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Advances in Technology of High Performance Ships in China

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Abstract: The research and development of high performance ships has been extensively carried out in China for years. This covers wing in ground effect vehicles, hydrofoil vessels, small water-plane area twin hull ships, wave-piercing catamarans, hybrid hydrofoil ships, air cushion vehicles,surface effect ships,high speed multi-hull ships, etc.This paper briefly describes the progress of technology in this wide field made in China,mainly providing the overall view of the achievements and the major products, rather than mentioning the detailed technical problems.
Key words: high performance ships; WIGs; hydrofoil vessels; SWATHs; wave-piercing catamarans; air-cushion vehicles; SESs
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1 Introduction

It was said that a bird could never overtake an airplane,a horse is unable to catch up a train, and however a small fish can easily swim ahead of a conventional ship. This means that the present ship science and technology is far from advanced when comparing with the existing features of ocean biosphere.It is certainly a dream that a ship could travel in waves with as small resistance and excellent seaworthiness as a fish.The effort made in this direction by the naval architects is partly in the development of technology of "High Performance Ships".Comparing with the conventional displacement ships with their weights being supported by the hydrostatic forces,the high performance ships are those types of ships that partly or totally rely on the hydrodynamic, aerodynamic, or aerostatic forces, or apply new concept of ship hull forms to apparently reduce their resistance and wave responses.

Varity types of high performance ships have appeared since the middle of last century.

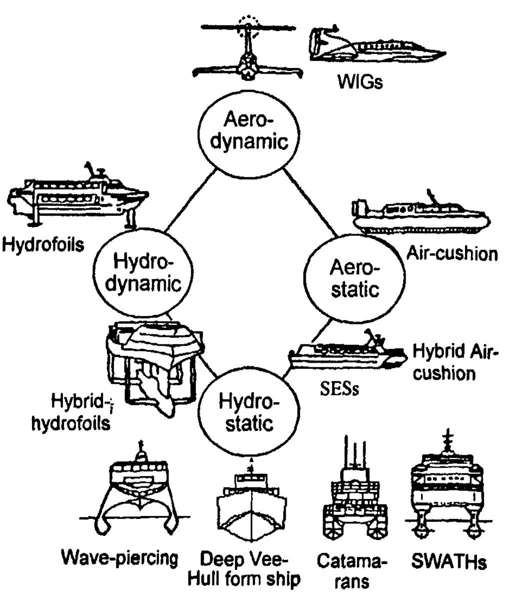

Fig.1 Different types of high performance ships

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Biography: WU You-sheng(1942-), male, Ph.D., researcher of CSSRC, academician of CAE.

Research and development of high performance ships are the one in marine technology filling with most profound and creative new technical concepts and ideas. The progress made in this field all over the world during the past decades seems to have been great with a speed rate faster than ever before.It was there in China that almost all types of high performance ships were studied since 1950s, ranging from wing in ground effect vehicle (WIGs), hydrofoil vessels, air cushion vehicles (SCVs), surface effect ships (SESs), small waterplane area twin hull ships (SWATH), wave piercing twin-hull ships, high-speed multi-hull ships, and hybrid hydrofoil ships,etc, as shown in Fig.1.

Many research institutes and universities in China have been quite active in the research and development of high performance ships. The major organizations involved in this field include China Ship Scientific Research Center (CSSRC), China Ship Design and Development Center (CSDDC), Marine Design and Research Institute of China (MARIC), Shanghai Merchant Ship Design & Research Institute (SMSDRI), Chinese Academy of Science and Technology Development (CASTD), Beijing Institute of Aerodynamics, Shanghai Jiao Tong University (SJTU),Harbin Engineering University (HEU), Wuhan Technical University, Dalian Technical University, Huazhong University of Science and Technology, Naval Engineering University (NEU), Dalian Maritime University,etc. The list is by no means complete, and the shipyards,which made great efforts in developing and manufacturing the high performance ships, are not listed here.

The advances in high performance ships in China based on years research work of above-mentioned organizations are summarized in this paper,mainly providing the overall view of the achievements and the major products, rather than mentioning the detailed technical problems.It is sure that the contents included in this paper are unable to cover all the achievements of technical progress in this field in China. The quoted literatures are not complete either. However the authors do hope that this paper could help the worldwide community of naval architects to know more about the history and the present situation of the technical development of high performance ships in China.

2 Wing in ground effect vehicles (WIGs)

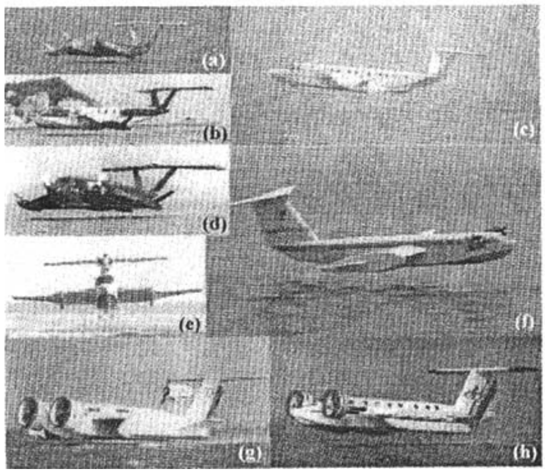
Soon after the Russian "Caspian Sea Monster" was revealed to public in 1967, CSSRC started to explore the axiom of WIGs. Its first WIG (961) was tested in 1968. Since then comprehensive research work was insistently carried out,resulting in 6 types of WIGs of the weight from 0.4 to 6 tons successfully designed and built during the year 1968 to 2003 as listed in Tab.1.Also included in the table are the WIGs developed by Marine Design and Research Institute of China (MARIC) and Chinese Academy of Science and Technology Development (CASTD). Fig.2 (a)-(e) show five of the WIGs designed by CSSRC. The one-man operated WIG "902" was the first one built in China in 1983, which thoroughly overcame the longitudinal stability problems and successfully took nearly a hundred flying trials on water sur-

