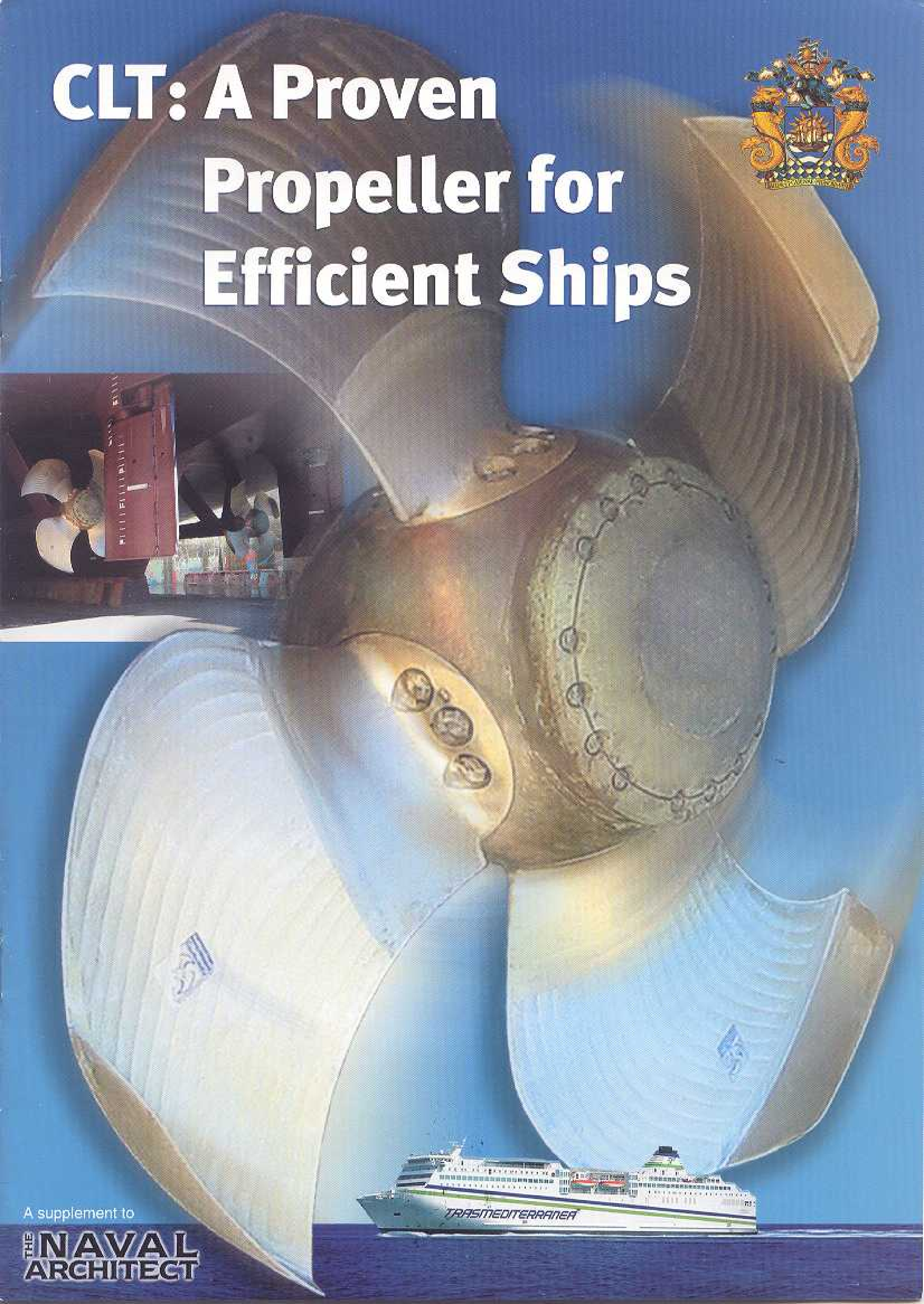
CLT: A Proven Propeller for Efficient Ships



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CLT: A PROVEN PROPELLER FOR EFFICIENT SHIPS

Superferry retrofit boosts SISTEMAR CLT credentials

NEW horizons are opening up for the Spanish CLT (Contracted and Loaded Tip) propeller. This follows the most recent programme of investigative work by a consortium made up of the CLT designer SISTEMAR, the major Spanish group of shipyards Navantia (formerly part of IZAR), El Pardo Model Basin (CEHIPAR), the specialist in vibration analysis and full scale measurements, Técnicas y Servicios de Ingeniería (TSI), and the shipping company Trasmediterranea, followed by the retrofitting of a set of CLT blades to the Trasmediterranea superferry *Fortuny*. Although CLT designs, designed by SISTEMAR (today a new member of the Cintranaval-Defcar group), have been around for more than 30 years, their true acceptance by a conservative marine industry has always been held back by difficulties in extrapolating the scale effect of this tipped creation: model tests have often revealed very pessimistic results, thus masking the most attractive fuel/power savings that can be made.

On three previous occasions, *The Naval Architect* has reported - in some considerable detail - on both the design and installations of CLT propellers (February 1997, page 33/ July/August 1998, page 21/ and July/August 2000, page 30). Notwithstanding this, success with the recent research project elevates the saga of this innovative design to a new level. Since 1976, the CLT has been evolved continuously by Dr Gonzalo Pérez Gómez, who first postulated the advantages that could be expected from this type of propeller. Propellers were designed using SISTEMAR's own New Momentum Theory and the New Cascades Theory.

Up till now, CLT propellers have suffered from a major commercial disadvantage, due to the fact that the performance of model propellers is not similar to the performance at full scale. Scale effects could not therefore be suitably evaluated, and the first CLT propellers were designed only using the special theories developed for this purpose.

