Dynamic Air Cushion Wing in Ground Effect Craft (DACWIG)
The Prospect of High Speed Water Transportation Tool in the 21st Century

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Abstract:

Three types of wing in ground effect crafts, i.e. power augmented ram wing in ground effect craft or ekronoplane (PARWIG), dynamic air cushion craft (DACC), and dynamic air cushion wing in ground effect craft (DACWIG) are introduced in this paper , of which the DACWIG is possible to be a very prospective type of high speed passenger craft in the 21st century in the world due to a series of advantages , such as high speed/ efficiency, safe, good sea-keeping quality, excellent amphibiousness and landability, simple equipment, rather low cost, and multi-operation mode. Taking the Shanghai-Nantong route as an example, the economic benefit of the DACWIG is demonstrated

I. Introduction

People always seek high-speed transportation tool in order to shorten the travel time and enlarge the space for their existence. The operation speed of various transportation tools has been improved a lot in recent half century, e.g.the speed of airplane raised up to 20 times, and more than 3 times for automobile, however, the speed of ships only raised up to double positive ,and always around of 40 kn. Since the wavemaking resistance of ships increases drastically at high speed, one attempt to take crafts either off or under the water surface. In the case, where craft off the water surface, it will become an airplane, and in case of under water surface, it becomes a submarine. We are not going to comment the characteristics of the hydroplane at present. To be a submarine, the interference of wave acting on the craft will be reduced so as to be a stable transportation platform, however the huge wetted surface of craft also cause a large increase of water friction drag along with the increase of speed. Hydrofoil operates over the water surface and leads the main hull left the water surface so as to reduce the wavemaking drag drastically, however, the hydrofoil still operates in the water, and still cause large water friction and profile drag, especially, the cavitation of the hydrofoil during high speed of craft will be the most troublesomes problem on its operation. Therefore, although the former soviet specialist R.Y.Alexeev invented the hydrofoil craft, and transferred it from test into the practical, as well as constructed about 800 crafts so far, and the U.S. deep submerged automatic control hydrofoil craft model "Jetfoil" possesses fine seakeeping quality, the cavitation barrier still limits its speed (no more than 50 kn).

The main hull of SES had been left off the water surface, and causes the dropping of wavemaking

drag, however, two sidewall still cause a large water friction , in addition, the wave interference will cause the unfavourite the motion of wavepumping and hull pumping so as to induce the vertical motion of the craft. Only in case of large displacement of craft, the craft can be operate at high speed and still at favourite Froude Number. Other crafts, such as Wave-piercing Craft, High Speed Catamaran etc are at same condition with the SES. At present, the enthusiasm on enlarging high speed ship is based upon such design idea as well, i.e, together with the increase of displacement , the craft still at the favorite Fr= (0.6-1.0). It leads to crafts with more favorite economy and seakeeping quality, still, since the craft are supported by hydrostatic and hydrodynamic lift and with water propulsion, there are no any difficulties on enlarging the size of the craft. However, even in case of SES, WPC, and CAT of 2000-3000t, the speed of which still at about 50kn, this is because $Frl=V/\sqrt{gL}$, the increase of speed is smaller than the increase of displacement.

During the operation of ACV, the craft leaves the water surface basically, and no under water appendages as well, the craft can obtain much higher speed theoretically, however, the hovering height is very small, and the craft operates very close to the water surface so as to cause a lot of spray and inertia drag of skirt, and once in case of operation in waves, the wide frontal area of bow/stern skirt and the vertical motion of craft may cause a large wave added resistance and serious speed loss, i.e. from 60kn on calm water dropping down to 30-40 kn in waves. Researchers have been perplexed by such problems for a long time.

Therefore, is it possible to develop a new type of craft with full off of water surface , without under water appendages, very high speed (70-100kn), a small influence caused by wind/wave, and with high lift/drag ratio because of operation in ground effect zone of craft, then the Wing in Ground Effect Craft (WIG), arose at the historic moment, i.e. in recent 20 years.

II. Some typical WIG

1. Power Augmented Ram Wing in Ground Effect Craft or Ekranoplane

Almost most of airplane pilots have the same feeling that during the aircraft launching down, the craft may obtain the addition lift by the so called ground effect so as to lead some troubles of landing according to the instruction. Such ground effect leads to some influences as follows:

* As shown in fig.1, owing to the blockage of flow, the pressure on the lower surface of main wing increases so as to increase the lift of wing during the craft operating in the ground effect region

* In addition, in case of the wing operating close to ground/water surface, the down wash velocity caused by wing tip vortex will be decreased, corresponding to with an image of same wing profile at the position symmetric to the ground, so as to reduce the induce resistanced due to the induced velocity of wing tip. (fig.1-b);

Fig.3 shows such phenomena, the upper figure shows the wing tip vortex without ground effect , the down figure shows that with ground effect, it is obviously that the decrease of down wash velocity due to the ground effect leads to the increase of lift, and decrease of resistance, as well as the increase of effective aspect ratio. That is the basic advantage of WIG.

Fig.2 (1) shows the lift/drag ratio verses the aspect ratio of wing and height of tip or endplate of lifting surface above sea or land divided by mean chord of lifting surface. i.e.

$L/D = f(h/c, AR)$

Where: L Lift
D Resistance
h Flying height
c Chord length of wing
AR Aspect ratio of wing

The figure shows the L/D increase in direct ratio with AR, and inverse ratio with h/c.

In general, WIG starts from displacement mode, then the craft transit the planning mode to flying mode. At the transition mode, the craft operates as a hydroplane, and a huge of hydrodynamic pressure will acts on the hull of the craft during the take-off. Therefore, designers attempt to mount a pair of ducted air propellers or turbofan before the leading edge of main wing to provide a pressured air under the main wing to create the power augmented ram wing in ground effect craft (PARWIG). The result is to create a large lift even in case of the craft at low speed, it leads to decrease the take-off speed, and hump drag, as well as improve the slamming of hull in waves, and take off ability, hull strength, stability, seakeeping quality etc. (2)

In fig. 4 (3), 1 presents the lift-drag ratio of WIG without fore-fitted ducted air propeller in calm water, 3 denotes that with air injection, 2, 4 denote that without and with air injection in beam seas. It can be found that the hump drag will be reduced drastically due to the action of air injection of fore fitted air propellers.

The same results also can be found from fig. 5. In the figure, 1 denotes hydroplane, 2- WIG with air injection (PARWIG), L lift of craft, W craft weight, one can see that the lift of PARWIG is higher than the former.

Therefore, in order to improve the landability, take-off ability, and seakeeping quality, the air injection of fore fitted air propeller is very effective and which might be a prospective measure on WIG. The operation mode can be shown in fig.6 (5),i.e .the angle θ_f of fore ducted air propeller may be taken to downward before hump speed and take-off as well as in case of landing, to increase the static lift, but it will turn to zero after take-off in order to increase the effective thrust

and thrust recovery coefficient.

The typical model of first generation of Russian WIG or Ekronoplane is so called "Caspian Sea Monster" with max take-off weight of 544 t, and the typical models of second generation in Russia are Orlyonok and Spasatel with rotated fore fitted turbofan, i.e. PARWIG.

In order to improve the aerodynamic property and stability of crafts, the composed wing can be mounted at the outside of main to increase the aspect ratio of the wing as shown in fig.7 (3), this is the latest model of the Russian third generation of WIG, however it is still not a practical.(9).

Although the fore fitted ducted thrusters were mounted on such craft to improve the take off , the static hovering lift is equal to only a part of craft weight, but not total weight. No day light clearance under the base plane of crafts can be made. Therefore, one can see that on Orlyonok (fig.11), there are rotated nozzles 1, two hydrodynamic slide plate 3,and landing gears are mounted on the craft. The landing gears were composed by two rotated bow wheels and nine main supported wheels. With aid of hydraulic actuators, the bow wheel can be retracted into the hull and located after hydrodynamic slide plate. To sum up, the hydrodynamic slide plate, landing gear, and fore fitted thruster make the craft being able to landing, launching into water of craft, and operation of the craft on ice, snow and beach.

In order to keep positive longitudinal stability of the craft, the initial design idea was similar as that to solve the longitudinal stability of hydrofoil offered by Alexeev, i.e. tandem arrangement of main wing (fig.8). It shows very good longitudinal stability of craft at low flying height Along with the improvement of hydrodynamics of the craft, the fore and rear wing evolved gradually to be the supported and stability wing respectively, and the rear wing evolved in high tail plane (fig.9). In order to keep good longitudinal stability, large plane area may be taken (sometime it was as big as 50 % of supported wing (4). Some measure might be taken, such as S profile of main wing etc, to decrease the area of tail wing and improve the aerodynamic property.

Since the crafts have to be operated not only in the surface effect region but also out of such region at shorter time, the both transverse and longitudinal stability of the will be complicated, it might be assured by means of effective flaps, ailerons, and other handling equipment with automatic systems, which has to be on the premise of precise instruments to measure the flying parameters of crafts. In addition, due to lack of height reserve on WIG operation, not similar to the airplane, which can fly in roomy space, the requirements for reliability and vitality of such automatic system is very high. Although the accident of 544t former Soviet " Caspian Sea Monster" was attributed a fault to the incorrect drive of the pilot, the excess complicated stability of craft in whole height of flying space , in which the pilot was very difficult to deal with , might be one of reasons led to this accident .

2. Dynamic Air Cushion Craft (DACC)

Since there are small aspect ratio on this type of craft, i.e. on the point of view of air cushion area, the craft has large cushion length beam ratio, in addition, the deepened sidewalls or buoys at both side of main wing and the flaps at the rear part of main wing make the wing just as the air cushion supported platform . The fore fitted ducted air propeller blows the pressured air into the cushion to make the craft being able to statically hover both on gruond and water surface. The fore fitted ducted air propeller has to be designed to assure the craft having higher both static lift thruster ratio, and thrust recovery coefficient. Just as shown in fig. 19, the fore fitted ducted propeller blows the pressured air and its mixture into the cushion chamber to make a pressured air cushion, in other side the pressured air flow along the backside of main wing due to the Coanda Effect, which makes the negative pressure on back surface of wing so as to form an added lift. The lift-thrust ratio* large than 4-4.5, and offer a certain day light clearance under the base plan of craft just as an amphibious ACV. Therefore, such craft not only possesses a good take off capability and seakeeping quality on the water surface, but also marvelous amphibiouness, and landability, which can operates on unready ground, ice/snow surface, beach etc. In case of opearating at high speed, the flap may be opened to make the main wing with more effective aerodynamics, however, the lift drag ratio of such craft is lower than that of PARWIG (ekranoplane) due to its smaller aspect ratio.