Tab.1 WIGs designed, built and tested in China

Types	961	902	750	XTW-1	XTW-2	XTW-3	751	DXF-100 (TY-1, 2)	XTW-4	AB-606	XTW-5
Year of test	1968	1983	1986	1988	1993	1997	1998	1998	1999	2001	2003
Weight	720 kg	400 kg	745kg	950 kg	3600 kg	4000 kg	7500kg	4800kg	6000 kg	2000 kg	4200 kg
Capacity (persons)	1	1	2	3~4	15	12	20	16	20	5~6	7~8
Material	Aluminum	GRP	GRP	GRP	GRP	Aluminum	Aluminum and GRP	Aluminum	Aluminum	GRP	Aluminum
Length	7.3 m	9.5 m	8.5 m	12.6 m	18.5 m	17.9 m	19.0 m	16.1 m	21.7 m	10.5 m	
Beam	5.8 m	5.8 m	4.8 m	8.2 m	12.7 m	11.8 m	13.0 m	11.0 m	14.5 m	8.9 m	
Height	2.0 m	2.3 m	2.3 m	3.4 m	5.1 m	5.3 m	5.2 m	4.9 m	6.0 m	4.3 m	
Engine and power	1 Walt diesel engine 74kW	2 HS-350A 2×15kW	4 Cayana diesel engine	2 ROTAX-447 2×30kW	2Lycoming IO-540 2×220kW	2 Lycoming IO-540 2×220kW	2 HS-6k 2×294kW 1 HS-6A 1×209kW	2 Lycoming IO-540 2×223kW	2 P&W PT6A-15AG 2×500kW	1 Lycoming 1×220kW	2 Lycoming IO-720 2×294kW
Cruising speed	110 km/h	110~120 km/h	120 km/h	110~130 km/h	130~150 km/h	140 km/h	80~130 km/h	160 km/h	150~180 km/h	142 km/h	
Cruising height	0~0.3 m	0~0.5 m	0~0.5 m	0~1 m	0~1.5 m	0~2 m	0.5~1 m	0.8~1.2 m	0~2 m	2~5 m	0~2 m
Maximum flying height	5 m	10 m	5 m	20 m	20 m	20 m	10 m	20 m	20 m	20 m	20 m
Taking off wave condition		Wind scale 6~7 (Lake)	Wave scale 2 (Lake)	Wind scale 6~7 (Lake)	Wave scale 2 (Sea)	Wave scale 2 (Sea)	Wave scale 2 (Lake)	Wave scale 2 (Lake)	Wave scale 2 (Sea)	Wave scale 2~3 (Sea)	Wave scale 2 (Lake)
Landing wave condition		Wind scale 6~7 (Lake)		Wind scale 6~7 (Lake)	Wave scale 3 (Sea)	Wave scale 3 (Sea)	Wave scale 2 (Lake)	Wave scale 2 (Lake)	Wave scale 3 (Sea)	Wave scale 2~3 (Sea)	Wave scale 3
Cruising range	—	—	—	400 km	900 km	≥400 km	300 km	400 km	500 km	300 km	
Designer	CSSRC	CSSRC	MARIC	CSSRC	CSSRC	CSSRC, Dayang Wig Ship Co.	MARIC	CASTD	CSSRC	Galaxy Dragon Co. & CSSRC	CSSRC

face (Fig.2a). In the design and test of the 6t WIG "XTW-4" (Fig.2c) the design loads and strengths of aluminum structures were specially focused on. The sea trials showed the craft could take off and fly in sea state 3 with excellent behaviors.

Fig.2 (f) is a remote control 1:14 scaled model of a 200t large WIG flying over Tai Lake in 2006,which was successfully investigated and designed by CSSRC as part of a research program. The model is of the length 4.32m, corresponding to a 60.5m long full-scale objective.The model tests in wind tunnel and towing tank,the remote control self-flying test in Tai Lake all proved that the hydrodynamic and aerodynamic configurations of the 200t WIG, especially the designed composite ground effect wings, the main hull and the empennage satisfied all the requirements of dynamic stability, performance and safety. It was predicted that driven by 4 engines with totally 52.8t thrust the full-scale ship could take off in waves of scale 4, and reach the cruising speed of 250kns.



(a) 902 (400kg, 1983); (b) XTW-2 (3.6t, 1993);
(c) XTW-4 (6.0t, 1999); (d) XTW-5 (4.2t, 2003);
(e) AB-606 (2.0t, 2001); (f) Test model of a 200t Wig (2006);
(g) 751 (7.5t, 1998); (h) DXF-100 (4.8t, 1998).

Fig.2 Examples of wigs designed and built in China

The technologies on WIGs accumulated by CSSRC include:

· Overall design method of small WIGs (Ye, 2002);

· Theory,prediction method and design criteria of longitudinal and lateral stability (Yuan & Shi, 2007);

· Design and calculation for dynamic augment;

· Aerodynamic and hydrodynamic configurations,performance prediction and hull form optimization (Shen, Yuan& Ye 2001; Zhou, Xu & Yuan, 2006a) (Fig.3);

· Techniques of wind tunnel and water basin tests (Fig.4);

· Techniques of self-running and remote control model tests (Fig.2f);

· Optimization of automatic control (Zhou, Xu & Yuan, 2006b);

· Prediction of structural loads;

· Design of weight critical structures (Zha, Wang & Wan, 2005);

· Structural safety assessment (Fig. 5);

· Manufacture of small GRP and aluminum WIGs;

· Techniques of sea trial measurement of full scale WIGs.