In spite of numerous published technical papers promoting the advantages that could be obtained with the original prototype TVF propeller and its successor, the CLT, SISTEMAR can be said to have crossed a technical and commercial desert between 1976 and 1997. During that time, most model basins, shipowners, and propeller manufacturers - with some notable exceptions - looked extremely sceptically at the propeller. Nevertheless, an early project was the 1979 retrofit on the 35,000dwt bulker *Sokorri*. Although that installation was not totally successful, it did reduce propulsion power by 10% and, with the help of two fins, vibration was limited.

Sistemar was able to make such a desert crossing because of its own faith and because some owners did react positively to the CLT's key attractions - to improve ship speed, to reduce fuel consumption, or to reduce noise and vibration. Supporters have included Naviera Petrogas, Flota Suardiaz, the leading Spanish ferry operator Trasmediterranea, Ership, and Cargill International (the latter's ships were featured in *The Naval Architect's* 1997 and 1998 articles), also shipyards Union Naval de Levante and Astilleros de Murueta.

Landmark comparative sea trials

One important landmark was the decision, in 1995, by Cargill International to request from the Spanish shipbuilding group AESA (today largely regrouped as Navantia) that one of two sister 164,000dwt bulk carriers under construction at the Puerto Real Shipyard was to be fitted with a CLT propeller. Sea trial results, published in *The Naval Architect* February 1997, showed that the ship fitted with the CLT propeller (*Cherokee*) required, for the same ship speed, around 12% less propulsion power than her sister *Comanche*. As a result, AESA became convinced of the superiority of CLT propellers over conventional types.

Later, Cargill International, which had already known the benefits of CLT propellers after an earlier retrofit (to cure vibrations) on the orange juice carrier *Bebedouro*, ordered a retrofit CLT propeller for *Cherokee's* sister, *Comanche*, and for other ships in its fleet (the 70,000dwt bulk carriers *Powhatan* and *Paiute*). Comparative results of sea trials with *Paiute* (conventional and CLT propellers) were published in *The Naval Architect* in July/August 1998.

Despite these success stories, CLT propellers were still rejected on several occasions due to the difficulties inherent to the extrapolation of experimental results. Nevertheless, as a result of those sea trials carried out with *Cherokee*, AESA seriously contemplated the possibility of installing CLT propellers on all its future prototypes. Therefore, a decision was made to try and to solve

Trasmediterranea's 2001-built superferry *Fortuny*, which has been suffering from severe propeller-induced vibrations in the off-design condition, has recently been retrofitted with CLT high-skew CP propeller blades. The project marks a new era in the evolution of the CLT tipped design.

the correlation problems affecting this design. With this aim, AESA proposed to CEHIPAR and to SISTEMAR that an R&D programme be initiated on the correlation procedure.

Procedure for extrapolation perfected

As a result, between 1997 and May 2005, four extensive and consecutive R&D programmes, some supported by the government agency Gerencia del Sector Naval, were carried out. During these years, AESA (later IZAR and now Navantia), CEHIPAR, and SISTEMAR worked intensively in close cooperation to obtain the newest most critical and most satisfactory results:

- a new procedure to extrapolate at full scale the results of propeller open-water model tests
- a method for determining the parameters of cavitation tests with CLT propellers (the normal procedure used with conventional propellers is not suitable for this type of tipped propeller).

The conclusions of these series of R&D projects were applied to the model tests carried out to check the performance of *Fortuny's* CLT blades.

In addition, new design features for the propeller emerged, while the extrapolation method will now be able to be included in the International Towing Tank Conference (ITTC 78) list of official procedures.

Breakthrough with *Fortuny* retrofit

A further key breakthrough came with a decision by the leading Spanish ferry operator Trasmediterranea to retrofit CLT blades to its superferry *Fortuny*, built in 2001 by IZAR's Puerto Real yard. This ferry, operating between Valencia or Barcelona and the Balearic Islands, was suffering from severe propeller-induced aft-end vibration under certain low-power off-design conditions - a phenomenon well-known to naval architects. After the retrofit at Union Naval de Barcelona, the vibration was completely eliminated.

For this particular project, geometrical definition of the CLT blades annular sections has been carried out using a new mean line, also developed by SISTEMAR. This is characterised by the fact that its slope at the trailing edge is slightly higher than the one corresponding to the NACA 0.8M mean line. This mean line contributes to increasing propeller efficiency and to minimising cavitation extension at the blade suction side, with consequent reduction of propeller-excited pulse-pressure levels. This geometry is also expected to be employed on future CLT projects.

Levels of global vibration which appeared during manoeuvring and reached velocities of 7.7mm/sec were drastically reduced. With the new CLT blades, cast by the Santander-based manufacturer Casuso Propellers, the equivalent vibration was only 2.6mm/sec. This reduction has been critically important, because in the case of high-skew conventional blades there exists, both in the model field and at full scale, a wide band spectrum of energy distribution over frequencies. Checks have been made that, with the CLT blades, this peculiarity now exists at neither at model scale nor at full scale.

Considerable financial assistance with this project, particularly associated with the turnkey manufacture and installation costs, has been provided by the Spanish merchant bank BBVA Trade, which has wide experience in marine projects. The eight blades were cast, machined, and delivered by Casuso in a very short time of three months (November 2004 to February 2005); the original hubs and shafting were retained. The *Fortuny* CLT blade design and manufacturing was approved and certified by Bureau Veritas, the ferry's class society.

Impressive reductions in sound pressures and required power

In manoeuvring conditions, the level of sound pressure with *Fortuny's* conventional blades reached 84dB(A); with the CLT blades, values were in the range of 60dB(A). Readers will also be most interested to note that, to date, at design service speeds in the range of 21knots-24.5knots, *Fortuny* has yielded power reductions of more than 11%, while at speeds below 15knots, this figure rises to a remarkable 30%. In view of these excellent improvements, Trasmediterranea is seriously considering ordering a set of CLT blades for the sister ferry, *Sorolla*, built by the Barreras yard in 2001.

CLT blades for new naval supply ship?