Fig.12 and 10 shows the Russian 8 seats DACC, and fig.13 90 seats craft. Fig.16 shows the artist's impression of U.S. DAC landing craft.

3. Aerodynamic Ground Effect Craft (AEGC) developed by Jorg of Germany

The design idea of this craft is very similar as the first generation of WIG developed by Alexeev. No fore fitted ducted propeller on the craft, the tandem wings arrangement offers satisfied longitudinal stability. Fig.17, 18, show such craft with inherit stability and needn't any automatic equipment. Since it is no fore fitted ducted propeller, the flying height of the craft is small, and is suitable to operate on inland river. Thanks to making great afford on the development, the company has developed the 2,4,8 seats crafts of this type, and got safety certification from IMO.

* η_{LS}=L/Tso

Where L lift (i.e.weight of craft)

Tso Thrust of fore fitted ducted air propeller with separately mounting, i.e. not Consider the tunnel efficiency of the propeller

4. Dynamic Air Cushion Wing in Ground Effect Craft (DACWIG)

This is a hybrid type of craft from DACC and PARWIG, i.e. the craft could be operated off the water surface and ground but still in the strong ground effect region, $\bar{h}$= 0.1-0.15. The aerodynamic arrangement of the craft is similar as the DACC, however, some measures has been taken so as to provide with fine stability in case of operating the craft not in the strong ground

effect region. The craft is unable to operate off the ground effect region, therefore, no complicated automatic system or/and other equipment on the craft to assure its stability during the flying off the ground effect region. The typical craft of such craft are Chinese 750 and "SWAN". (fig.14, 15), (10).

III. Some limitations for DACC and PARWIG as passenger crafts

1. DACC

DACC is very suitable for a passenger craft running on inland rivers due to its simple, low cost, and easy handling and maintenance. However, it is rather difficult to operate in the sea due to its smaller flying height, and poor seakeeping quality. The leading particulars of such crafts are listed in table 2.

2. PARWIG (Ekranoplane) (17) (18)

The basic data of built Ekranoplanes in Russia is listed in table 1.

It is the common knowledge that the Ekranoplane possesses great advantages as follows:

(a) The transport efficiency PARWIG is higher than airplane, and ACV, SES, HYC (table 2,3)

(b) The cruising speed (or economic speed) of PARWIG is 3-5 times as high as ACV/SES/CAT/HYD, and 10 times as high as displacement vessel (table 1, 2), therefore the transport capability of such crafts is very high.

(c) The navigation of PARWIG is different from that of conventional ship, without the limitation of depth of sea or river bed and tidal condition. The craft can be operated in shortcut and not on the definite navigation route. They also can be operated beyond the distance from the port definited by concerned administration, e.g. which can be larger than 100 n.mile, because of its unlimited seakeeping quality in case of its flying mode of operation.

However, due to the specified characteristic of PARWIG on profile, configuration, flying mode, take-off/launch, etc, some limitation or/and requirements also restrict the operation and commercial business as a passenger craft as follows:

(a) Configuration featrues: The PARWIG is difficult to operate alongside with other craft and wharf due to its protruding object, such as main and tail wing, which also increases the collision dangerous, in addition, the vision field for pilots is so limited that they are difficult to drive by eye sight in the narrow water way.

(b) Seaworthiness: There are three operation modes on PARWIG, i.e. hull borne, flying , and

transit mode between them. The seakeeping quality of hull borne mode and in case of take-off and touch down is poor due to the high hydrodynamic impact load acting on the hull, in addition, the motion at such case is unsteady, and some times even less inherit stability. All of this make the operation very complicated, particularly in case of operating the craft close to port and at narrow navigation route in uncalm sea condition.

(c) Maneuverability: At hull borne mode,the PARWIG can operate at speed of 15-20 kn with no limited of maneuverability, just as a conventional monohull, at flying mode the PARWIG might be operated at speed of 300-400 km/h with a flight height of 3-5 m ,and turning radius of PARWIG in such case is very large, moreover, the take-off distance of such craft is also long, the craft can maneuver neither as a ship on the water surface, nor as an airplane in the free air. The special navigation air zone (or belt) have to be prepared for the motion of PARWIG during its normal flying, in which no ships be permitted to operate. The positioning and measuring such special navigation air zone of PARWIG have to be taken into account with aid of radio navigation equipment, radar, and satellite navigation system.

(d) Tools and method of navigation: There are rather different method of navigation between the conventional ship, ACV, HYC, and PARWIG due to the special observation position and working condition of captain, as well as the limitation of such tools for navigation on PARWIG. The handling and control of PARWIG are also different from that of conventional high speed vessel. Some restrictions of maneuverability for PARWIG are also existed due to its large span of wings.

All of this make the PARWIG difficult to maneuver on water surface.

(e) Safety of navigation for PARWIG: The collision dangerous for PARWIG operating on water surface is higher than that of conventional high speed crafts, because of its super high speed. Therefore, the navigation equipment on the PARWIG have to be fast responsive, precise, small, light, vibration absorbed, and reliable.

(f) On shore equipment for PARWIG routes: It has to be similar as that on airports for hydroplanes or conventional airplane, and ensure that:

* All of equipment and systems on PARWIG have to be with high reliable, and working without any instruction from the navigation base;

* Embarkation and disembarkation safely of passengers from/to shore;

* Loading and unloading the fuel, fresh water, and provisions;

* Obtaining the weather, hydrology data, and possible encountering ships on the navigation route;

* All of radio communication on the flying navigation routes.

In addition, the following conditions have to be prepared for successful organization of the PARWIG passenger route:

* Preparing the observation for operational WIG, and equipment for salvage;

* Organization of work for recovering the vitality of WIG, and arrangement of passenger luggage's;

* Organization of technical service, maintenance, rest for crews and passengers, take-off, and launch down, as well as the mooring of WIG;

(4) Obtaining the data of waves on the navigation route, e.g. height, length , and direction of waves, etc.

All of these make the PARWIG difficult to develop in civil application, particularly in passenger water transportation.

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Table. 1 Basic Data of Built Ekranoplanes in Russia.

	SM-6	Orlyonok	KM	Spasatel	Volga-2
Type of craft	WIG	PARWIG	WIG	PARWIG	DACC
Mission	Small experimental self propelled model of Orlyonok	Transport	Experimental ship (Caspian sea monster)	Guide missile or/and rescue ship	Passenger boat
Displacement (max.take-off, t)	26.42	140	544	up to 400	2.7
Payload:Transport modification (t) Passenger modification (t)	1.0	10-20 15(150 passenger)	--	up to 100 45.0 (450 passenger)	0.75 0.75 (8 person)
Main dimension L×B×H (m)	31×14.8×7.85	58×31.5×16	92.3×37.6×22	73.8×44×19	11.6×7.6×3.7
Aerodynamic configuration(geometric supporting layout)	Aircraft type layout with trapezium	as same as left	Aircraft type layout with straight	Aircraft type with swept formed wing	Aircraft type layout with rectangular

	shape wing		square wing		wing
Geometric characteristic of lift wing: S (m)	73.8	307.0	662.5		44.0
AR	2.81	3.07	2.0		1.0
Power Plant: Starting, type and power	2RD9 turbojet engine 2040kg thrust for each	2 × NK-8-4k fan-jet engine 10t thrust @	8× VD-7-NM turbojet engine 11t thrust @	8 × NK-87 turbofan engine 13 t thrust @	2 × rotary piston engine 150hp each driving two propellers
Cruising : type & power	1×AI- 20 turboprop eng. 4000 hp	1×NK-12 MK turboprop engine 15000hp	2×VD-7NM turbojet engine 11t thrust @	8 NK-87 turbofan engines 13t thrust	
Cruising speed km/h (kn)	290 (157)	370-400 (200-215)	500 (270)		120
Range,km (n.mile)	800 (432)	1300 (800) 2200 (1180)	2000 (1080)	4000 (2160)	300 (182)
Seaworthiness wave height h 3% (m) Takeoff/landing	up to 1.0	1.5	5.0	2.5/3.5	0.5
Cruising mode	up to 1.5	no limited	no limited	no limited	0.3
Starting distance (km) Oncalmwater/in specification sea state	2.7/4.5	2.4-2.8/4-5	--6.0		1.0
Starting time,(s) On calm water/in specification sea state	50/75	80/150	130/200		70/50
Touchdown to stop distance, (km) on calm water/spec.s.s	1.2/1.8-2.7	1.2/1.7	3.1/4.5		0.8/1.0
Min turning radius at v=20-30 km/h,R(m)/rolling angle(deg)	50/0	50/0	100/0		15/0
at Vc	4500/3-5	2500/15	8000/10		500/0
Take-off speed (km/h)	210	220	280		80
Jump (permitted or not)	no	yes	no	yes	no
Jump attitude (m)		up to 50		up to 50	
Basing	On	on pontoon	afloat or near	afloat or near	on gently

	unequipped relatively flat coast site or on pontoon platform	platform or equipped site with ramp	special pier	special pier	sloping coast with slope angle up to 3 deg. (1/19)

Table 2 The leading particulars of some Russia (Former USSR) DACC, HYF, ACV, and MH (11)

Craft type	MH	HYF	HYF	ACV	SES	DACC	DAC WIG	DAC WIG	DACWIG
Model	Zalia	Raket	Lastochika	Irbis	Balguzin	Volga-2	Vilyou	Ardan	Vitim
Production condition	Batch production	Batch	Batch	Batch	Batch	Batch	design	Design	design
Classification	P	P	O	P	M	P	O	O	O
Seats	60	58	70	28	130	8	80	50	50
Power(kw)	1 660	1 660	2 995	2 126	2 735	2 95	5000	2500	1500
Speed(km/h)	42	60	85	45	50	100	300	270	240
Range(km)	500	500	700	450	600	500	1500	1000	500
Transport capability(Pass. km/h)	2520	3480	5950	1760	6500	800	34000	13500	7200
Transport eff. Person km/kw	3.85	5.56	3	5	4.55	4.34	5	5.56	5

Table. 3 Leading Particulars and Economical Parameters of Various fast Transportation tool

