ROLLA

Combination Surface Propeller and Water Jet Systems[1]

Contents

Abstract

Propulsion systems have developed in the last 20 years to redefine the "high speed" vessel. Forty knots is now considered an obtainable speed. The technology to move into the realm of fifty, sixty, seventy knots and above are now available and have been proven. The conventional propulsion system of fully submerged fixed pitch propeller and inclined shaft has been left behind for the development of surface piercing propellers and water jet propulsion.

These technologies, surface propellers and water jets, are products of differing developmental paths. Generally pursued by differing manufacturers, each has distinct benefits and performance standards. The purpose of this paper is to document by example and theoretical calculation the performance of existing craft and present this data for designers in the development of future craft.

1.0 Introduction - Application of New Technologies

Sea state and fuel consumption are the nemesis of the new high speed craft. Due to sea state or mission requirements consistent top speed running may be impossible or undesirable. The need to be efficient at cruise and then also achieve ultra-high speed has led to multiple power

[1] Paper Presented at the 3rd International Design Symposium on Yacht and Small Craft Design, Chianciano Terme, Italy May 1993

[2] Naval Architect and Marine Engineer, Rolla SP Propellers USA, Melbourne Florida

plants. Cruise is now defined as significantly lower than top speed. Not the traditional 10% RPM drop normally associated with diesels. The understanding of the entire mission of the vessel has led to the development of a new and interesting mixture of technology. Due to the basic speed-power curves of planing vessels, power requirements are substantial with changes in speed. The matching of power to drive system at large speed differential is difficult.

The general designer trend is to believe in one technology, surface propeller or water jet, and let this dominate the entire propulsion selection. Each has their own set of limitations that vary over differing speed ranges. By mixing the technologies the advantages of both can be utilized.

The modern surface propeller has evolved initially in the rigors of racing. 100 MPH and above are common place in today's offshore racers. This has created the realization of multi-blade propellers (4,5,6,7,& 8 blade) for the main stream of surface piercing vessels. There are now thousands of crafts using surface piercing propellers. In recent years propeller technology has advanced to include the 40 knot pleasure, commercial, and military craft.

The commercial water jet has developed from of the needs of today's faster commuter ferry and yachts. Initially the development was centered on the 30-40 knot vessel. Technological development and market conditions created vessels that now can exceed 60 knots. A great example of this was the advances documented in the 60 knot "Destriero."

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2.0 Description of Applications

Examples of mixing the advantages of both systems has proven beneficial. Gentry-Transatlantic and Baglietto's MY "Adler" are recent examples of this. These craft have outboard twin diesel KaMeWa water jet systems. This system is used for maneuvering, getting on plane, and cruise speed operations. Both vessels then incorporate Lycomming TF 40 turbines and Rolla designed surface propellers using Arneson Surface Drives. These systems are used in high speed cruising and ultra high speed modes in tandem with the diesel-water jet systems. The surface propeller is only used when the water jets are under power. There is no intent to use the surface propeller system for on-plane, or maneuvering performance. The intent is to take advantage of the high speed efficiency of the surface propeller.

The significant change in vessel speed has shown little change in propulsive efficiency and power consumption with the water jets. Water jet intake design does get significantly more involved to eliminate the detrimental effects of cavitation while maintaining the low speed efficiency. In documented trials with both vessels engine demanded horsepower has shown only slightly smaller reduced consumption when turbine power is engaged. The marrying of these technologies creates a vessel where both systems are extremely efficient working in tandem.

The use of the Arneson system allows for the optimum trimming of the surface propeller. It's other significant benefit is the ability to trim the propeller clear of the water flow when not in use.

2.1 Example Gentry - TRANSATLANTIC

The Gentry Transatlantic was the first of these vessels to use this solution. The setting of the new Trans-Atlantic record required the utilization and optimization of complex demands.