Fundamental research work in the corresponding fields has been continuously carried out till these years in China with a number of publications, for example Gu, 1997; Hong, Xu, et al, 2003; Xing,Wu & Zhu, 2004; Yun, Wu & Xie, 2000; Yun, Xie, et al, 2000; Zhang, Cheng & Wu, 2000; Zhang, Huang & Zhou, 2000; Zhang, Lou & Zhou,1999; Qu & Liu, 2006; …to just mention a few. Design Guidelines of WIGs were also produced based on the research and development practice (Ye, 2006).

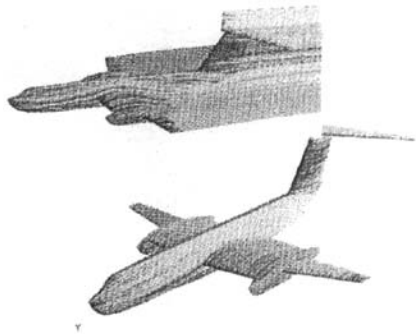


Fig.3 CFD analysis of aerodynamic performance of a 200t wig

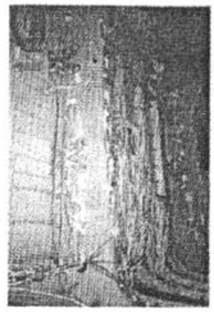


Fig.5 Strength measurement of full scale XTW-5 ship tank

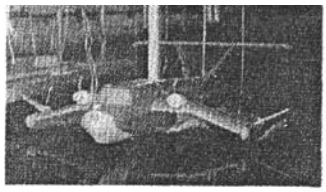


Fig.4 Model test of XTW-5 in towing tank

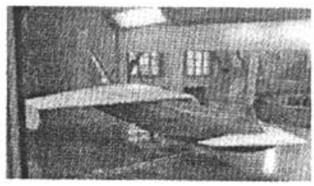


Fig.6 Model test of a supercritical partial wing-in-ground-effect ship in wind tunnel (2006, CSSRC)

The concept of supercritical partial surface effect wing ship was also investigated by CSSRC. Fig. 6 shows the wind tunnel model test of a supercritical partial wing-in-ground- effect ship performed by CSSRC in 2006.In full scale the ship is of the weight 500t.In cruising condition with the speed 120kns in the sea,the ship does not totally leave the water surface. The aerodynamic lift force supports 88% of its weight,while the hydrodynamic force of the planning hull supports 12% of the weight.

It may be concluded that the present WIG technology in China is mature to design and produce small and medium size wing ships.It is under way to design and build WIGs of the weight from 20t to 200t depending on the demand.

3 Hydrofoil vessels

The first hydrofoil vessel built in China was a 40 seats passenger ship "Hydrofoil 1" designed by CSSRC,lunched in 1959 and operated in Yangtze River. In the following nearly half a century the fundamental theoretical and experimental researches on hydrofoil vessels were carried out and the corresponding technologies were continuously improved mainly by CSSRC. These include:

· Optimized hydrofoil form and configurations;

· Self-stabilized surface piercing hydrofoil system;

· Prediction and measurement techniques of multi- component hydrodynamic forces acting on complex hydrofoil system (Zhu, Li & Yang, 1993);

· Prediction of taking off and foil sailing performance;

· Automatic motion control technique of deep submerged hydrofoil ship;

· Prediction method and model test techniques of flow and powering behavior of combined hydrofoil with inlet and water-jet system (Li, Yang, et al, 1994; Li, Zhu et al, 1992);

· Test technique of efficiency, cavitation and erosion behavior of high-speed water-jet system (inlet, outlet, pump and inner flow);

· Multi-purpose model test facilities of self-adaptable hydrofoil ships;

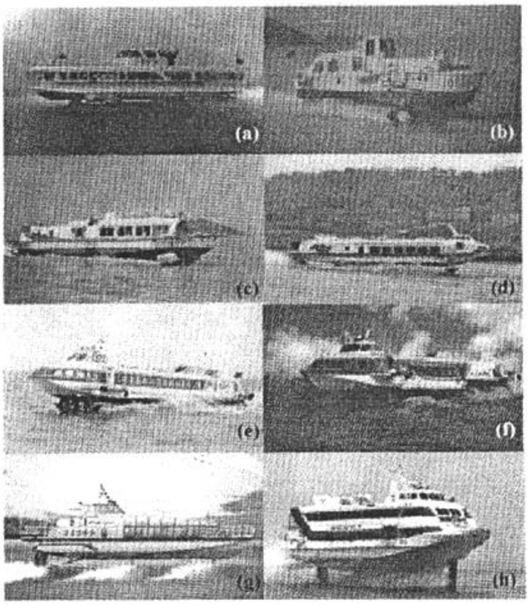
· Load prediction and structural design methods;

· Tri-hydrofoil ship.

Along with the technology development, 9 different types of hydrofoil ships were designed and built up in China. The particulars of these ships are listed in Tab.2,among which 8 are shown in Fig.7,including six surface piercing twin-hydrofoil ships (Fig.7a-f),one type of Fully submerged automatic controlled twin-hydrofoil ship (Fig.7h), and one type of tri- hydrofoil ship (Fig.7g). The passenger ships (Fig.7d-g) are now in service in upper reaches of Yangtze River.