Craft type	DACWIG	DACC	Small Airplane	Light Airplane	Helicopter	ACV	SES	HYF
Model	SWAN	Volga-2	Y-11	AH-28	AS332C	7113	SEMO-SES	Jetfoil
Country	China	Russia	China	Russia	France	China	S.Korea	USA
Condition	Constructed	Batch Production.	Batch	Batch	Batch	Design	Batch	Batch
Max.weight, kg	7200	2500	3500	5800	8350	26000	167000	11500

Payload, Kg	15-20 passenger	900	940		2734	4000		29000
Seats	20	9	7	15-19		47	350	290
Machinery		VA-413	HS-6A Aviation piston engine	Turbo propeller	Turbomeca Makila	Deutz diesel	2 MTU16V 396TE74 +2 GM12V-92TA	Allison 501-K20A G.T.
Cost,US$/seat,(thou.$)			100	100-200	>200	17	17	62
Total power,kw		2 103	2 210	1385	2 1327	1150	4998	5456
Speed(km/h)	130	120	170	350	280-296	83	83-92	78
Fn		4.2				1.67	1.3	1.3
Trans. efficiency Kn		4.0	3.9	3.16	2.4	5.13	7.0	4.2

IV. The features and advantages of Dynamic Air Cushion Wing in Ground Effect Craft (DACWIG)

On the point of view of strong air cushion function, DACWIG is more similar to a DACC due to her small aspect ratio, (or large cushion length beam ratio), powerful pressured air supplied by the fore fitted thruster, and the guide vane after the thruster for improving the regulation of center gravity of the craft and its longitudinal stability. In addition, the craft possesses a good stability during its operation in the strong ground effect zone, or/and even in the medium ground effect zone due to its large area and aspect ratio of high tail wing, as well as its extending longitudinal distance of the tail wing position from the C.G. of the craft. On the point of view of operational flight height , it is more similar as the PARWIG (but it is unable to oprate beyond the ground effect zone). Therefore, it can be taken as a hybrid craft from both DACC and PARWIG. (fig 15), (10). The features and advantages of the DACWIG can be listed as follows:

1. High speed and transport capability

The speed of DACWIG is two times higher than HYF and ACV/SES with same lift drag ratio , that means, lift drag ratio of DACWIG will be close to ACV/SES/HYC in case of 2-3 times Fn higher than that of the later(table 2, 3). The speed of such craft can be as high as 70-150kn.

2. Good economy

Table.3 lists the leading particulars and transportation efficiency of various high speed transportation tools, where

$Kn = W\,Vs/102N = \eta W/R = \eta_t \eta_p W/R = \eta_t \eta_p K$

Where W Weight of craft (kg);
Vs Craft speed (m/s);
N Power output (kw);
η Propulsion efficiency;
η_t Transmission efficiency;
η_p Propeller efficiency (including hull efficiency);
R Drag of craft;
K Lift drag ratio.

From the formula, it can be seen that the non-dimensional coefficient Kn denotes only the hydrodynamic characteristics of the craft, but not expresses the construction technology, the specification of the main engine, equipment, etc.

From the table,it can be seen that the Kn of DACC (and DACWIG) is close to that of other high speed crafts, but with the speed (or Fr) 2-3 times higher than the later. The Kn of SEMO's SES is very high, it may be due to the large displacement of the craft with the speed record at very calm water. In addition, due to the decrease of lift power at the cruising speed, i.e .post hump speed, and just take-off while the craft is in lower flight height and lower resistance, the fuel consumption of the DACC and DACWIG at cruising speed is also lower, and close to the other high speed vessel with lower speed.

3. With multi-operation mode

Since the DACWIG is able to operate at hull borne, cushion borne, and air borne mode, the craft can not only run on the roomy sea surface, but also on the narrow river by hull borne, even beyond the main navigation route by the cushion borne. In addition, the craft can be alongside with other vessel and piers just as the conventional ship.

4. With good amphibious, landability, and low speed maneuverability

Since the craft is with strong air cushion effect, the craft has higher lift drag ratio at very low flight height. The craft also can be hovered on the ground, therefore, the craft is with good amphibiouness, and low speed maneuverability just as an air cushion vehicle without the flexible skirt. Moreover, the wavemaking caused by the craft is small, due to its small cushion pressure

and day light clearance under the craft base plan, which may less influence on the operation of nearby small boat and piers.

5. With good inherit stability during flying in strong ground effect region

From fig.2, it can be found that the lift drag ratio (or lift thrust ratio) will increase drastically with decrease of non-dimensional flying height of the craft running in the strong ground effect region ($\bar{h}=h/C<0.1$, where h is flying height, C chord length of main wing). Therefore, the craft is with good inherit both longitudinal and transverse stability, and needn't any complicated automatic control systems, and precise instruments as well as equipment for measuring the running attitude of the craft.

6. Easy to handling, and with safe and reliable

The craft can be operated safely due to its strong ground effect and inherit stability. The craft can drop down smoothly to the water surface arisen from the sudden reducing/stopping of engine revolution, and will not cause the accident of air crash as airplanes. In addition, the DACWIG is running in ground effect zone, which is nearly in plane motion, therefore, it is easy to handling, just as an ACV.(12).

7. Good seakeeping quality

Since the craft will be with small hump draft both on calm water and seas due to its strong dynamic air cushion effect, the craft possesses good take-off/touch down ability, and rather small slamming load on hull in rough seas. For instance, a DACWIG with 90 seats , 32t of overall weight, and flight height of 1.8-2.7m can be operated safely in seas with significant wave height of 2.5-3.5m. In addition, since the cruising speed of the crafts is very high, say about 80-120kn, and the encounter wave frequency is also very high, much more higher than the natural frequency of pitching and heaving of the craft, i.e. the craft will be running at super critical mode, as a result, the relative speed loss of the craft due to both wind and waves will be smaller compared with ACV/SES and other high speed vessels, still, the craft can be operated on nearly platforming, which is most hopeful for the operators.

8. With good stealth ability

Since the craft operates in ground effect zone, i.e.close to the water surface, which is located in the blind area of observation for enemy's radars. It's very important characteristics for the crafts with military applications.

9. Easy to construct and maintain, and with lower cost for the construction and maintenance

Since the DACWIG is a ship in general, and without special equipment (hydrofoil for HYF,

flexible skirt for ACV/SES, landing gear and airtight fuselage for airplane, and automatic control systems for PARWIG and HYF etc), therefore, the cost of DACWIG will be lower.

10. Easy to develop in the water transport system

Since the DACWIG is a ship in general, and operates on/or very close to the water surface, all of the navigation rule, equipment, safety code, instruments, and observation for navigation might be complied with that for the conventional high speed vessels, such as SES/ACV/CAT/HYF/WPC/SWATH etc, and needn't to develop novel articles mentioned above, and no special difficulties for navigation and operation of PARWIG, which described in III. 2. article.

To sum up, DACWIG possesses a series of advantages to develop as fast sea and river transportation tool, however, also has some disadvantages, such as lower lift drag ratio compared with PARWIG due to the low aspect ratio, and lower flying height etc, in addition, since the craft possesses three advantages, such as fine amphibiouness, high speed, and good seakeeping quality, it is no doubt to cause a lot of design problems, such as aero-hydrodynamic configuration design of craft for satisfying both the longitudinal/transverse/vertical stability, and equilibrium of various force acting on the craft for various operation mode, such as hull/cushion/air borne mode, and the strength problems for satisfying the slamming load on the hull/sidewall/flap of main wing etc.

V. Operational analysis of DACWIG

1. Selection of routes

In general, the running time of high speed marine passenger vehicles in seas is about 2-3 hr, which has to comply with the comfortable requirements of the ISO2631 for passengers . Even though the operation of craft in inland river, the running time of the craft had better no longer than 4-5 hr as well due to the higher vibration and noise level in cabins of fast vessels. We assume the speed of conventional vessels is 30-40kn, then the maximum range will be 80-120 n.mile in sea and 250-350km on river. However, the distance of some routes in Chinese coastal area and inland river is much more than this limited range, such as:

Navigation route	Shanghai to Qin- Dao	Shanghai to Wen-Zhou	Xia-Men to Gao-Xiong	Fu-Zhou to Ji-Long	Hai-Kou to Hong-Kong	Tian-Jin to Da-Lian	Han-Kou to Nan-Jin
Range (n.mile)	408	281	165	149	--280	218	395

Therefore, the conventional high speed vessels are not able to satisfy such requirements mentioned above. With respect to the DACWIG, the craft speed of such type with 90-250 passengers is about 100-150kn, which can satisfy the operational time requirement for above routes, i.e .only take 2h 45min from Shanghai to Qin-Dao by speed of 150kn of DACWIG, and 4 h 10 min for Han-kou to Nan jin even by the craft with speed of 100kn. Thus, it makes the route range extending as high as to 2-3 times so as to extend the application of the craft to a large extent.

2. The estimation of operational economic analysis for a typical navigation route of DACWIG

2.1. Navigation route

In order to simplify the comparison and analysis, we take the Shanghai-Nantong route for the estimation, the range is about 100 km with wide river bed, and belong to navigation region of A class.

2.2. Craft type

We take the Russian DACWIG model Kometa-2 as the typical craft for the estimation, the leading particulars of the craft is as follows:

Weight of craft during take-off (t)	32
Passengers	120
Length overall (m)	36
Width overall (m)	20
Machinery	Two A 24 Gas Turbine
Total power (kw)	3680
Speed (km/h)	170
Range (km)	800
Seakeeping quality	Can take-off and touch down at 3-4ss
Cost of the craft	According to the cost of Chinese similar craft, the cost will be Y25 mil, i.e. Y 200000 for each person.

2.3. Operation time for each sortie, and sorties of each craft for each year

Range 100km, and operational time for each sortie is 36 min, 10 sorties for each craft per day, therefore, total operational time for each year is 1800 hr due to 300 operational day for each year.

2.4. Ticket fare

At present, the ticket fare for this route operated by high speed catamaran is Y75 for lower cabin, and Y85 for upper cabin. Considering the bus fare from the down town of Shanghai to the pier of

CAT is Y10, therefore, the ticket fare of the actual craft for the CAT is Y65/75.

2.5. Operational cost and profit estimation

The operational cost can be estimated as table.4, where

(1) Depreciation fee for the craft: Average depreciation fee for each year may be Y 4.06 million due to the interest rate 10%,and depreciation duration 10 year, as well as not considering the residual value of the craft.