Vosper-Thornycroft built the hull using the following power plant:

Water jet system (twin systems)
Diesel MTU 16V396TB94 rated 3433 HP at 2100 RPM
KaMeWa 63 series water jet
Gear ZF BW755 1.87:1 ratio
Turbine System
Lycomming TF40 Rated 4000 HP
Arneson ASD-16 Surface Drive
Rolla Designed 33" Diameter Surface Piercing Propeller

Gentry's addition of the surface propeller system to the water jet package was the first of its kind. It was a pursuit of additional speed to ensure the breaking of the transatlantic record. This system proved its value in breaking the existing record by 18 hours. The full combination system was run the entire time except for 1 hour. The vessel has since been converted to a yacht, MY "Gentry Eagle," retaining it's propulsion system.

2.2 Example Adler - Baglietto

The desire of this 110' Motor Yacht was for increased speed. Due to the compact size turbine-surface propeller package, this system was added to the completed vessel. The addition increased the full throttle speed from 32 knots to 44 knots with all systems running at full throttle. This is a remarkable speed gain.

Water jet system (twin systems)
Diesel MTU 12V396TB94 rated 2450 HP at 2100 RPM
KaMeWa 63 series water jet
Turbine System
Lycomming TF40 Rated 4000 HP
Arneson ASD-16 Surface Drive
Rolla Designed 36" Diameter Surface Piercing Propeller

3.0 Analysis of Propulsion Systems - Gentry TransAtlantic

To properly investigate performance of these craft it is best to compare theoretical and actual performance of existing craft. The Gentry-Transatlantic is a very good vessel for this analysis. The vessel was designed by Peter Birkett. Detail is provided through the use of calculations provide by the project naval architect, Thomas M. Ward(1). The method used here to investigate the performance is to provide a straight forward comparison of the expected and actual performance.

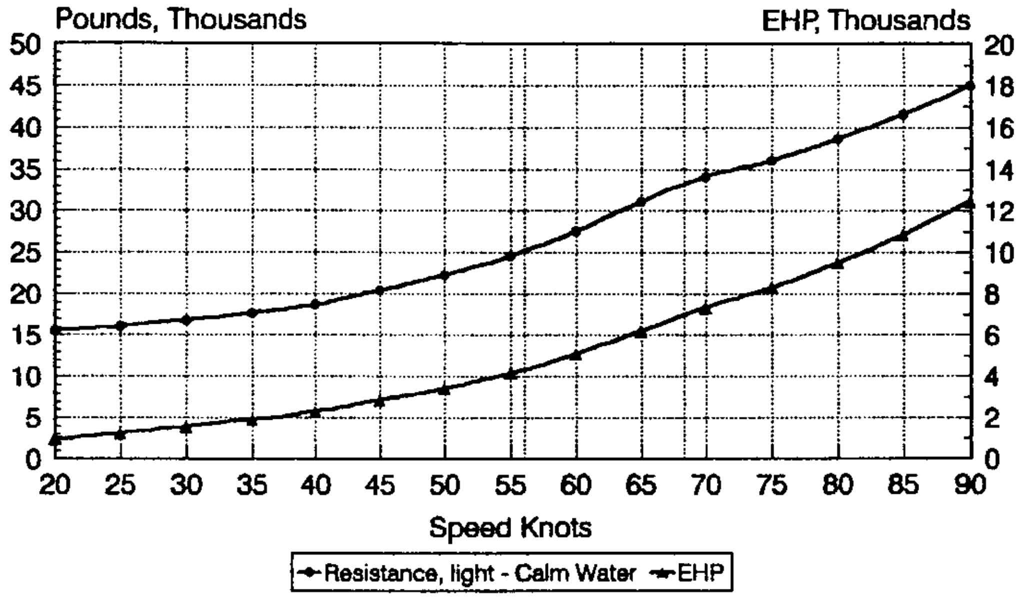
3.1 Resistance Calculations - Comparative Data

Resistance calculations were performed and presented by the naval architect and are provided below in the lightship condition. The method for calculating resistance is not given but appears to be a modified Savtisky calculation based on the following;

Length	109.9 ft
Beam, Chine	23.6 Ft
Deadrise	20.0 Degrees
Light Ship	122,000 lbs
LCG	26.7 ft (from Transom)
VCG	7.5' above keel

Resistance and EHP Curves

Gentry - Transatlantic Lightship



At seatrials in calm seas in the light condition the speeds were documented at 68 knots with all systems running and 56 knots with only water jets with diesels. To keep this in a proper perspective these calculations are only to be used as an estimate.