The tri-hydrofoil configuration of the newly built tourist ship "Qingzhou-II" makes its amidships bending moment much smaller than a twin-hydrofoil ship of the same displacement, and allows the main deck apartment mounting with totally transparent glass loaf and side walls,and the tourists gaining overall view when traveling through the three gorges (Fig.8).

More importantly model tests showed that the well- designed tri-foil configuration (Fig.9) greatly improved the seakeeping behavior of the ship. Fig.10 exhibits the comparison of variations of



(a) The first passenger ship "Hydrofoil 1" (40 passengers, 1959)
(b) The hydrofoil test ship "101" (1969)
(c) The aluminum hydrofoil "Flying fish" (28 passengers, 1988)
(d) The passenger ship "Geleshan" (82 passengers, 1996)
(e) The passenger ship "Yuanzhou-I" (108 passengers, 1998)
(f) The passenger ship "Yuanzhou-II" (102 passengers, 2000)
(g) The tri-foil tourist ship "Qingzhou-II" (86 passengers, 2007)
(h) The automatic controlled deep submerged hydrofoil ship "PS30" ("Nanxing" in Hong Kong, 294 passengers, 1994)

Fig.7 Examples of hydrofoil ships designed and built in China

Tab.2 Examples of hydrofoil ships designed and built in China

1	Types "Name"	"Hydrofoil-I"	"101"	"Flying Fish"	"Geleshan"	PS30 "Nanxing", "Beixing"	"Yuanzhou-I"	"Public Security 202"	"Yuanzhou-II"	"Qingzhou-II"
2	Year of delivery	1959	1969	1988	1996	1994	1998	1998	2000	2007
3	Passangers	40		28	82	294	108	60	102	86
4	Light displacement (t)			10.6			33.5	37	36	39
5	Full displacement (t)	25.6	13	13.0	32	118	45	45	46.8	48
6	Length (m)	24.5	11.5	15.6	22.96	29.1	29	28.6	28.6	31.5
7	Beam of hull (m)	4.6	2.6	3.7	4.8	8.6	5.2	5.2	5.2	5.00
8	Beam over foils (m)	5.6		5.2	7.6	9.2	7.2	8.52	8.52	8.10
9	Draft on hull (m)		0.74	0.48	0.67		0.68	0.68	0.71	0.70
10	Floating draft (m)	1.9	2.6	1.65	2.05	4.5	2.22	2.35	2.35	2.34
11	Draft in flight (m)	1.05	1.6	1.09	1.10		1.3	1.3	1.43	1.48
12	Engine	12V180Z	12-180	12V150Z	KTA19-M2	Allison-501KF	DDC16V-92TADDEC	DDC16V-92TADDEC	DDC/MTU 12V2000M90*	DDC/MTU 12V2000M90*
13	$\frac{\text{Full speed power (kW)}}{\text{Operation power (kW)}}$	$1\times\frac{882}{662}$	——	——	——	$2\times\frac{3180}{2865}$	$2\times\frac{787}{720}$	$2\times\frac{787}{720}$	$2\times\frac{840}{795}$	$2\times\frac{890}{838}$
14	Maximum speed (km/h)	65.7	83.9		70	93	80	80	80	75
15	Operation speed (km/h)	62.8		57.5	68	80	77	77	78	72
16	Cruising range (km)	600		250	400	185	730	750	700	300
17	Wave hight in foilborne condition (m)	0.6	Wave scale 3~4	1.2		Wave scale 4	1.2	1.2	1.2	
18	Turning diameter (m)			300			700	700	700	390
19	Type of foils	Shallow submerged, Self-stable	Surface piercing, Auto-control	Semi-submerged, Self-stable	Surface piercing, Self-stable	Fully submerged, Auto-control	Surface piercing, Self-stable	Surface piercing, Self-stable	Surface piercing, Self-stable	Surface piercing, Self-stable
21	Foil load fore/aft (%)		68/32	51/49	52/48	30/70	50/50	50/50	51/49	Tri-foils
22	$\frac{\text{Persons}\times\text{Speed (km/h)}}{\text{Operation power (kW)}}$	3.79		4.88	6.05	4.11	5.78	Public affairs	5.41	3.69

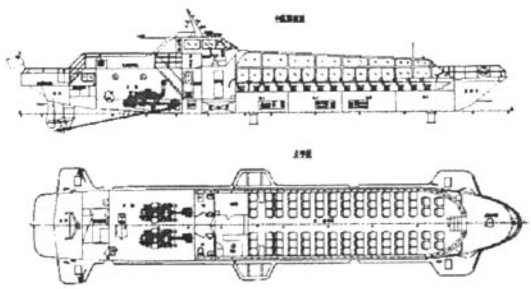


Fig.8 The tri-foil tourist ship "Qingzhou-II" (2007)

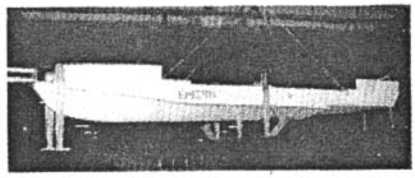


Fig.9 Configuration of tri-foils

heave responses (accelerations at the gravity center $\ddot{Z}_{G1/3}$)of different ships traveling in same irregular waves with regard to non-dimensional significant wave height $H_{1/3}/\Delta^{1/3}$ (Δ is the displacement of the ship). The advantage of tri-foil ship is apparent.

4 Small waterplane area twinhull ships

Comprehensive researches on SWATH ships were carried out (Huang, 1993) and more than tens of different types of SWATH ships were investigated and designed in China during the last two and half decades.In 2000 and 2002 the first two SWATH ships in China were delivered with great success.These are Customs surveillance vessels as shown in Fig.11a, designed jointly by Shantou Dayang Shipping Industry Co. and CSSRC, and built by the former.Later on SMSDRI designed and built an oil field traffic ship as shown in Fig.11b.