(2) Maintenance fee: 5% of the craft cost, Y 1.25 mil;

(3) Payments for fuel and lubrications: considering the specific fuel consumption of engine is 370g/kw. h, and the price of fuel is Y2000/t,as well as the cruising power of the craft is 60% of the total power output, then the total fuel and lubrication fee is about Y2.97 mil;

(4) Insurance fee for the craft: 1 % of the cost of craft, i.e. Y. 1/4 mil per year;

(5) Payments for crews: Y 0.20 mil per year;

(6) Auxiliary payments: Y 50000 per year;

The total fee for (1) --(6) is named as direct fee, is Y8.78 mil;

(7) The indirect fee of the craft such as mooring fee, navigation administration fee, overhead fee, and other auxiliary indirect fee is about 21% of the craft cost;

(8) Tax: 3% of the craft cost.

According to the mentioned above analysis, the operational cost for the Shanghai-Nantong route can estimated as following table 4:

Table 4 The estimated operational cost for Shanghai-Nantong route.

Item	Value	Value
Direct cost (Thousand Yen)	8780	8780
Ticket fare (Yen)	85	85
Occupied rate for passenger(%)	70	80
Annual income for passenger transport (thousand yen)	21420	24480
Indirect payments (thou.yen)	4500	5140

Annual total cost (thou.yen)	13280	13920
Tax (thousand yen)	640	730
Profit (thou.yen)	7500	9830
Profit plus depriciation fee (thou.yen)	11560	13890
Investment returned period (year)	2.41	1.96

3. Conclusion

In case of the ticket fare for DACWIG only higher 15% than that of high speed catamaran, the investment returned period of the DACWIG is about 2 years, according to the traditional estimation method for the economical operational analysis of crafts. That means the economic efficiency of the craft is much more high than that of conventional high speed vessels.

VI. Summary

1. Although the DACWIG is a newly developing transportation tool in recent 20 years, the craft has been envisaged seriouly by international shipping communities due to its series advantages, such as super high speed (100-150 kn), good economy (the fuel consumption of which is close to that of ACV), safe (operating in ground effect region), fine seakeeping quality, small speed loss of the craft in rough sea, (craft weighing 30-40t can be operated in rough sea with wave height of 2m) etc.

2. The DACWIG is a special ship, but not an airplane. She can operate at low speed just as a ship, and also can operate at both medium (cushion borne) and high speed (air borne). Therefore, the craft is able to loiter and be cruising on the sea, even suspend statically over the ground/water surface. It needn't not only runway for aircrafts, but also pier for conventional ships. It possesses amphibiouness and landability with simpler equipment and lower cost compared with airplanes, and just slight higher than ACV. In short, the DACWIG might be the unique craft in the high speed vessel family, which possesses triple advantages, i.e. super high speed, fine seakeeping quality, and marvelous amphibiousness in the world.

Of course, the DACWIG is still at the initial research and development stage so far, there are a lot of technical and engineering practical problems faced us, especially on the real passenger ships. However, it seems that no radical difficult and unsolved problems, such as aero-hydrodynamics, control systems, equipment, engines, material, etc existed so far, therefore, we consider it might be the prospect of the high speed passenger crafts in 21 century of the world.

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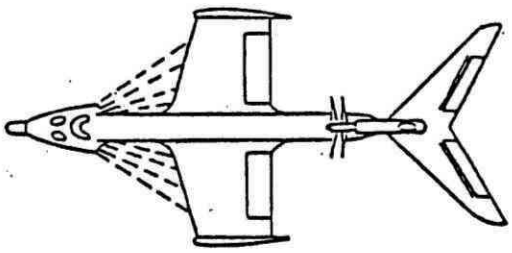
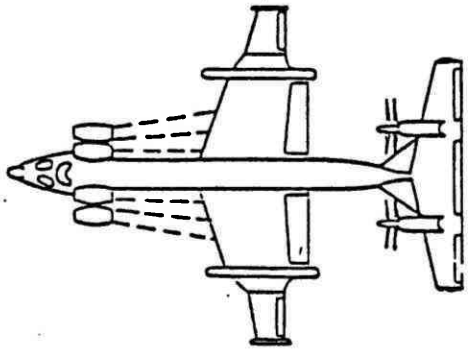
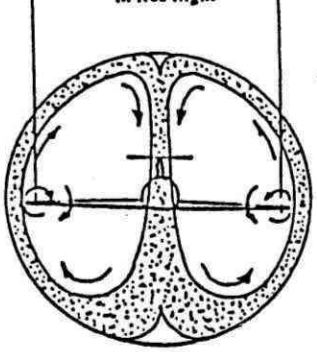


Ekranoplan 1



Ekranoplan 2

Figure 7 (3)



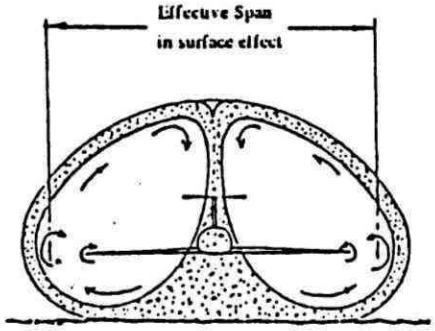
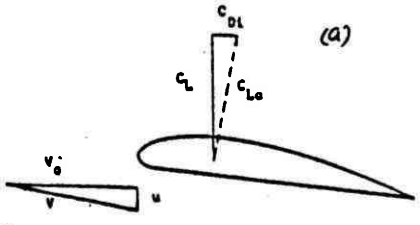
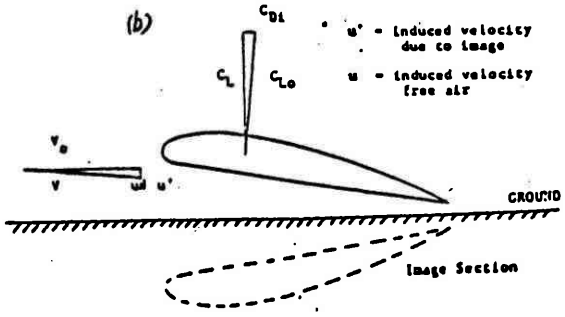


Fig3 Ground effect alters the cross-section of the mass of air being worked upon, increasing the effective span between the trailing (tip) vortices and the aspect ratio (eq. (1)), so reducing the energy lost to downwash, the lift-dependent drag and required power.



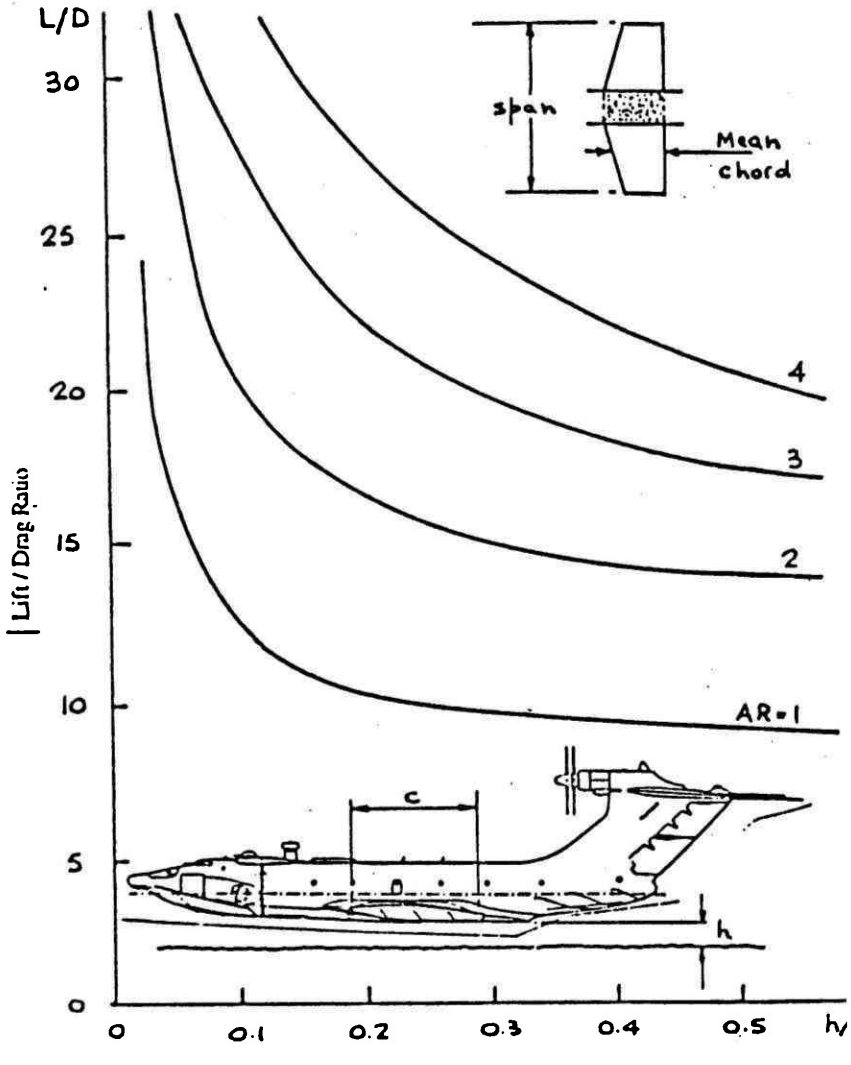
Wing Section Operating Out of Ground Effect



Wing Section Operating in Ground Effect

Figure 8 Comparison of a wing section operating in ground effect with section operating in free air.

