



In future it is necessary to consider axial water jets, which can allow to install smaller sized waterjets in the center hull and to avoid additional weights and costs of gearboxes combining prime movers.

The following Machinery Propulsion Options were considered:

- **GAS TURBINE & WATERJETS**

This option is traditional for high speed trimarans developed in previous studies. Three GE LM6000 are the machinery for the Center hull coupled each through the gears with mixed flow waterjet of LJ290 type or in future - axial waterjets, and the same LM6000 coupled with waterjets is the machinery propulsion system for each of the side hulls. Each waterjet would absorb 40MW full power.

- **LOW SPEED DIESEL PLUS MEDIUM SPEED DIESEL/ELECTRIC AND PROPELLERS OPTION**

This option is based on large slow-speed diesels 2 x Sulzer RTA 96 (102 RPM) and Fixed Pitch Propellers (FPP) in the Center hull and conventional electric motors geared with Controllable Pitch Propellers (CPP) or Lips waterjets in the side hulls. The rationale is the substantial fuel saving at long sea voyages, which can fully compensate the increased engines weight and higher propulsion efficiency coefficient. With the Flex option (electronic fuel injection) these slow speed engines can easily run at 40% power - the side hulls could be feathered or run at low power. This would have less drag and much better fuel efficiency. With Gas turbines, which require much more crew attention than a simple electric motor we are putting the prime mover (diesel generator) in the center hull where it is readily accessible to have inspection and maintenance. Standard geared electric motor or future Superconducting electric motor can be installed in the side hull for this machinery option.

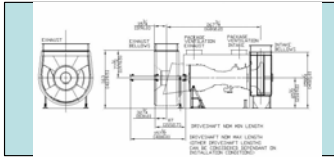
- In **Gas turbine and Waterjet** option the mixed flow LJ290 has very large sizes and for Mid Term technology this option would be more attractive with smaller diameter axial-flow waterjets, which are the subject of further development in current related research projects.
- In **Diesel/Electric and Propeller** option FPP would have about 9 meters diameter, CPP would have about 4.6 meters diameter, and alternative to CPP waterjet would be of LJ200-LJ210 type. For Side hull propulsion a conventional electric motor running at 1200 or 3600 RPM would easily fit in the side hull, driving the propeller or waterjet through a reduction gear which would be smaller than that required for the 36MW gas turbine at 3600RPM. The motor will need MUCH less care and feeding, and its driver will consume much less fuel and need much less maintenance.

## HALSS Machinery Technology Tradeoffs

*Gas Turbines – Diesel – Diesel / Electric Options:*

HALSS Center Hull: **3 x GE Gas Turbines LM6000** or **2 x Sulzer RTA 96 (102 RPM)**

Side Hulls: **LM6000** or **HTS Electric Motor powered by 2 x Wartsila 16V46**



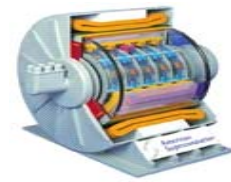
**GE gas turbine  
LM6000 40 MW**



**Sulzer low-speed  
RTA and RT-flex  
engine 80 MW.**



**Wärtsilä  
Medium-Speed  
Diesel**



**16 and 36 MW HTS  
Superconducting AC  
Motor**

## HALSS Propulsion Technology Tradeoffs

*Waterjets – Propellers Options:*

HALSS Center hull: **3 x LJ 290** or **2 x Lips FP Propellers**

Side Hulls: **LJ290** or **Lips CP Propeller or LJ210**



**LJ210E at 20mW  
(26,800HP)**



**World's Largest  
Fixed Pitch Propeller  
66 mW - 94.5 Ton**



**World's Largest  
Controllable Pitch  
Propeller 44 mW**

**HALSS solutions:**

**LJ Waterjets:**  
Center and side hulls:  
LJ 290E ~ 5m  
or LJ 200/Axial ~ 3.5m

or

**Propellers:**  
Center hull FPP ~ 9m/102 RPM  
Side hull CPP ~ 4.6m/201 RPM



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