Based on years of research work and accumulated experiences, China Shipbuilding Industry Corporation (CSIC) has developed a complete set of practical design tools of SWATH ships (Wu, Ni et al, 2007). These include:

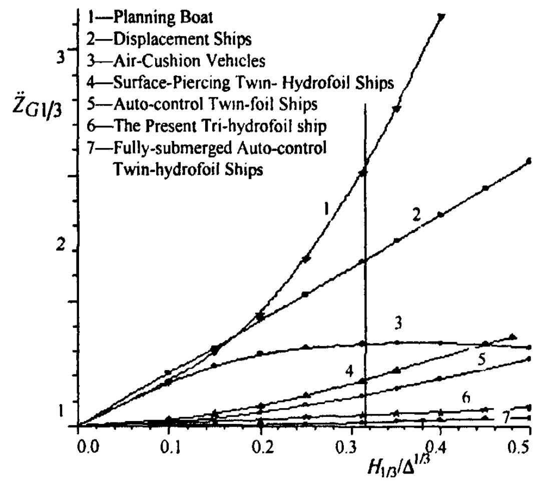
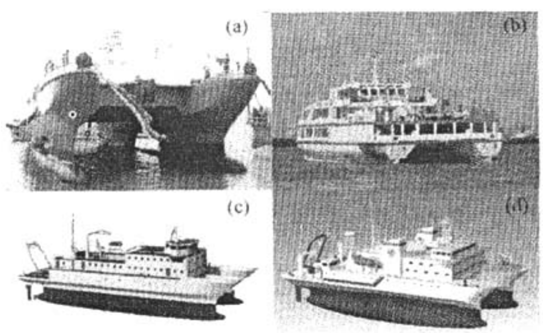


Fig.10 Comparison of significant value of heave responses of different ships in irregular wave



(a) Customs surveillance vessel"Customs 201/202" (228t, 2000)

(b) The oil field traffic ship"New Century-1" (440t, 2004)

(c) The ocean-survey ship "Dongyuan 02" (1500t, 2007)

(d) The marine research ship"Experiment-1"(2500t, 2008)

Fig.11 SWATH ships built in China

· The optimization program of principal dimensions for low resistance (Ge, 1992);

· Predictions of powering performance (Ge, 1985, 1986), Fig.12 exhibits the good agreement of the predicted active power with the test results of a 1500t ocean survey SWATH ship "Dongyuan 02";

· Predictions of seakeeping behavior and motion stability (Ge & Guo, 2000);

· A computer aided conceptual design package with 12 independent parameters for optimization of shipform and overall behaviors (Yi, 2004; Ni and Ye, 2005);

· The techniques of model tests for hydrodynamic behaviors and wave loads;

· Determination of design loads (Lin, Qian & You, 2006);

· The direct calculation methods of structural loads and safety assessment based on linear and non-linear hydroelastic analyses (Wu, Ni et al, 2007);

· Auto-control techniques of fore and aft stabilizing fins to further minimize motions in waves (Fig.13 shows the comparison of model test results of heave motions of a SWATH ship with and without auto-control of fore and aft stabilizing fins).

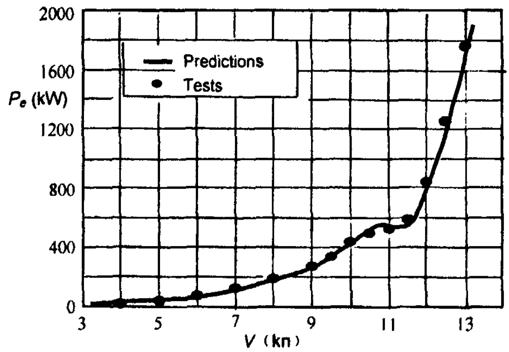


Fig.12 Active Power of the Ocean-Survey SWATH Ship

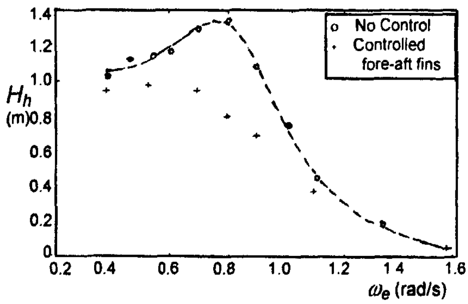


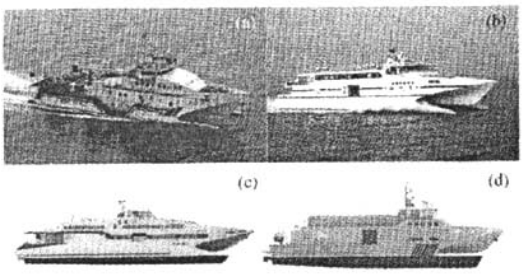
Fig.13 Comparison of model test results of heave motions with and without auto-control of fore and aft fins

Employing these design tools an ocean survey SWATH ship of 1500t displacement (Fig. 11c) and a marine research ship of 2500t displacement (Fig.11d) were designed with satisfactory model test results of performance in waves.These two ships are now in construction and will be delivered in winter of 2007 and summer of 2008 respectively.

5 Wave-piercing catamaran

Soon after the wave-piercing catamaran appeared in Australia in 1985,several research institutes and universities in China started their research on this type of ships.However the first part of wave-piercing catamarans running in China originated from Australian technology. In 1990s,Sea-Bus Co. in Guangzhou imported the design drawings of wave-piercing catamarans AMD150, AMD183 and AMD350 from Australian AMD Company. Several AMD150- and AMD183-type ships were built up during the second half of 1990s, and first three 49m long fast salvage ships employing AMD350 design were built up and delivered during 2004 and 2005 (Fig. 14a).