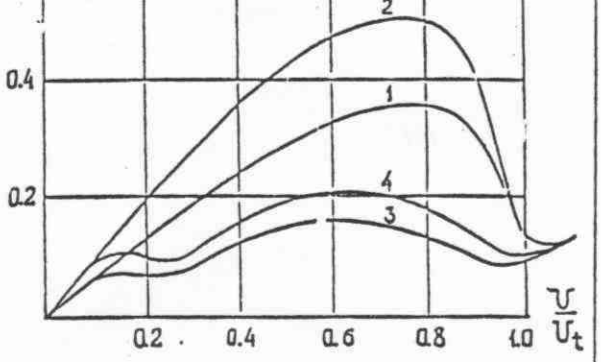
[2]



Height of Tip or Endplate of Lifting Surface above Sea or Land
Mean Chord of Lifting Surface

104

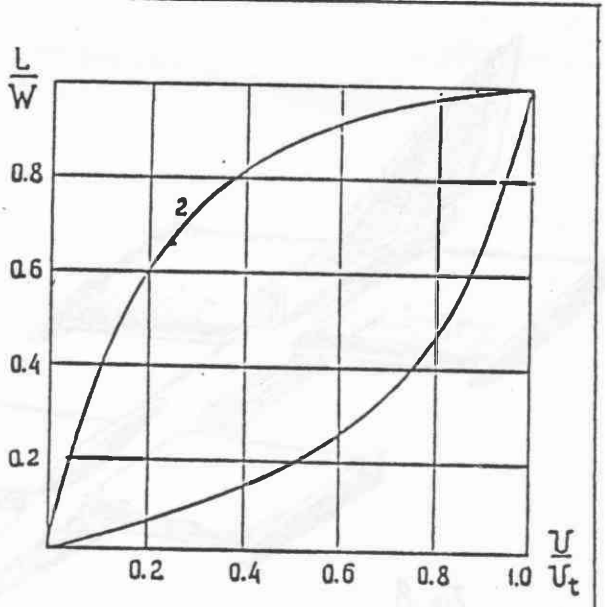
(1) Fig. 2. Improvement in (lift/drag) ratio of lifting surfaces of different aspect ratios in terms of tra



D-drag, W-weight, V-speed, V_t-take-off speed

1-calm sea, without air injection
2-rolling sea, without air injection
3-calm sea, with air injection
4-rolling sea, with air injection

Figure 4 (3)
Drag of craft in calm and rolling sea with and without air injection



L-lift, 1-seaplane,
2-ekranoplan with air injection

Figure 5 (3)
Relative lift of seaplane and ekranoplane with air injection

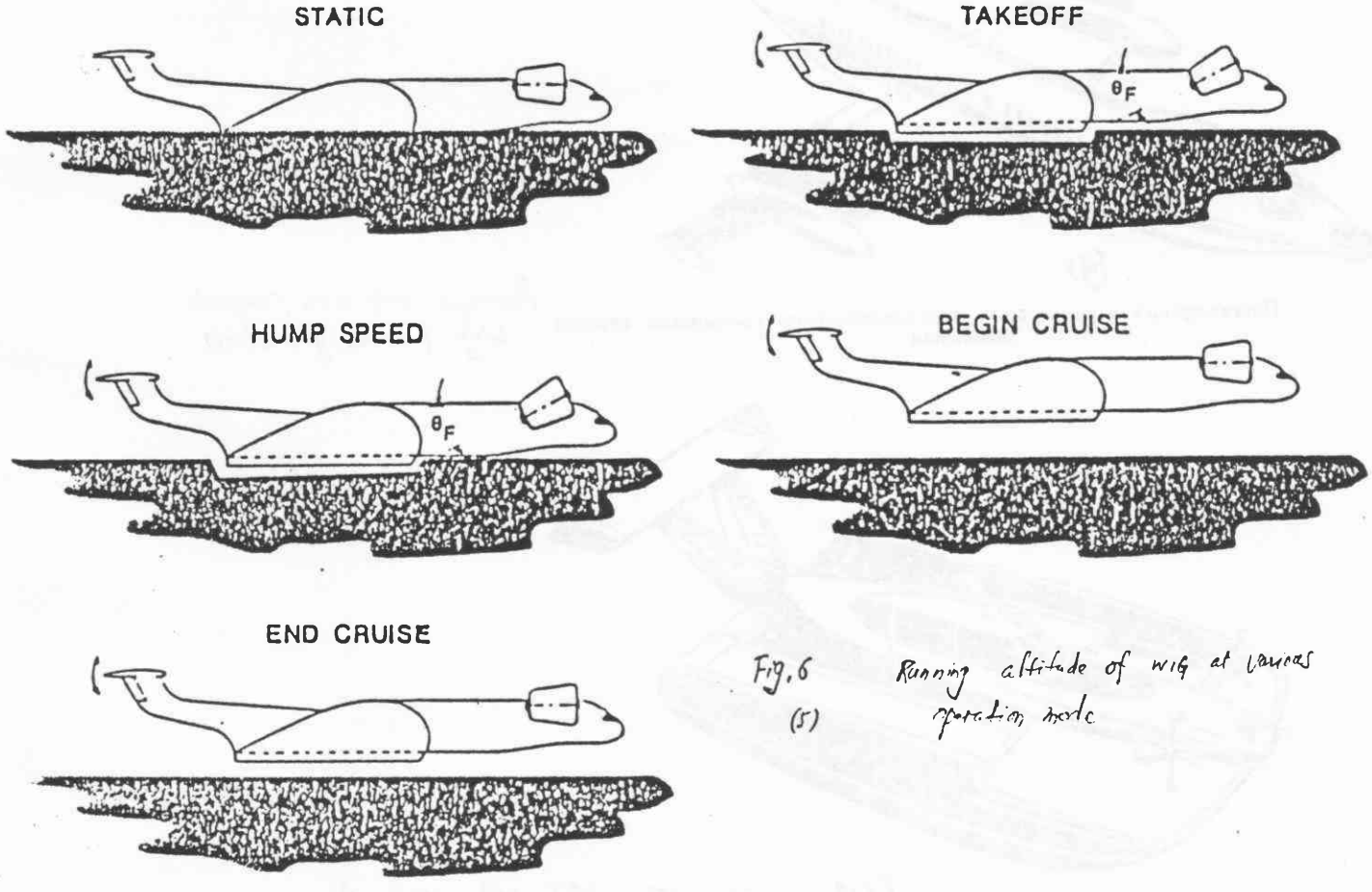


Fig. 6 (5) Running attitude of wig at various operation modes

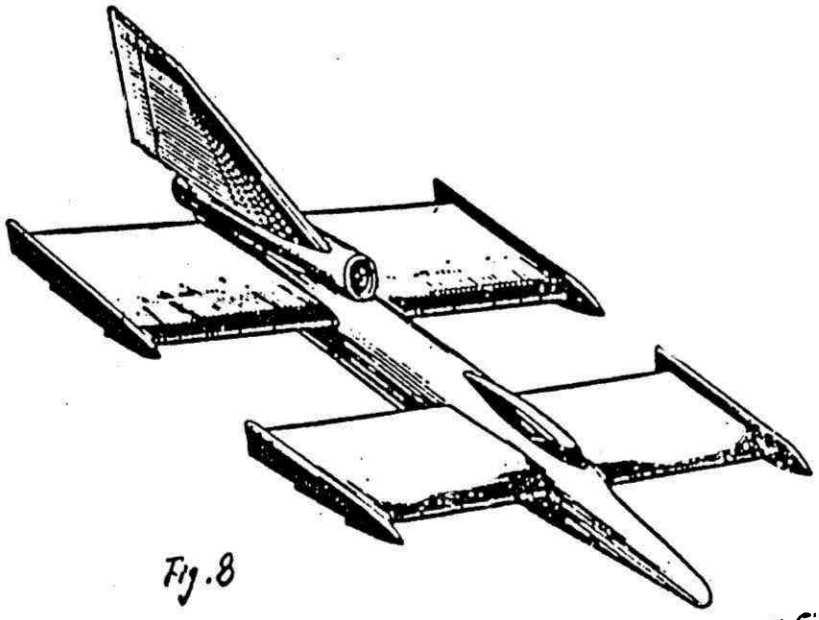


Fig.8

Схема экраноплана «тандем»

WIG with tandem aerodynamic arrangement

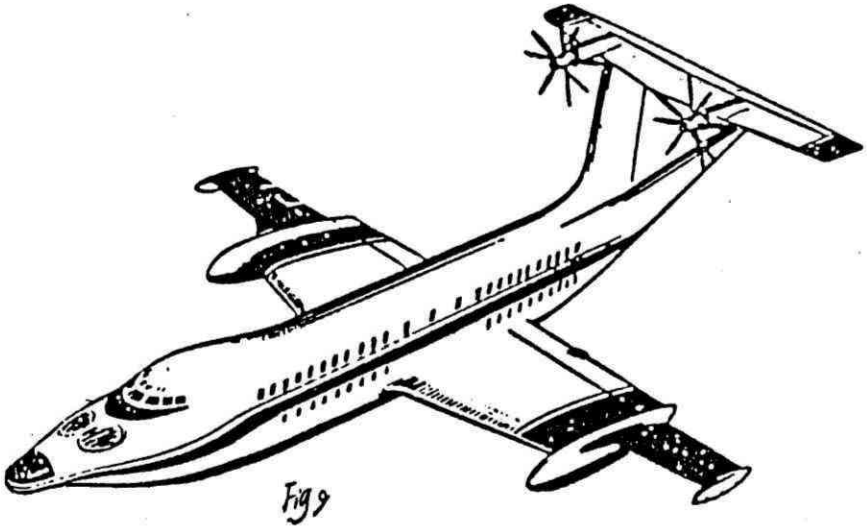


Fig 9

Пассажирский экраноплан в аэродинамической компоновке второго поколения

Passenger WIG with composite wing (second generation)