3.2 Power Plant

As detailed previously the power plant total power is as follows;

Installed Power

Water Jets Only	2 x 3433 = 6,866 BHP
Turbine	1 x 4000 = 4,000 BHP
Total System	10,866 BHP

3.3 Efficiencies

Condition	Speed Knots	EHP	Total Power	Net Efficiency
Water jets only	56	4,240 HP	6,866 BHP	62%
All Systems	68	6,860 HP	10,866 BHP	63%

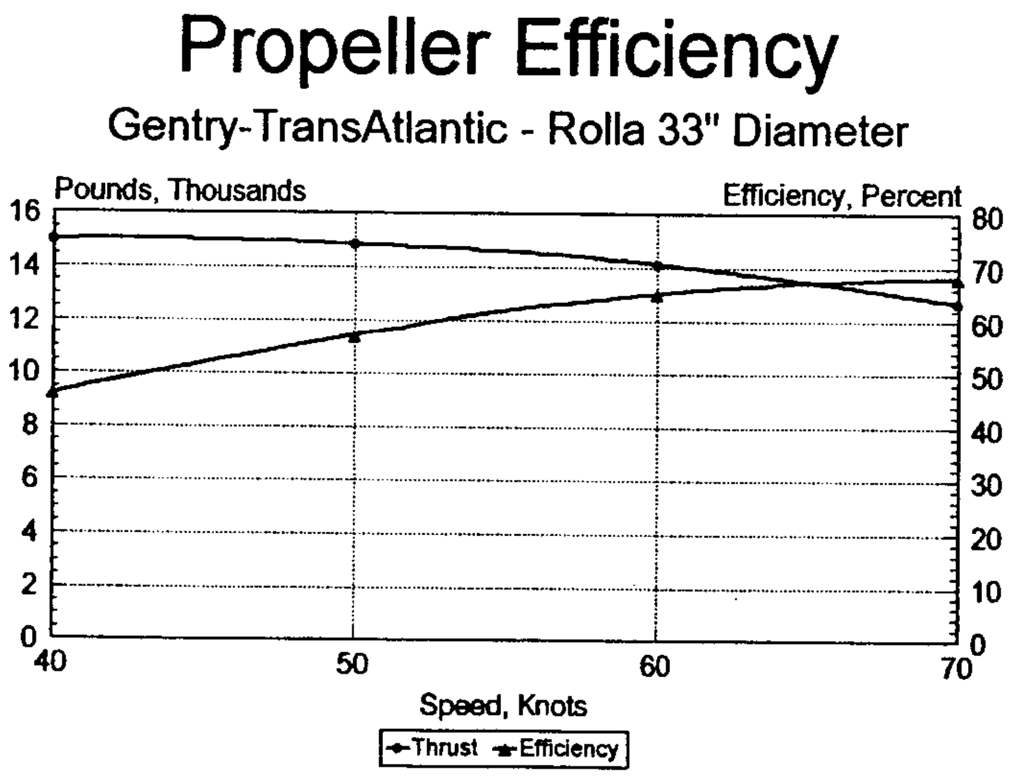
For the wide range of performance requirements of this vessel these numbers are quite encouraging to the match of the systems. The vessel was required to operate at other loadings. As the resistance information was not documented at full load by the previous authors[1] it is not going to be assumed here. For the required performance at the higher loads the system would have needed similar efficiency gains.

3.4 Propeller Efficiencies

Calculations utilized the surface propeller data from the paper of Rose and Kruppa[2]. The propeller had the following particulars;

Diameter	33"
Pitch	45
P/D Ratio	1.36
Blades	5
BAR	105%
Design RPM	1900

Maximum thrusts can be obtained by the above paper giving the following efficiency and thrust versus speed.