In 2000 CSDDC,CSSRC and HEU started a joint research project called "WP60".In the project taking a 60m long wave-piercing catamaran as the object ship (Fig.15), systematic model tests on resistance, powering, seakeeping and maneuvering behaviors and wave loads for different shipforms were performed, preliminary and technical designs were carried out.The research achievements covered wide range of technologies about wave-piercing catamaran.As the result of application,a 252t wave-piercing catamaran "Strait" was built in 2005 (Fig.14b). Mounted with four 2240kw water-jet systems, it's maximum speed could reach 41.5kns.A 360t wave-piercing catamaran "Dongyuan-01" is in construction and will be lunched in 2008 (Fig. 14c).A 385t wave-piercing type marine cruising ship has also been designed to meet the needs of service around the Yangshan Port in Shanghai (Fig.14d).



(a) Fast Salvage Ship (210t, 29kns, built in 2004)
(b) "Strait" (252t, 41.5kns, built in 2005)
(c) "Dongyuan-01" (360t, 36kns, will be lunched in 2008)
(d) Maritime Cruising Ship in Yangshan Port (385t, 30kns, designed in 2007)

Fig.14 Wave-piercing vessels designed and built in China

Fig.15 The object ship of the research project "WP60"

6 Hybrid hydrofoil ships

Since 1980s high-speed catamarans have played important role in waterway transportation in Zhujiang delta of China.In middle of 1990s the total number of conventional catamarans and wave-piercing catamarans operating in that area were over 50.When traveling in high waves with a catamaran, the passengers may suffer from very uncomfortable simultaneous roll and pitch motions of the ship.To minimize the wave-induced motions,the hybrid foil catamaran was investigated by CSSRC and Dalian Maritime University, etc. (Lin & Xu, 1995; Ren & Yang, 2004; Ren, Yang & Du, 2004; Ma, 2001).

Fig.16 shows a catamaran equipped with fixed foils,which was designed by CSSRC and built up in 2005.Model test results exhibited great improvement of seakeeping behaviors of the ship in comparison with a bare catamaran.When the ship with attached foils is traveling with the speed of 13kns in irregular head waves of sea state 5,its significant values of roll, pitch angles and accelerations at bow and stern were reduced for 28.2%, 34.5%, 31.7% and

30.4% respectively comparing with the same ship without foils.

Fig.16 The foil assistant catamaran(2005)

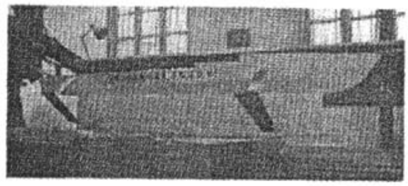


Fig.17 Test model of the hybrid hydrofoil small waterplane area single hull ship

To improve the performance of wave piercing catamarans in waves,CSSRC also investigated and tested a hydrofoil-assistant wave-piercing catamaran.With three sets of foils mounted on the hull, the resistance and rolling responses of the ship in waves were also greatly reduced in comparison with the bare hull.

Shanghai Jiao Tong University investigated a type of hybrid single hull ship with small waterplane area and surface piercing hydrofoils as shown in Fig.17 (Liu, Qiu, et al, 2000a, 2000b; Qiu, Gu, et al, 2001). The calculation methods and the corresponding criteria of resistance, static and dynamic stability of the ship in floating and foilborne conditions were developed.The model tests were carried out.The theoretical predictions and the test results were well agreed to each other and proved low resistance and excellent stability behavior in the transit condition (from 22 to 26kns of the prototype speed) and foilborne condition (from 29 to 39kns of the prototype speed).

7 Air-cursion vehicles and surface effect ships with sidewalls

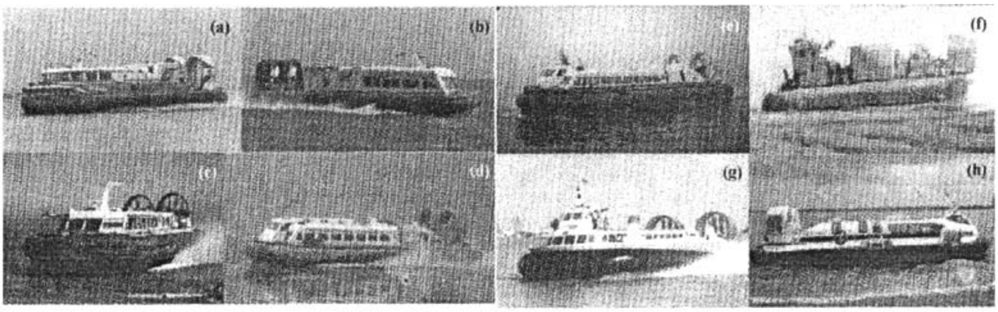
Early in 1957 Harbin Military Engineering College of China started to develop the technology of Air-cushion vehicles. As a result on July 12, 1959, about 13 days earlier than the first trial of the British air-cushion vessel "SRN-1" traveling 25 nm across the English strait with the average speed of 13kns, a Chinese test air-cushion vehicle "33" of the weight 1.7t took its long distance virginal voyage of 16nm with the speed of 27kns from West Lushun Harbour to Yangjiawa region of Bohai Sea.