The success of all this R&D work has also resulted in a hoped-for significant contract from the Spanish Navy. Navantia, the recently hived-off mainly military arm of Spain's nationalised shipbuilding industry (formerly grouped under IZAR) considers the CLT design as being of strategic interest. One of these propellers (CP type and cast in copper-nickel-aluminium alloy, as are normally all CLT designs) is now, hopefully, to be fitted to the Spanish Navy's new BAC double-hull combined tanker and fleet supply ship/tanker *Cantabria*. This is being built and outfitted jointly by Navantia's Puerto Real and San Fernando yards. Model tests have been already conducted, and a power reduction, at constant ship speed, of around 10% is predicted with the CLT blades.

New possibilities in the patrol boat sector

Apart from the new Spanish Navy supply tanker, other interesting opportunities may be opening up in the patrol boat sector, where CLT blades could offer benefits in the variable speed conditions under which such craft operate. Already, at the request of the Italian Navy, the Spanish Navy and the Italian Navy have decided to carry out a joint R&D project (at the El Pardo tank, and at the INSEAN and CETENA research organisations in Italy). Fincantieri and Navantia will also participate in this R&D project.

This work will measure and evaluate differences in the performance of a series of twin-screw (CP blades) Italian patrol boats with optimum conventional blades and with CLT ones. The lead vessel, *Cigala Fulgosi*, has already had observation windows fitted to its hull, in an attempt to find a solution to the same problems as the Trasmediterranea ferry: severe propeller-induced vibration in off-design conditions. This R&D project will include, in addition to comparative full-scale speed trials, special measurements of hull vibrations, noise levels, pressure pulses, and radiated noise.

Optimism for the future

There seems little doubt that a new era is opening up for the CLT propeller in several types of ship, particularly where ship size and speed are increasing but where draught remains the same. Ferries especially fall into this category, calling for high propulsive power density with high-skew propeller blades. In off-design conditions, propeller-induced vibration is highly likely, and the CLT tipped design, due to its special radial loading distribution and the resulting pressure-force distribution on the blades, can provide a positive solution, while also limiting cavitation.

Although physical manufacturing costs for a CLT propeller are, unsurprisingly, higher (between 10% and 25%) than for a conventional model, the propeller diameter will be smaller, and the potential fuel savings at the present crushing fuel prices, highly attractive - payback time for a newbuilding can be only four months. An update on SISTEMAR's newest achievements will be reported to the World Maritime Technology conference, to be held in London next March, also to the Spanish Association of Naval Architects and Marine Engineers.

Note: Some of the material that appears in this Special Supplement is extracted from the paper 'Scale effects in model tests with CLT propellers', presented by various authors from SISTEMAR, CEHIPAR, and IZAR at the 27th Motor Ship Marine Propulsion Conference, held on January 27-28 2005, in Bilbao, Spain, and organised by Highbury Business, Swanley, Kent BR8 8HU, UK.

Model-test and full-scale results for *Fortuny*

SINCE 1997, several series of intense R&D projects have been carried out to try and solve some of the pecularities of SISTEMAR's CLT tipped propeller design, in particular to determine a method to extrapolate model results to full scale, since these had generally produced negative and unattractive results - notwithstanding that several progressive owners had showed the benefits in reduced power requirements (up to 10%) that can be achieved.

Progress to the end of last year was reported in depth at *The Motor Ship's* 27th Propulsion Conference, held in Bilbao, Spain in the paper, 'Scale effects in model tests with CLT propellers', presented by a team from SISTEMAR, CEHIPAR, and IZAR. Approximately two years ago, a new opportunity arose to examine these beliefs further when the leading Spanish ferry operator Trasmediterranea sought help in attempting to solve severe off-design vibration problems (induced by the vessel's original high-skew conventional blades) in the 28,000gt *Fortuny*, one of two recently completed superferries operating to the Balearic Islands.

This article summarises the newest and most successful work carried out in recent months. Retrofit high-skew CLT blades are now in place on the ferry, and included here are some of the most important sea trials results. It is too early to report any documented in-service results but these are expected to be available before the end of this year.

Prior to the full-scale sea trials, including comparative trials carried before the propeller conversion, a set of resistance, open-water, and self-propulsion tests has been carried out by CEHIPAR at the El Pardo basin. In the case of the conventional propeller, the model results of the open-water and self-propulsion tests were extrapolated to full scale applying the ITTC-78 method.

Three different pitches were used to perform the tests:

$H/D_1 = 1,083$
$H/D_2 = 1,020$
$H/D_3 = 0,402$

Fig 1 shows the results of the open-water characteristics. The values of ΔKt and ΔKq to extrapolate these experimental results to full scale were calculated according with the formulae proposed by ITTC and then, in the case of H/D_2, the maximum efficiency changes from ETA0m = 0.612 to ETA0s = 0.614 at the same J = 0.8.

Model test results with CLT blades and extrapolation to full scale

The accompanying graph (Fig 2) shows the experimental results of open-water propeller tests carried out with CLT blades for three different pitch ratios used to perform the self-propulsion tests.

$H/D_1 = 1.108$
$H/D_2 = 1.117$
$H/D_3 = 0.744$

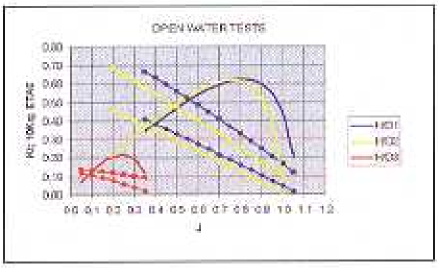

Fig 1. Results of the open-water characteristics at three pitches (conventional propeller).

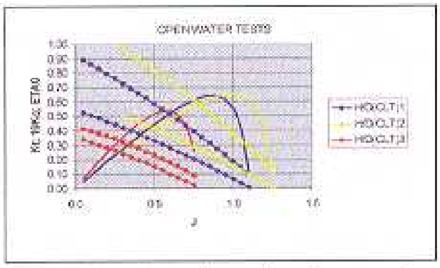

Fig 2. Experimental results of open-water propeller tests with CLT blades for three pitch ratios.