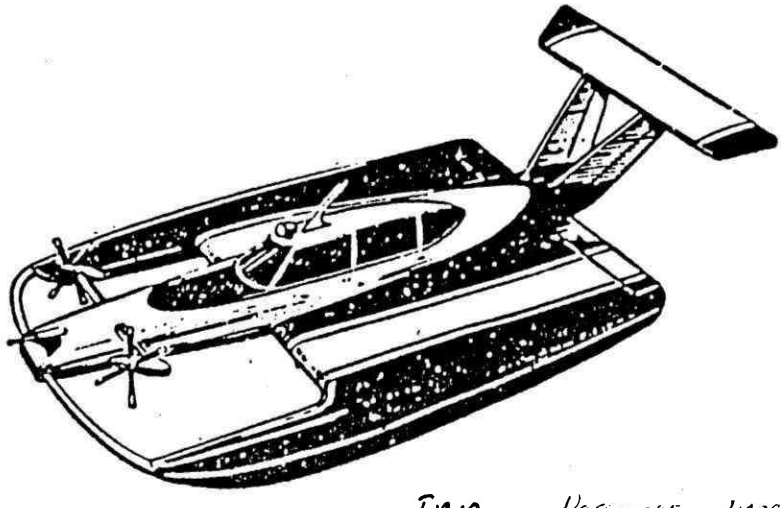


Fig 10 Passenger craft with small AR

Пассажирский катер-экраноплан с крылом малого удлинения

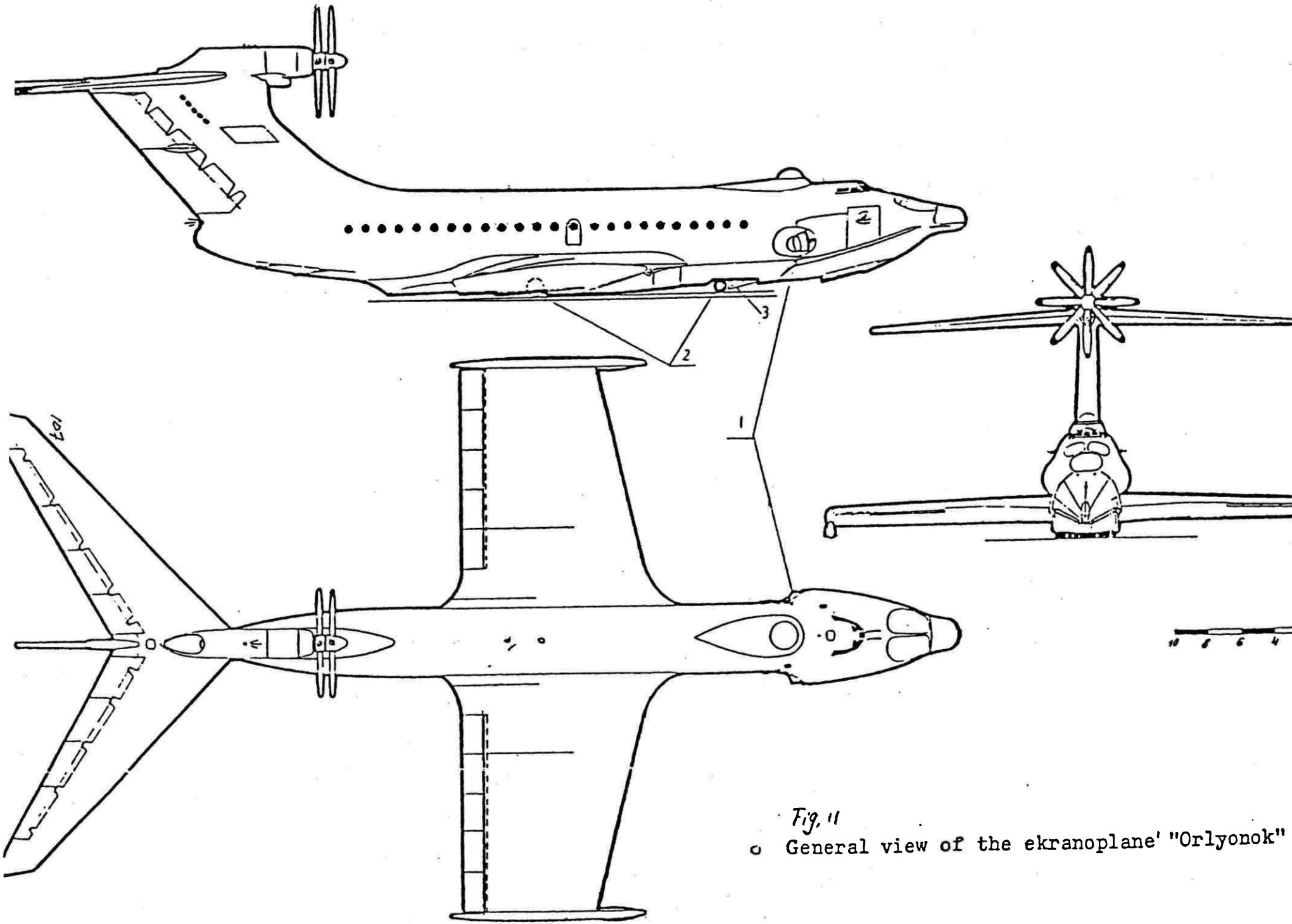
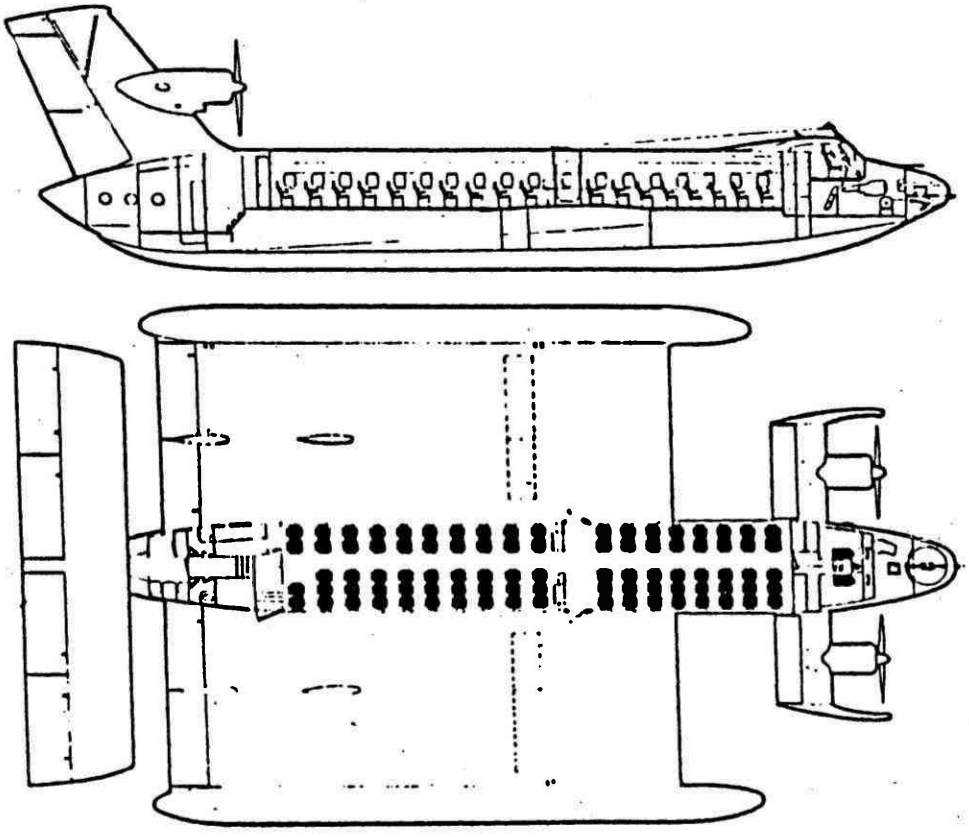


Fig. 11

General view of the ekranoplane' "Orlyonok"



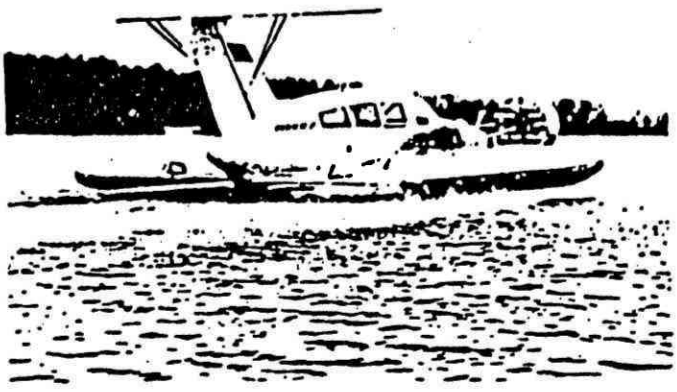
(2) 13

Fig 13 WIG type Rocket-2

ТЕХНИЧЕСКИЕ ХАРАКТЕРИСТИКИ

Длина габаритная	34,8 м
Ширина габаритная	19,8 м
Высота габаритная	10,0 м
Осадка	0,5 м
Масса пустого	20,3 т
Полная масса	32,7 т
Скорость	180 км/ч
Дальность	800 км
Двигатели:	
тип	ТВ7-117 С
мощность	3 × 2440 л.с.
Пассажировместимость	90 чел.
Мореходность, высота волны	1,2 м
Амфибийность:	
препятствие	0,7 м
уклон	5 градусов