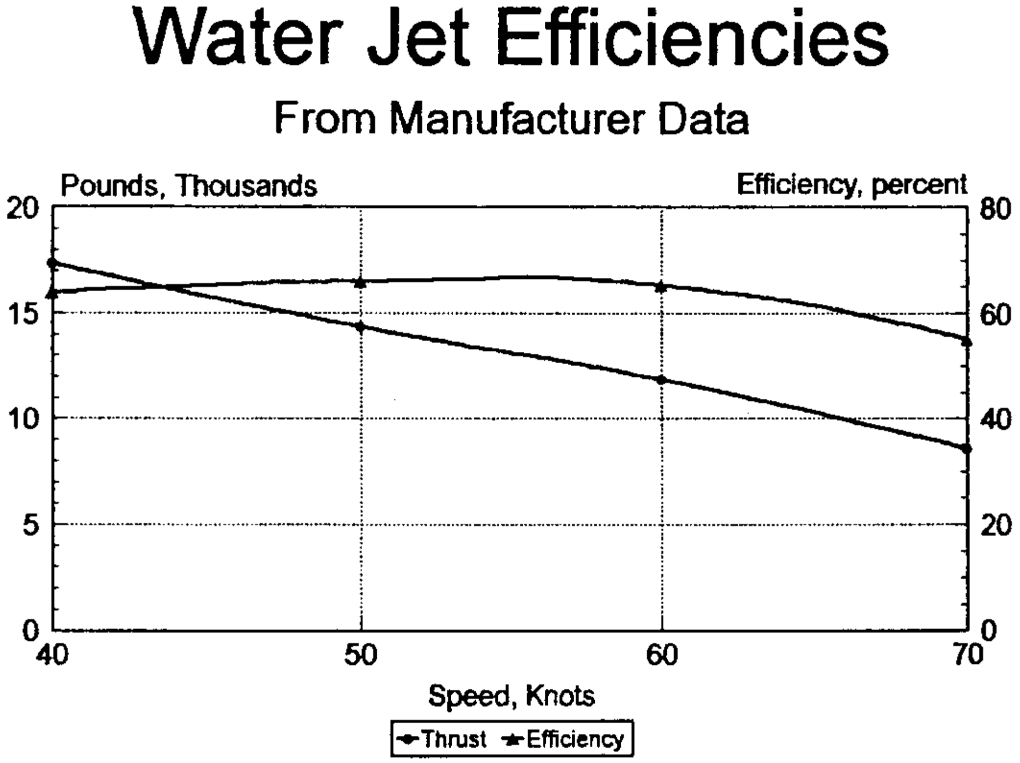


3.5) Water Jet Efficiencies

Detailed information on the expected performance of the water jet was provide to the project Naval Architect by the water jet manufacturer(1). This data per water jet is as follows;

Speed Knots	Thrust Lbs
40	17,324
50	14,763
60	11,819
70	8,539

The above was based on full power deducting 3% for losses. With the above the following efficiency curve can be derived. These efficiencies are similar to the documented results of Svensson (3). The drop off in efficiency at over 60 knots can be attributed to the intake design and optimization for lower speed operation.



3.6 Net System Efficiencies

The combination of the systems allows for an interesting comparison of performance. Using the water jet efficiency of 67% at 56 knots and actual of 62% from above, this leaves a total installed loss of 8% which appears reasonable in todays engine room installations.

In the combined installation the turbine system and water jet systems are much more difficult to accurately confirm the propulsive coefficient and there is possibly some interaction that is not covered here. It is not intended that this be exacting in detail, but justify the trends.