In the case of the CLT blades, the extrapolation of open-water propeller tests was carried out as explained in *The Motor Ship* conference paper, and then, in the case of H/D, the maximum efficiency changes from ETA0m = 0.642 at an advanced ratio of J = 0.850 to ETA0s = 0.785 at J = 0.95.

Correlation factors used in the extrapolation were the same as in the case of those tests carried out with conventional blades. For the nominal pitch in the design of both types of propeller, the full-scale power prediction can be observed in Fig 3.

It can be seen, that at constant delivered power, the speed predicted for the CLT propeller blades is higher than for the conventional ones; alternatively, that there is very good power economy at constant speed. Consequently, the CLT propeller blades were considered advantageous with respect to the conventional blades from the point of view of the propulsion efficiency and, after a check of their cavitation behaviour, it was decided to proceed with casting the full-scale CLT blades.

Speed trial comparisons with conventional and CLT blades

Trial results with conventional blades

On February 3 2005, preliminary sea trials with the conventional-blade propellers were performed off the Barcelona coast. The significant wave height was between 1.5m and 0.5m, and the wind speed between 1knot and 13knots. Depth under the keel was always more than 200m. The draught was practically the same as in the towing tank experimental programme. The hull was clean due to the use of self-polishing paint.

Corrections to the trials data, to obtain ideal conditions, were carried out using the MARIS program, developed for CEHIPAR on the occasion of the C-29 research programme. Table 2 shows the measurements during trials, the correction for differences between the conditions of sea state and wind, and the ideal ones.

Speed trial results with CLT blades

On April 25 2005, after drydocking, a new set of sea trials with the CLT blade propellers was performed off the Valencia coast. The significant wave height was between 0.8m and 0.3m, and wind speed was in the range of 20knots. Depth under the keel was always more than 150m. The load condition of the ship corresponded to the same draught as in the sea trials with the conventional propellers. Again, the hull was clean.

Comparison between the speed-power curves corresponding to conventional and CLT blades

For the conventional propeller, Fig 4 shows the comparison between sea trials corrected for ideal conditions with the self-propulsion tests results. All the points correspond to a propeller speed of 183.4rev/min. In Fig 5 can be seen the results of the corrected values of the sea trials carried out with CLT propellers, plotted against the results of the predictions for full- scale from the self-propulsion tests. In the case of the CLT propellers, the test results agree very well with the measurements during sea trials.

In the case of the conventional propellers, the predictions are slightly optimistic, with respect to the results obtained during sea trials. This deviation can be justified because the sea trials with conventional propellers were carried out before drydocking, and there is an increase of hull resistance due to roughness, which was not taken into account with the extrapolation of tests results.

Taking this consideration in mind, the results of sea trials with both propellers are shown in Fig 6. The better efficiency of the CLT blades obtained at sea agrees very well with the expected results obtained from the tests.

Pressure pulses from conventional and CLT blades

Extrapolation to full scale of model test results with conventional blades

A set of cavitation observations and pressure fluctuation tests for *Fortuny* have been carried out with both conventional and CLT propellers. The port model propeller was used in all cavitation tests except in the case of test No 4522; in that test, the starboard model propeller was used. The tests for the conventional propeller were conducted at two different pitches:

$H_{0.7}/D = 1.083$ $H_{0.7}/D = 0.402$

Extrapolation to full scale of model test results with CLT blades

The CLT propeller was tested in four different conditions at the design pitch position, $H_{0.7}/D$ =

TECHNICAL PARTICULARS
FORTUNY

Length, bp..................................157.00m
Length, waterline.............................169.22m
Breadth.......................................26.20m
Draught, service..............................5.81m
Displacement........................15.327tonnes
Block coefficient.............................0.6149
Midship coefficient...........................0.9688

1.108, and in one condition at the pitch $H_{0.7}/D$ = 0.744 where no cavitation was observed on the CLT blades.

TRIALS DATA		CORRECTIONS					IDEAL CONDITIONS		
Speed (nudos)	Power (C.V.)	ΔV wind nudos	ΔV waves nudos	ΔV rudder Nudos	ΔV courr. nudos	ΔV deep nudos	Speed (nudos)	Pd (C.V.)	RPM
21.75	26500	-0.06	0.14	0.00	0.27	0.00	22.10	26546	183.4
22.30	26591	0.08	-0.01	0.00	-0.27	0.00	22.10	26546	183.4
23.21	29658	0.06	-0.01	0.00	-0.35	0.00	22.91	29672	183.4
22.57	29686	-0.03	0.02	0.00	0.35	0.00	22.91	29672	183.4
23.40	32542	-0.03	0.02	0.00	0.03	0.00	23.42	32559	183.4
23.45	32576	0.00	0.00	0.00	-0.03	0.00	23.42	32559	183.4
23.55	34872	0.00	0.00	0.00	0.19	0.00	23.73	34843	183.4
23.90	34814	-0.01	0.02	0.00	-0.19	0.00	23.73	34843	183.4
11.92	9269	-0.02	0.00	0.00	-0.01	0.00	11.89	9220	183.5
11.88	9170	0.00	0.00	0.00	0.01	0.00	11.89	9220	183.5

Table 1. Sea trials measurements on *Fortuny* (conventional blades), corrected for differences between sea conditions and ideal conditions.