Since then extensive research and development work on air cushion vehicles (ACVs) and surface effect ships with sidewalls (SESs) has been carried out in China, especially at Marine Design and Research Institute of China (MARIC). The technologies developed include:

- Performance optimization;
- Responsive skirt;
- Lift system;

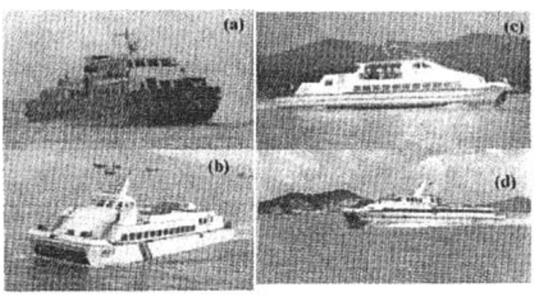
- Ducted air-propeller;
- Pitch and roll stability in motions;
- Control of broaching-to effect;
- Maneuverability and auto-maneuvering system design.

Tab.3 and Tab.4 provide the particulars of some ACVs and SESs designed and built up in China. Fig.18 (a)-(f) and Fig.19 exhibit some examples among more than 100 ACVs and SESs designed by MARIC and manufactured in China during the past 40 years.Since late 1970s, Beijing Institute of Aerodynamics (CASTC) developed its own ACV technology and built up variety types of ACVs. Fig.18(g)-(h) show two of the ACVs (HT903 and HT981) designed by CASTC and built up by Tiantong High Speed Ship Company.



(a) 716II Passenger ship (21t, 70pasgs, 67km/h, Alum., 1986)
(b) 7212 Passenger ship (10.5t, 33pasgs, 54km/h, Alum., 1987)
(c) 7218 Passenger ship (30t, 70pasgs, 70km/h, Alum., 1995)
(d) 7246 Passenger ship (24.6t, 65pasgs, 65km/h, Alum., 2000)
(e) 4010 Passenger ship (29.8t, 80pasgs, 80km/h, Alum., 2002)
(f) 7301 Amphibious Hoverbarge (80t, payload 35t, 18km/h, steel, 1987)
(g) HT903 Passenger ship (30t, 100pasgs, 70km/h, Alum., 1983)
(h) HT981 Passenger ship (10t, 20pasgs, 50km/h, Alum., 1986)

Fig.18 Air-cushion vehicles designed and built in China



(a) 719II Passenger ship (123t, 257pasgs, 51km/h, Steel, 1984)
(b) 7211 Passenger ship (60t, 162pasgs, 56km/h, Alum., 1989)
(c) 7215 Passenger ship (50t, 135pasgs, 50km/h, Alum., 1993)
(d) 721 Passenger ship (140t, 70pasgs, 61km/h, Steel, 1995)

Fig.19 Surface Effect Ships designed and built in China

Tab.3 Examples of air-cushion vehicles designed and built in China

1	Types	7212	722 II	724	7218	7226	HT-903
2	Year of delivery	1989	1990	1994	1995	1996	1994
3	Full displacement (t)	10.5	78	6.35	31	17	40
4	Length (m)	14.1	31.2	13	22.1	18.6	24.35
5	Beam overall (m)	6.1	15.7	5.3	9.44	7.6	8.8
6	Overall height (m)	2.7	10.7	3.7		4.6	9.5
7	Engine	BF12L913C		BF12L913L	BF12L513FC	BF12L413F	BF12L413FC
8	Total power (kW)	410	2×1985	280	1109	560	4×360
9	Propulsive device	Ducted air propellers	Ducted air propellers	Ducted air propellers	Ducted air propellers	Ducted air propellers	Ducted air propellers
10	Hull material	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum
11	Passangers	33	150	10	70	40～50	100
12	Cruising speed (kn)	32	47	40	38	32	35
13	Cruising range (nm)	120	200	100	140	120	150
14	Operation area	Coast zone	Coast zone	Coast zone	Coast zone	Coast zone	Coast zone
15	Designer	MARIC	MARIC	MARIC	MARIC	MARIC	CASTC
16	Builder	Dongfeng shipyard	Dagu shipyard	Dagu shipyard	Dongfeng shipyard	Tongfeng shipyard	Tiantong high speed ship company
17	Operation course	Zhengzhou	Military	Zhanjiang	Hainan	Qinhuai island	Shanghai—chongming/Cixi

Tab.4 Examples of surface effect ships with sidewalls designed and built in China

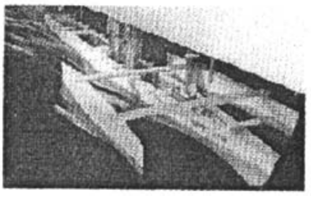
1	Types	717C	7211	719Ⅱ（7217）	7221	721	"Tiecheng"	"Kangping"
2	Year of delivery	1984	1992	1988	1995	1995	1995	1995
3	Full Displacement (t)	23.5	68	123～130	90	140	60	240
4	Length (m)	21.0	29.9	44.0	32.15	42.0	27.1	52.3
5	Beam Overall (m)	4.8	7.6	8.0	7.9	8.8	7.5	12.3
6	Overall Height (m)	0.7	1.82	2.5	1.75	2.14	0.78	1.7
7	Engine	2×Cummins	2×TBD234V12 1×TBD234V6	3×TBD234V6	2×TBD234V12 1×TBD234V8	2×MTU12V396TE74 1×MTU8V396TE74L	2×DDC12V−92TA 1×DDC6V−92TA	2×GM12V149 2×CumminsKTA10
8	Total Power (kW)	2×236	1460	2265	1890	3055	1533	2800
9	Propulsive Device	Water-jet	Water propellers	Water propellers	Water propellers	Water propellers	Water-jet	Water propellers
10	Hull Material	Aluminum main hull, GRP wall	Aluminum	Aluminum	GRP	Steel main hull, Aluminum super structure	GRP	Steel main hull, Aluminum super structure
11	Passangers	70	162～171	257～260	225	70ps＋2t Cargo	160	450
12	Cruising Speed (kn)	23	30	26	33	33	25	27
13	Cruising Range (nm)	200	200	250	200	300	250	350
14	Operation Area	Inland river, B, J- Grade	Coast zone	Coast zone	Coast zone	Coast zone	Coast zone	Inland river, A-Grade
15	Designer	MARIC	MARIC	MARIC	MARIC	MARIC	Shanghai Shipping Research Institute	Zhongzhou Co.
16	Builder	Dongfeng shipyard、Chongqing shipyard	Huangpu shipyard	Zhonghua shipyard、Beihai shipyard	Jianghui shipyard	Jianghui shipyard	Jianghui shipyard	Luzhou shipyard
17	Operation Course	Chongqing－Yibing /Wanxian	Shekou－Hong Kong	Chongming－Qingdao	Shekou－Hong Kong	Military	Shekou－Xiaolan	