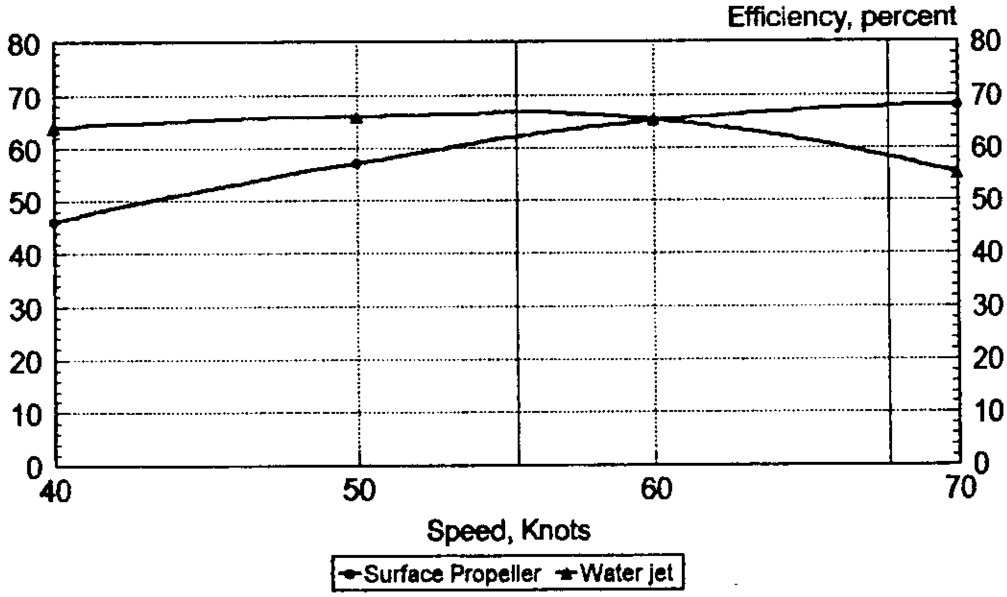
Water Jet Contribution - 68 knots	
Thrust 2 x 9,000 lbs	18,000 lbs
Surface Propeller Contribution at 68 Knots	
Thrust -	13,000 lbs
Total Thrust	31,000 lbs

Total Delivered Horsepower at 68 knots	6,470 hp
Estimated EHP from resistance calculations	6,860 hp
Difference	-6%

From resistance to estimated available thrust there is a difference of a negative 6%. This is before any installed losses and ambient conditions which would be assumed to be an additional 3 to 8% in normal installations. This implies that there is either an overestimate of the resistance calculation or the propulsive coefficients are higher than expected, or both. It is beyond the scope of this paper to determine this. By the above it can be seen that the combination has very favorable results and better than expected. The paper by Ward[1] claims an expected speed of 66 knots was exceeded at trials.

Comparative Data

Surface Propeller and Water Jet



The above plot of the relative efficiencies is similar to the results documented in the paper by Kruppa(3). The net average for the entire operating range is what is important here, 40 - 68 knots. The net efficiencies are good.

4.0 Conclusion

Future applications

The future of combining surface propeller and water jet technology is very promising. The incorporation of optimum efficiency over a large range of operating conditions is a large advantage. The future high speed patrol vessel could use this concept with various craft types. The modern patrol vessel spends significant operating time at cruise or loitering. For obvious reasons the high speed operation is desired in some situations. Gentry's vessel as been tested at length by the US Government for a better understanding of the performance of such vessels. To date this information has not been released to the public.

The yacht market as demonstrated by the MY "Adler" has shown significant gains by the inclusion of these joint technologies. Similar to the Patrol Boats the time spent above 40 knots would generally be limited.

Sea states and fuel consumption have significant effects on the performance of these craft. There are many sea states which it is impossible to proceed at very high speeds. The high speed power plant can be saved for the proper time and still maintain efficient propulsion. The surface propeller-turbine combination is significantly low weight (Especially when compared to the diesel-water jet power plant). There have been other systems that have tried to use one or the other system exclusively. Due to physical and design constraints these systems have had limited success. In terms of optimization of installed power and total system weight these combination systems have proven successful and will find more future uses.

References

(1) Ward, T. and Connor, J: "Design and Performance of the Gentry Transatlantic Racer", SNAME Los Angeles Metropolitan Section, February 1989

(2) Rose, J and Kruppa,C: "Surface Piercing Propellers - Methodical Series Model Test Results" Fast 91, Trondheim, Norway June 1991

(3) Svensson, R: "A Description of the Water Jets Selected for the DESTRIERO", Fast 91, Trondheim, Norway June 1991

(4) Kruppa, C: "Propulsion Systems for High-Speed Marine Vehicles", 2nd Conference on High-Speed Marine Craft, Kristiansand S, Norway, September 1990