TRIALS DATA		CORRECTIONS					IDEAL CONDITIONS		
Speed (nudos)	Power (C.V.)	ΔV wind nudos	ΔV waves nudos	ΔV rudder Nudos	ΔV courr. nudos	ΔV deep nudos	Speed (nudos)	Pd (C.V.)	RPM
22.62	24721	0.00	0.00	0.00	-0.44	-0.12	22.30	24036	183.4
22.73	23584	0.01	0.00	0.00	0.44	0.12	22.30	24036	183.4
22.44	26992	0.02	0.00	0.00	0.51	-0.11	23.08	26787	183.4
22.46	26840	0.02	0.00	0.00	-0.51	-0.12	23.09	26787	183.4
24.18	30353	0.00	0.00	0.00	-0.63	-0.12	23.67	30210	183.4
22.89	30359	0.02	0.00	0.00	0.63	-0.11	23.66	30210	183.4
24.04	34630	0.00	0.00	0.00	0.44	-0.13	24.61	34525	183.4
24.91	34751	0.01	0.00	0.00	-0.44	0.13	24.61	34525	183.4
21.12	17708	0.02	0.00	0.00	-0.87	0.00	20.26	17543	183.5
11.88	9170	-0.01	0.00	0.00	0.87	0.00	20.26	17543	183.5

Table 2. Sea trials measurements on *Fortuny* (CLT blades), corrected for differences between sea conditions and ideal conditions.

Comparison of test results for conventional and CLT blades

At the design pitch, the pressure pulses corresponding to the first harmonics of the CLT propeller are higher than those measured with the conventional one.

Amplitudes of the first harmonics, measured in the CLT propeller tests, are higher at the first and second transducers, mainly due to cavitation phenomena observed at the outer part of the end plate - which is a difficult area to record at model scale.

Cavitation observations on the conventional propeller model, corresponding to the low pitch, test No 4522-Cav, reveal face cavitation in all propeller disc positions. There is not much extension of the phenomena, but cloud cavitation is present in more than half of the positions of the propeller disc. Tip vortex and sheet root cavitation appear in all propeller disc positions. In the same condition, no cavitation was present on the CLT propeller blades, test No4502-Cav, low pitch.

First-harmonic amplitudes at low pitch are not important, although they are higher for the CLT propeller. Amplitudes of the second, third, and fourth harmonics are higher for the conventional propeller than for the CLT type.

Apart from peaks of the amplitudes at the blade passing frequency and its harmonics, there is broad-band excitation - as can be seen in Fig 7 - at the pressure spectrum of the conventional propeller in low pitch conditions, mainly present at frequencies higher than the second harmonic.

The origin of this broad-band excitation may be the tip vortex and also other cavitation

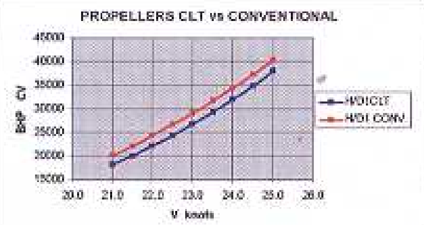

Fig 3. Full-scale power prediction for the nominal pitch in both types of propeller.

phenomena observed during model tests. These intermediate frequency amplitudes, which appear between the blade passing frequency and their multiples, could be dangerous due to the fact that this broad-band frequency may considerably increase vibration of the ship structure.

A pressure spectrum of the conventional propeller model at low pitch is shown in Fig 7 (blade passing frequency 68Hz). A pressure spectrum of the CLT propeller for the same pitch is shown in Fig 8 (blade passing frequency 70Hz). Figs 9 and 10 are zooms of Figs 7 and 8 in the corresponding frequencies between second and third harmonics.

The results shown in this article reveal an optimistic set of figures for the performance of CLT propellers and hopefully help to overcome most previous opposition to wider use of this interesting design. The way could now be open for more installations, which should lead to better propulsion efficiency and fewer vibrations.

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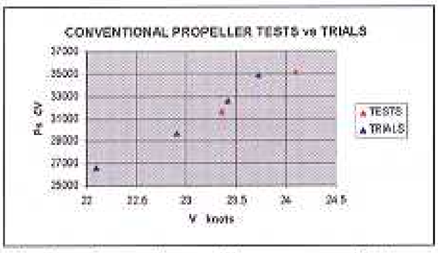


Fig 4. Comparison between sea trials on *Fortuny* (conventional blades) with the self-propulsion results, corrected for ideal conditions. All points correspond to a propeller speed of 183.4rev/min.

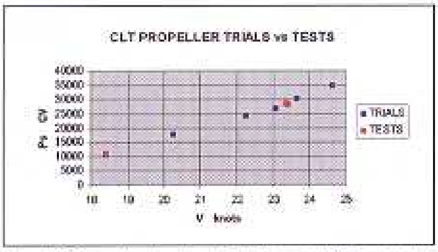


Fig 5. Corrected values for the sea trials results on *Fortuny* (CLT blades) plotted against the predicted full-scale results from the self-propulsion tests.

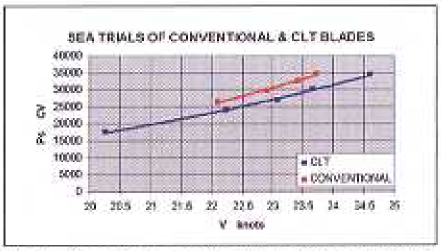


Fig 6. Sea trials results for *Fortuny*, showing both conventional and CLT blades.

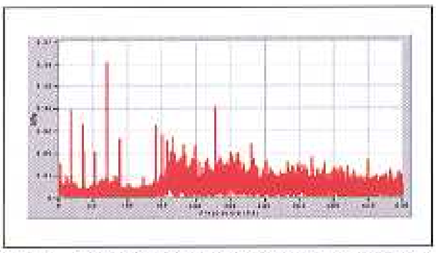


Fig 7. Pressure spectrum of the conventional propeller model at low pitch condition (blade passing frequency 68Hz).

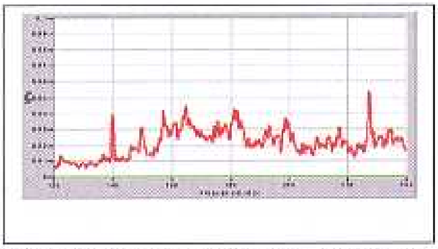


Fig 9. Zoom of Fig 7 (conventional propeller) in the corresponding frequencies between second and third harmonics.