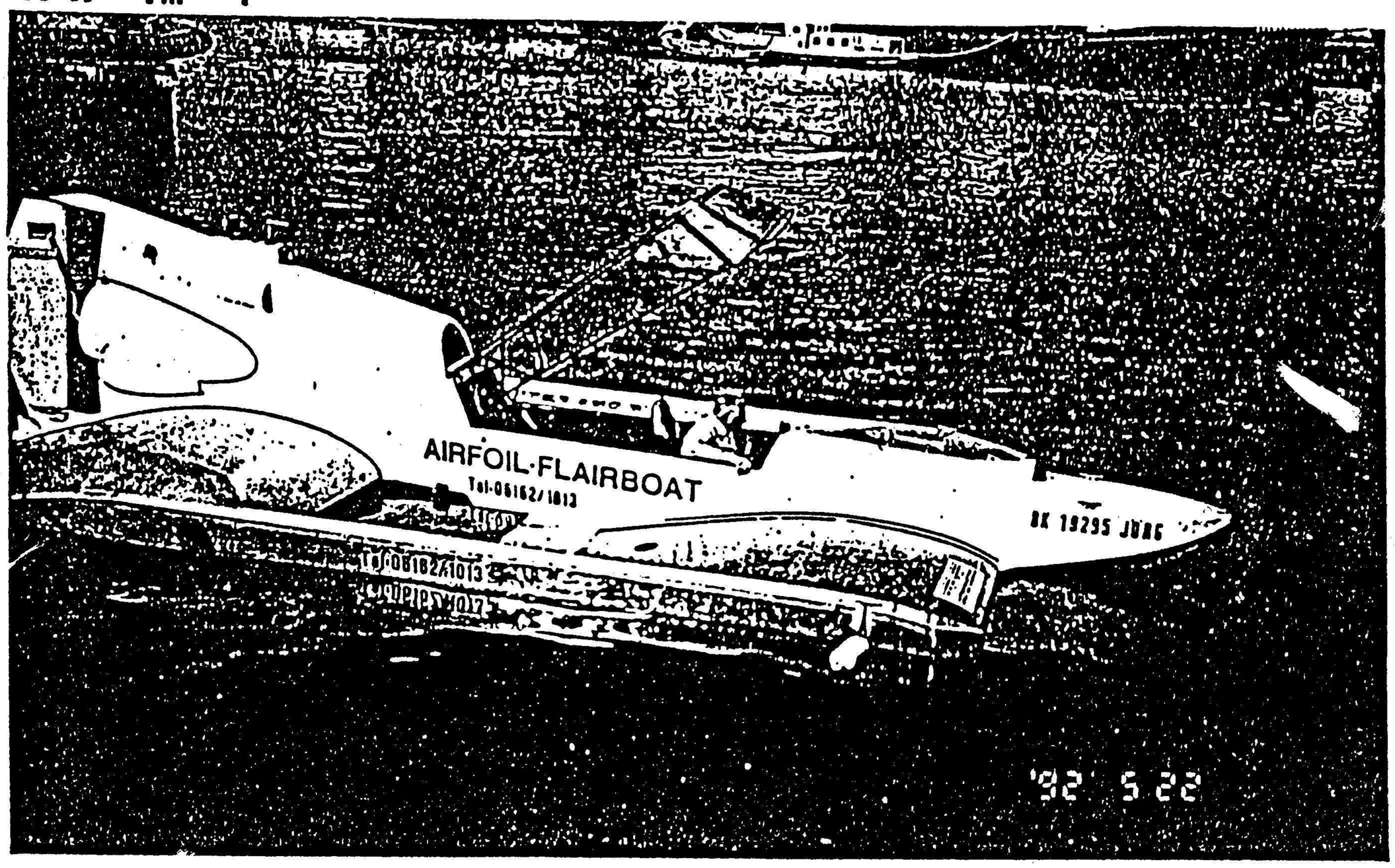
(2) 12



Аналог газотурбохода РАКЕТА-2 восьмиместный катер ВОЛГА-2

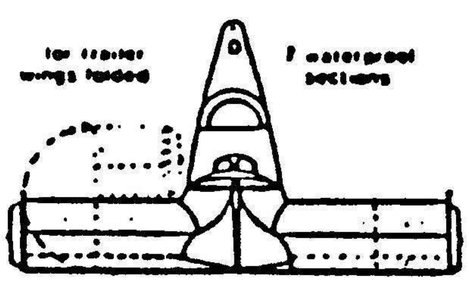
fig 12 DACC type Volga-2

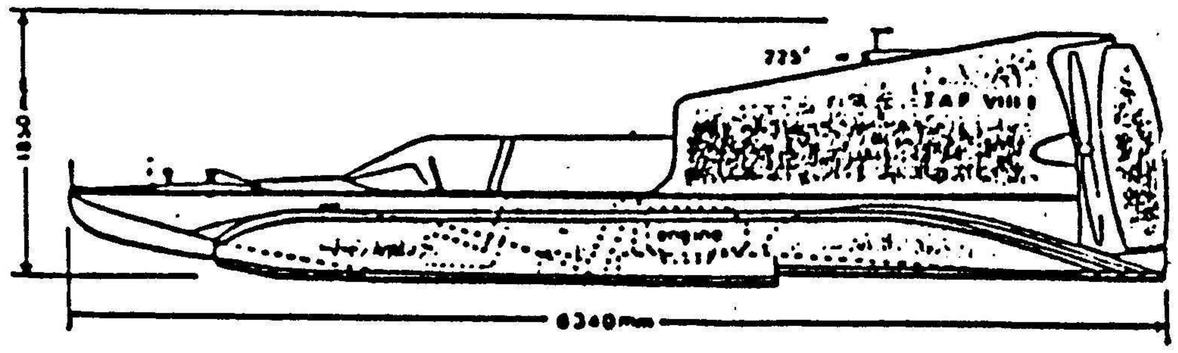
TAF VIII–1

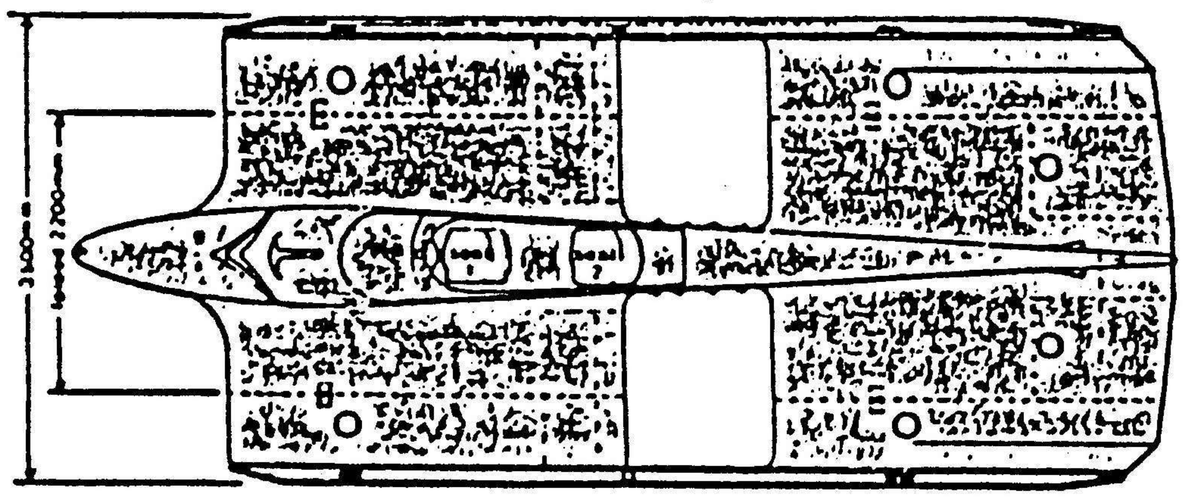


TAF VIII–1

Fig. 17

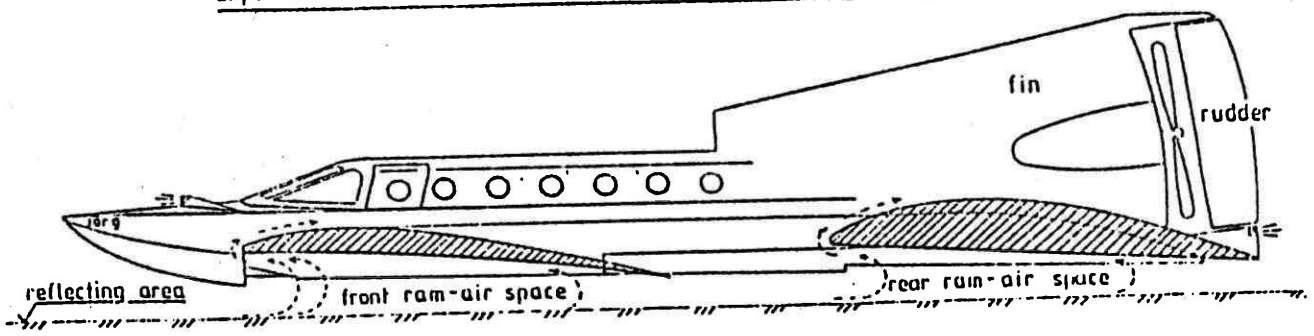






Overall length:	8.30m	Passengers:	1
Overall width:	3.40m	ENGINE:	100HP
Overall hight:	2.00m	Cylinder:	4
Max Weight:	0.75t	Cruising Spend:	125-135km
Max.Useful Load to:	0.20t	Cruising level:	0.25m
Capacity people:	(2)	Normal Range:	200km
Crew:	1		

Explaination of the stable aerodynamic ground-effect flight

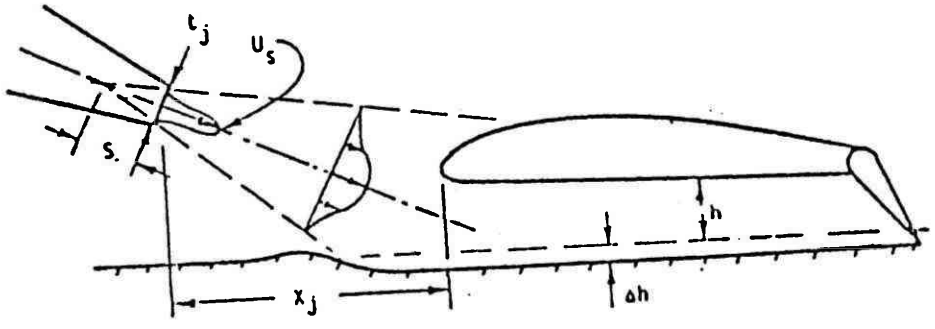


front wing ~ / ram-wing section has a higher lifting rate

rear wing section controls the variabilities of the level flight

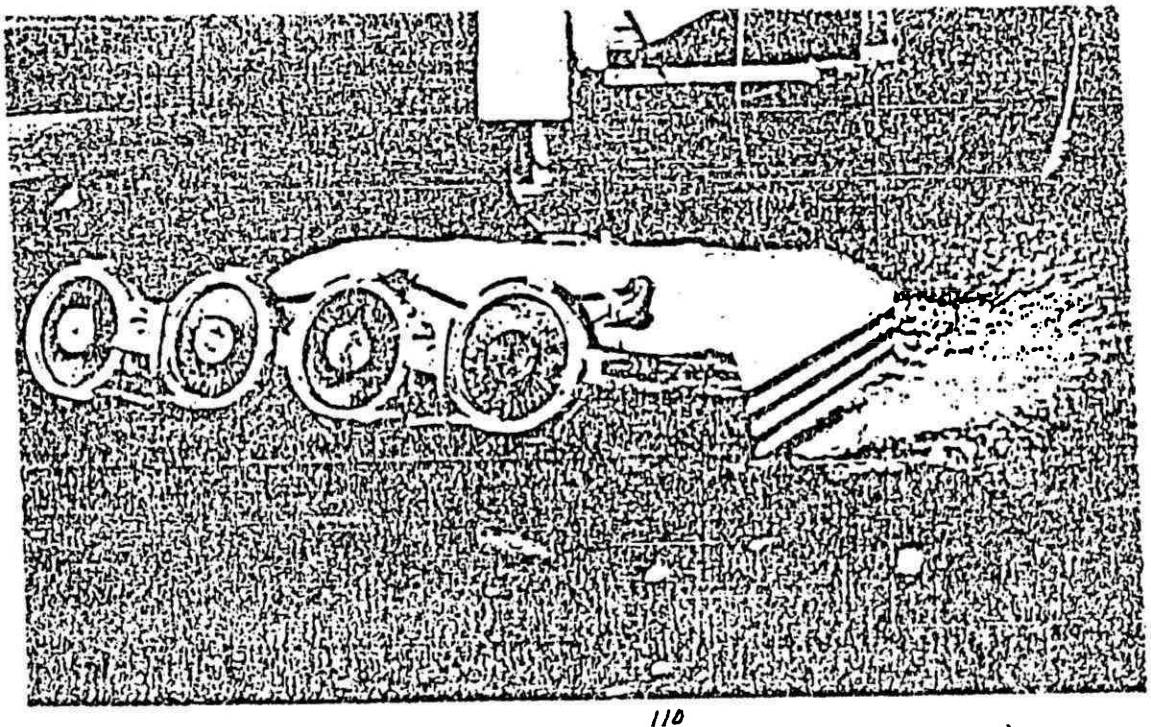
Fig 18

This aeromechanic solution allows a stable ram-air flight without pitch and roll controls. Pct. 1c