8 High-speed multi-hull ships

The research on high-speed multi-hull ships other than SWATH ships started in China relatively late. British "Triton" concept and the related publications stimulated great interests of Chinese naval architects to further investigate the high-speed multi-hull ships. The research and development work in this field has been mainly carried out in universities, for example, HEU, SJTU, NEU, as well as the research and design institutes, for example CSSRC, MARIC, CSDDC, etc.

Since 1997 HEU and CSSRC did series model tests of trimarans in calm water and in waves (Fig.20). The hydrodynamic characteristics and performances of the trimarans under investigation with regard to different configurations of the large center hull and the smaller outrigger hulls were obtained. HEU also developed the prediction methods of resistance, powering performance and seakeeping behaviors, as well as the optimization method of shipform and configuration of trimarans (Huang, Duan, et al, 2006; Hang & Huang, 2000). Fig.21 shows the comparison of the tested and calculated results of total resistance of a test trimaran model.

In exploring the possible new shipforms of future marine synthetic support and surveying ships, CSSRC proposed a type of quartmaran (Fig.22). In 1990s HEU tested and investigated pentamarans.



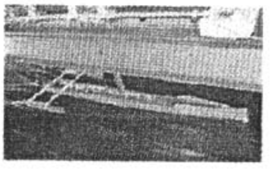


Fig.20 Trimaran models tested in CSSRC (left) and Harbin Engineering University (right)

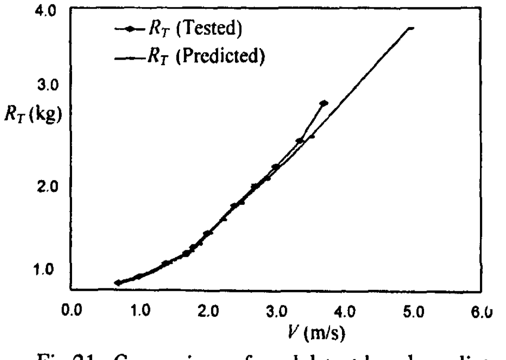


Fig.21 Comparison of model testd and predicted results of total resistance *Rt* of a trimaran model FA1-B (HEU)

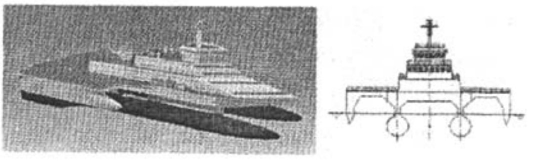


Fig.22 Quartmaran proposed and investigated by CSSRC

9 Concluding remarks

The technical situation of high performance ships in China may be briefly highlighted as follows:

· The research on WIGs in China has achieved great progress,resulting in the profound technology of design and manufacture of small and medium size WIGs, although the financial support from different resources has been very limited.

· During the past nearly half a century,the research and development of hydrofoil vessels, ACVs and SESs in China were in relatively large extent and reached the level satisfactory to Chinese market. Consequently more than 10 different types of hydrofoil vessels and more than one hundred different ACVs and SESs were designed, built, and played important roles in waterway transportation in China.

· Based on systematic research,design technology of SWATH ships in China has reached a stage of relying on a comprehensive package of practical design and optimization tools, rather than just relying on design guides and experiences.

· The research project "WP60" (2000–2005) successfully enhanced the technology and capability of design and production of wave-piercing catamaran in China.

· The technology of hybrid single-hull and twin-hull ships,especially hydrofoil-assistant, and high-speed multi-hull ships (trimaran, quartmaran and pentamaran, etc.) have been widely studied and partly applied,appearing to be more attractive and focusing research field in China.

The potential applications of high performance ships in China will be great in the future for either inland river and coast zone transportation, and the ocean research, survey and resource exploration.It is expected that the research and development in this field will be kept ongoing to certain extent.

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我国高性能船技术进展

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摘要：数十年来，我国在高性能船研发与应用领域广泛深入地开展了大量、卓有成效的研究与开发工作，主要包括地效翼船、水翼船、小水线面双体船、穿浪双体船、水翼复合船、全垫升气垫船、侧壁式气垫船、高速多体船等等，文章对这方面的工作与技术进展情况进行了概要论述。然而，受到这一技术领域的广泛性以及篇幅的限制，文中侧重于我国在高性能船方面取得的主要技术成果的回顾与主要产品的简要介绍，而对其中大量的具体技术细节不能一一提及，更无法详细展开进行深入论述。

关键词：高性能船；地效翼船；水翼船；小水线面双体船；穿浪双体船；全垫升气垫船；侧壁式气垫船

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