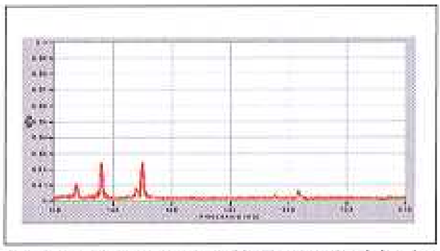


Fig 10. Zoom of Fig 8 (CLT propeller) in the corresponding frequencies between second and third harmonics.

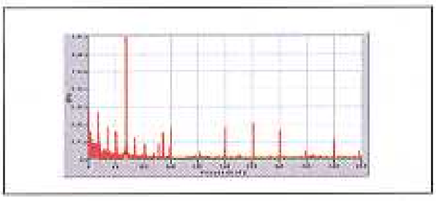


Fig 8. Pressure spectrum of the CLT propeller for the same pitch as in Fig 7 (blade passing frequency 70Hz).

annular sections and potential application to pods'.
2. G Perez Gomez and J Gonzalez-Adalid. 'Scale effects in the performance of a CLT propeller', *The Naval Architect*, July/August 2000.

Trasmediterranea - a positive owner

A KEY player in the chain of organisations involved in the new work on CLT propellers has been the leading Spanish ferry operator Trasmediterranea. Today, this company, which was privatised two years ago, is, with its fleet of 22 ships plus five chartered vessels, a member of the Acciona group.

Trasmediterranea had an urgent need to solve a major technical problem on one of two sister superferries, the 28,275gt *Fortuny*, completed in 2001 by IZAR's Puerto Real yard (today transferred to Navantia). Significant sums of money (up to €6000/day) were being lost because tickets for the first-class accommodation at the stern of the ship could not be sold, and the public rooms there were also uncomfortable - both owing to severe propeller-induced vibration at lower speeds and power - ie, in the off-design condition, when problems can arise, as naval architects know well.

Trasmediterranea already had good experience with retrofitted CLT propellers on several other freight ro-ro vessels (*Ciudad de Burgos*, *Ciudad de Alicante*, and *Ciudad de Cadiz*, also on some hydrofoils) but particularly on an earlier new freight ro-ro vessel, *Superfast Levante*. The latter was a one-off design built in 2001 by Union Naval de Valencia. A ship speed of 0.35knots higher than contract had been achieved, noise and vibration were well below ISO standards, and special measures for hull vibrations immediately above the propellers had shown a low level of pressure pulses produced by cavitation developed on the blades.

First *Fortuny* sea trials with CLT blades were carried out with the fin stabilisers active and were therefore not comparable with those completed with conventional blades, carried out with the stabilisers retracted.

However, a second sea trial earlier this year confirmed the success of the project, with much-reduced vibration levels; also reduced to a very significant level was the fuel consumption. Now, monitoring of fuel use will take place over coming months, and it is anticipated that by the end of this year, figures be available. Maybe the time to recoup all costs will also be known - an interesting factor for other owners.

The company is additionally trying to compare savings with those of sister *Sorolla* (built 2001 by Barreras); this is difficult since she is sailing on a different route - Barcelona to Palma de Mallorca (Majorca) in a different trading pattern. Nevertheless, at current IF380 heavy fuel prices of around US$240/tonne, any savings are certain to be most attractive. Should the CLT blades on *Fortuny* prove a success, a further set could be ordered for *Sorolla*.

Fortuny (like her sister) is installed with twin propeller shafts driven by four Wärtsilä 8L46A medium-speed diesel engines (4 x 7240kW at 500rev/min). Generally, the engines (normally two or three operating at one time) are run at constant revolutions so that best use can be made of the two 1570kW alternators driven off the gearboxes on the ship's principal service from Barcelona to Mahon (Menorca).

CLT propellers for new freight ferries?

In a new development, Trasmediterranea is close to placing an order for two new pure ro-ro ferries, designed to increase capacity on its long-haul Spain-to-Canary Islands service. It is interesting to record that the company is experiencing a big growth in the number of lorries carried on all routes (compared with only 2% growth in passengers). These ships could also be candidates for CLT propellers.

Speedy CLT propeller production by Casuso

ALTHOUGH only five years old, Casuso Propellers is growing into a major force in the casting and machining of marine propellers, having succeeded in breaking into a difficult and highly competitive market - and playing an important role in the CLT retrofit for Trasmediterranea's passenger/vehicle ferry *Fortuny*. The factory is situated at Entrambasaguas, just outside Santander in northern Spain, and is staffed by youthful and highly qualified personnel. They are assisted by excellent technical resources and production capacity, plus efficient quality control.

Products include monobloc propellers up to 5.50m diameter and 10tonnes weight, and CP blades in weights up to 5tonnes; CP finishes can be either Class II, Class I, or Class S, and they can be balanced on x and y axes. Hubs up to 7tonnes weight and other CP components, also elements for hydraulic turbines, are additionally produced.

Manufacturing capacity is close to 400tonnes annually, with a flexible philosophy that makes it possible for the company to adapt production to the special requirements and characteristics of customers. Casuso products are approved by most major class societies - ABS, BV, DNV, GL, LR, and RINa - and the company is certified to ISO 9001:2000 standards for both the manufacture and repair of propellers.

This combination of attributes enabled Casuso to deliver successfully the eight new CLT CP blades - 4.36m diameter and 0.52 blade are ratio - for the *Fortuny* retrofit in a very short period of time. Originally, the plan had been to take a final decision to proceed with manufacture at the end of July 2004, following analysis of model results by CEHIPAR. However, some tests were delayed, and consequently the decision was not taken until mid-November 2004; therefore, only a very short period was available until the scheduled drydocking in mid-February 2005 at Union Naval de Barcelona.

Measuring improvements with CLT propellers

FOLLOWING the retrofit of CLT propellers to the Trasmediterranea superferry *Fortuny*, a key set of onboard measurements were made by Técnicas y Servicios de Ingeniería SL (TSI), a Spanish company which has been specialising in shipboard measurements and testing for 28 years. The three detailed tasks, which also included essential comparative parameters recorded prior to the retrofit, were:

- power measurement on both shaft lines
- vibration and noise measurements before and after the new propellers were installed
- pressure pulses induced by the new CLT propeller above both shaft lines.

The target of these measurements were to check and compare the behaviour of the ship with both her conventional propellers and with the new CLT blades, from the following points of view:

- power efficiency
- pressure pulses
- vibrations onboard
- noise onboard.

In February 2005, tests with the original conventional CP propellers were carried out, and after that, measurements with the new CLT propeller took place in two phases. Within this project, TSI has been responsible for establishing all the protocols, equipment, and accessories needed for this critical task. The whole operation was a challenge since it had been decided to present the signals from 40 channels at once on the computers; this allowed the engineers to analyse pressure pulses, vibrations, and noise, all in real time.

From the project point of view, it is important to note that the visit to *Fortuny* was not new for TSI, since a vibration and noise prediction had been carried out by this company during construction of the ferry at IZAR's Puerto Real yard.

Pressure pulse measurements

Fortuny's pressure pulse measurements have been one of the primary goals in this project. The main target was to measure the total force induced in the aft of the ship by the propellers and to compare these results with those estimated under model conditions by CEHIPAR. It was extremely important to correlate model and full-scale results.

Results

Vibration levels with *Fortuny's* conventional CP propellers at constant revolutions, using the ISO 6954:2.000 as classification standard, proved to be good at medium- and high-load levels (steps 5 to 10), but at lower levels (step 4) vibration levels were too high, in some cases, as in the steering gear room, vibrations were severe, although in some other decks the level was acceptable.

Vibrations at low loads showed that the maximum levels were in the bottom of the hull, and that the lower levels were at the top (deck 9).

Noise levels in the ship, according to IMO A.468 XII, have similar behaviour to the vibration levels; in steps 5 to 10 the levels are lower than those set by the code, but in step 4 the noise levels are over the limits imposed by the code in some places.

Measurements with the retrofitted CLT propellers show that vibration levels at modest power output are lower than those measured with the conventional blades, while in the constant-revolution mode, for medium and high power levels, vibrations levels are almost equal to those measured with conventional propellers. They were a little higher for step 10 but always good according to ISO 6954, except for deck 9 where a slight increase in vibrations in all steps is noticeable, passing from good to acceptable. With respect to noise measurements, results are very similar to those obtained with the conventional propellers except for step 4, were the levels are now according to those imposed by the IMO A.468 XII.

In combinator mode, the results for both propellers show good behaviour in all aspects, also regarding noise and vibration, except for the comments stated above when the ferry is operating at higher power (steps 8 to 10), where the propeller revolutions are the same for both modes.

Pressure pulse results

Those results obtained from the measuring of pressure pulses were processed using LMS SCADAS III and Teslab V5 and Matlab.

The study of the spectrums (Fig 1) obtained show peaks in all the frequencies related to shaft rotation pass (SFP) and blade frequency pass (BFP). Peaks associated with SFP show no appreciable reduction until the range 40Hz-50Hz is reached, but in the peaks associated with BFP this reduction appears with the second harmonic. This is normal for points close to the propeller; when spectrums in fields far from the propeller are studied, the second BFP harmonic becomes the most important - this is more noticeable at high power.

Regarding the evolution of BFP harmonics with the power, the first harmonic shows a constant increment with the power, but the second harmonic shows a maximum in its evolution at medium power. In addition, the evolution of the pulse phases with the power has been studied, and analysis revealed that evolution of the phase of those points on the starboard side of the propeller is homogeneous and opposite to the phase of those points in the port and starboard side of each propeller.

The evolution of the phases shows points of conjunction between port side and starboard side; this is very important because at those points all the pulses are in the 'same direction', and then the forces will be higher.

Another important fact obtained from the study is the area of pressure influence generated by the propeller in the aft; for this study the pulse phases are not taken in to account.

Concerning the results, we can say that the shape of these surfaces is almost constant with power for the first BFP harmonic, but for the second harmonic, its behaviour shows very different shapes, which probably reveals

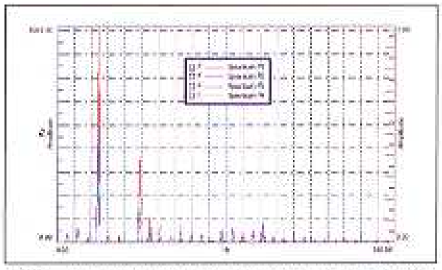


Fig 1. A pressure-pulse spectrum for the CLT propellers, showing peaks in all frequencies related to shaft rotation and blade frequency pass.

cavitation effects. In the calculation of force induced by the pass of the blade, only the first and the second harmonics have important values.

The evolution of the force first harmonic with the power shows two maximums, and if the results of the first BFP harmonic of the pressure pulses are checked, a direct correlation can be seen. However, this relationship can be found if the phase evolution graphics are examined: there it can be seen how the phases of the pulse are coincident at the points with the peaks.

The evolution of the second force harmonic is similar to the previous one, except that here the second BFP harmonic of the pressure pulses has a peak in its evolution; this shows that the force of the 2nd harmonic is almost equal to that of the first harmonic at medium power.

Finally, regarding the pulses measured in the model by CEHIPAR and the pulses measured by TSI in the ferry, it can be said that correlation between the results is generally good. Only a few points were out of range but the mean value of all pulses is almost equal to those measured in the ship. In the same way, the value of the first force harmonic obtained from the ferry was very close to that obtained from CEHIPAR's model, which again means that the phase correlationis good.

Conclusions

After reviewing all the information measured during the trials and processed ashore, the most important conclusions of this project for TSI are:

- the problem with vibration levels at low power and constant revolutions has been solved, and the new levels are good for almost all decks and at all steps, according to ISO 6954
- noise levels with the new CLT propellers are in accordance with IMO A.468
- the resultant force calculated by TSI, by means of the pressure pulses obtained, is according to the results of vibrations measured
- the area of influence of the pressure pulses for the new propellers has been determined
- there is good correlation between the results measured and calculated by CEHIPAR in the model, and those carried out by TSI on the real ferry. However, further investigations are needed for the second harmonic.

Complete packages from the Cintranaval Group

Ship design and CAD/CAM software.

SINCE its foundation, the design office CINTRANAVAL-DEFCAR SL has become one of the top technical companies in the Spanish shipbuilding industry. A high degree of specialisation as a designer of all type of vessels, allied to a programme of continuous CAD/CAM software development, is the key factor in the company's success.

From its origins as CINTRA SA - founded in 1964, CINTRANAVAL SL claims a special position because of its prolific activity, having designed more than 500 vessels to date. This vast experience ranges from preliminary design to detailed engineering, spanning all stages of a project and subsequent construction.

In March 2003, CINTRANAVAL merged with the Madrid-based technical consultancy DEFCAR Ingenieros SL, a company of CAD/CAM software programmers and originator of the DEFCAR system, which is used in 24 countries. This move combined design and software experience, with the aim of offering new, innovative marine products and services. The result was the company CINTRANAVAL-DEFCAR SL. With the intention of responding to the ever more demanding requirements of the market, and being conscious that swift response and a capacity to offer complete packages are essential requirements to success, the CINTRANAVAL Group was founded in June 2005.

Hydrodynamics and ship propulsion

A few months ago, CINTRANAVAL-DEFCAR became the majority shareholder in SISTEMAR, the company specialising in hydrodynamics and ship propulsion. Staffed by naval architects noted for their research into hydrodynamics, SISTEMAR is originator of the high-efficiency CLT (contracted and loaded tip) propeller. After many years of research and development, and using unconventional blade geometry, SISTEMAR created this special design, which can offer not only lower fuel consumption, but also a substantial reduction of noise and vibration levels, when compared with conventional types. To date, more than 250 CLT propellers have been installed.

Besides promoting high-efficiency CLT propellers and being involved in international research, development, and innovation (so-called R+D+i) programmes, SISTEMAR works as a consultant in hydrodynamics. This is a key stage during the project of any vessel, and such expertise allows more efficient hull forms to be created, thus minimising resistance.

International project coordination

With shipbuilding becoming almost totally globalised today, it is absolutely necessary to seek collaboration agreements with other countries. Nevertheless, this prospect is not affordable for many companies, because of its structure and the necessity to fulfil very short delivery times plus the need to divert staff into external projects. To try and overcome this problem, and with the aim of supporting shipowners and shipyards in international deals, SIATEG SL became part of the CINTRANAVAL Group in June 2005.

Having a broad international experience, SIATEG's experts offer the following services:

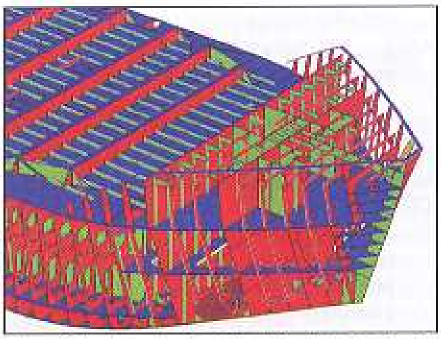
- consulting on mixed construction of vessels in both Spanish and foreign shipyards
- logistics of international projects
- technology transfer, training, and technical assistance abroad
- technical and commercial support to shipowners in other countries.

Likewise, SIATEG also will coordinate international operations for the CINTRANAVAL Group, having the technical support of all its companies.

Shipping consulting

Recently, a consulting firm specialising in shipping and port activities, Bilbao Plaza Maritima SL, also has reached an agreement of collaboration with CINTRANAVAL-DEFCAR. Through this, the company has been split into two new divisions: Bilbao Plaza Maritima Shipping and Bilbao Plaza Maritima Puertos. The former has just become part of the CINTRANAVAL Group and can provide the following services:

Retrofitted Sistemar CLT propellers on the Trasmediterranea ferry *Fortuny*.



An oil tanker designed and developed by CINTRANAVAL-DEFCAR using the DEFCAR system.

- technical, commercial and legal consulting
- surveys and inspections
- feasibility studies.

With regard to shipping activities, Bilbao Plaza Maritima has broad experience in studies and technical consulting in many different countries. Among this should be highlighted work on ESSS (European Short Sea Shipping) and a large number of feasibility studies for shipyards and fishing ports ranging from Latin America to Southeast Asia.

On the other hand, Bilbao Plaza Maritima has also carried out many important works in the field of ports, mainly regarding planning, organisation, management, and operating, as well as sea and inland transport. The new company, Bilbao Plaza Maritima Puertos, will continue with these tasks, and even though not part of the CINTRANAVAL Group, it will keep close contact with all group members.

CINTRANAVAL GROUP

Cintranaval-Defcar, S.L.

Consultancy services
Ship design
CAD/CAM software, The DEFCAR System

SISTEMAR

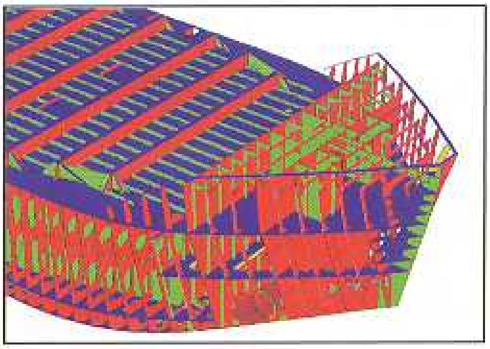
Hydrodynamics
CLT Propeller

SIATEG, S. A.

International projects coordination
Logistics
Training

BILBAO PLAZA MARÍTIMA *Shipping*

Technical, commercial and legal consulting
Survey and Inspections
Feasibility studies



REFERENCES

- 40 Years' experience in 30 different countries
- 500 high-tech and innovative projects
- 100 CAD/CAM DEFCAR's users
- 250 high-efficiency CLT Propellers
- 50 survey and feasibility studies abroad

STYLE

- Complete independence
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