(6)

Figure 19 Under-Wing Pressure Recovery versus X_j/h
(Conditions as Shown)



(7)

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Figure - U.S. Navy PAR-WIG Model in Tow Tank (7)

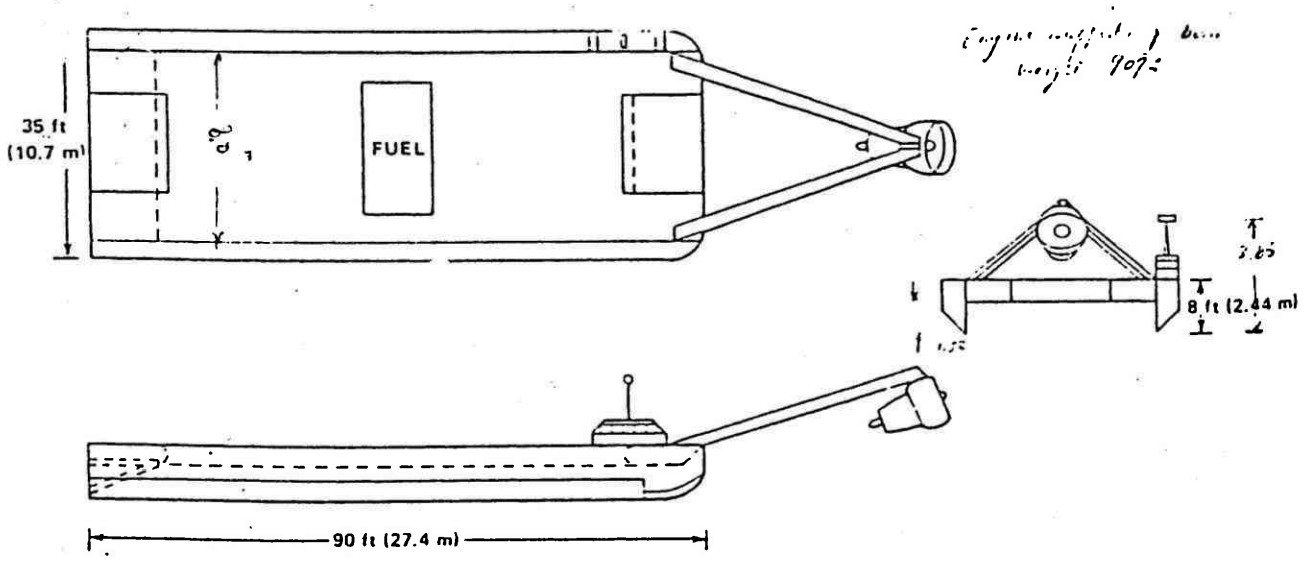
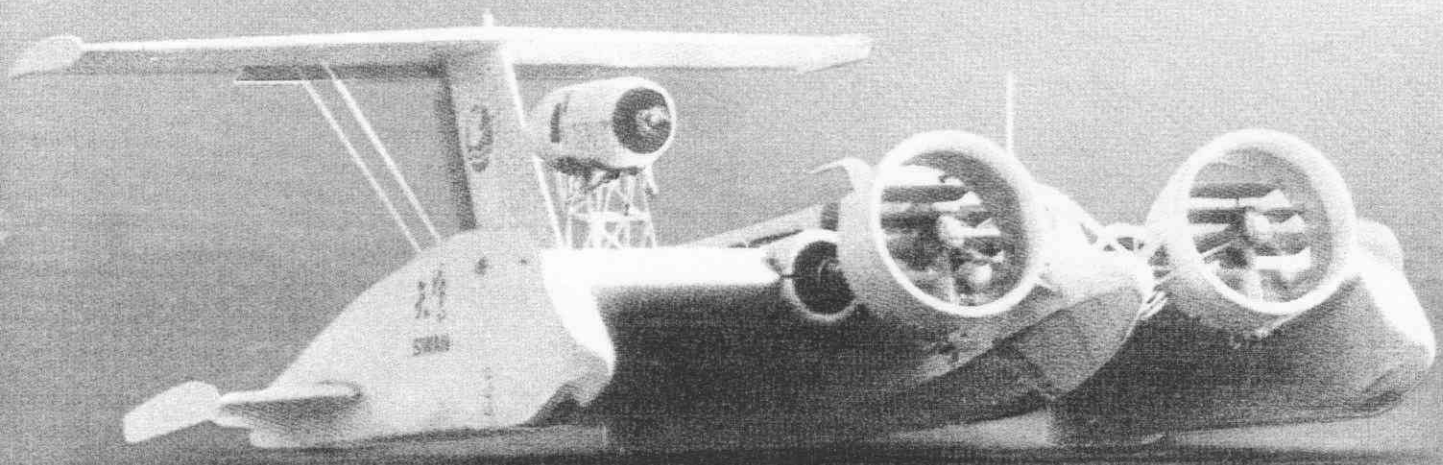


Figure 4 General arrangement—three view PAR landing craft

Fig. 16 [81]

天鹅号地效翼船



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求新造船厂
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Fax : 021-63779744
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Address : 132 Ji Chang Road Shanghai
Post code : 200011
Tel : 021-63783228
Fax : 021-63772100

“天鹅”号地效翼船是一种新型高速运输工具。

● 在强地效区内航行，驾驶方便，安全可靠，建造成本低，维护简便。

● 沿5度斜坡气垫登陆，水中和陆上机动能力强，具有全垫升气垫两栖性特点，无需专用码头。

● 多航态航行能力，排水、气垫航行速度0~80公里/小时，离水飞行速度80~130公里/小时，飞行高度0~1.0米，续航里程300公里。

● 最大起飞重量7.2吨，载客15~20人。

● 2~3级浪海况下起降，安全航行。

“SWAN” WIG craft is a novel type of high speed water transport tool.

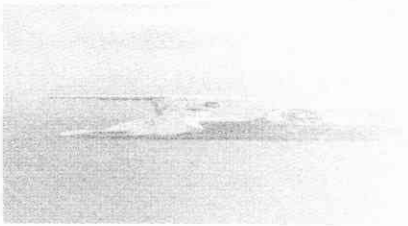
* Operating in strong surface effect zone with easy handing and maintenance, safe,credible, and reasonable construction cost.

* Possessing amphibiouness(just like an amphibious hovercraft), the craft is able to land on air cushion along a slope with the gradient of 5 degree, and with fine manoevreability both on ground and water. It's not necessary to prepare a special pier for the craft.

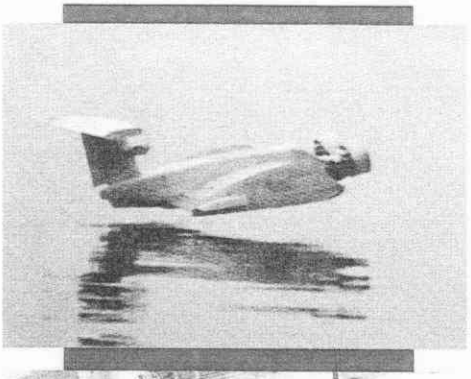
* With multiple operation mode, the craft is able to operate on hull borne, air cushion borne(0-80km/h), and flying mode with the speed of 80-130 km/h, and flying height of 0-1.0m, as well as range of 300 km.

* with max take-off weight 7.2t, and 15-20 passengers.

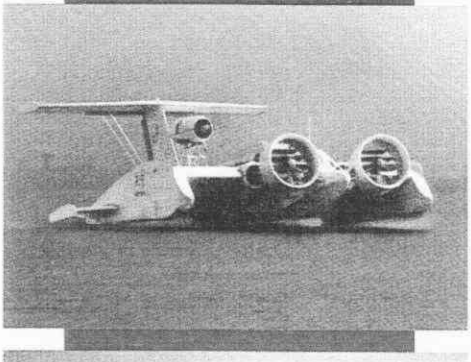
* The craft can operate, take-off, and touch down safely in SS 2-3.

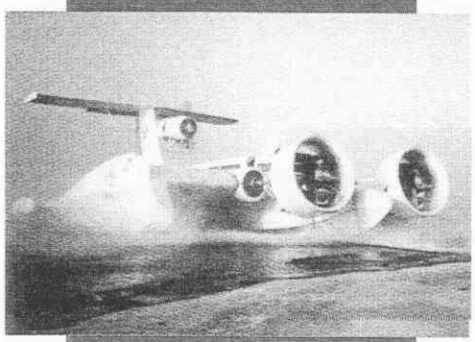


1 摇控自航模飞行试验
Remote-control free flying model test
2 模型水池试验
Model towing tank test
3 天鹅号地效翼船高速飞行
SWAN WIG flying
4 天鹅号地效翼船登陆
SWAN WIG landing









Taking Steps to Promote the fast development of WIG in China

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Abstract

The eager desire of the high-speed passenger water transportation in China is described briefly in this paper. The paper also introduces the features of Dynamic Air Cushion Wing in Ground Effect Craft (DACWIG), and predicates that it will be the one of most hopeful high speed passenger craft in the 21st century. The paper introduces briefly the China made DACWIG type "750" and "SWAN" designed by MARIC. Proposal for taking the steps to promote the fast development of DACWIG in China are also carried out in this paper.

1. Eager Desire for the High-Speed Passenger Craft in China

China has a large amount of populations with wide territory. Accompanying with the set out of the open policy in China, the economical construction of the country developed rapidly, so as to speed up the development of the transportation, particularly, the passenger transportation.

However, due to that the business mechanism for the water transportation did not transfer into the market economy on time, the tendency of passenger flow in the water transport is dropping down with comparison of train and long distance bus passenger transportation. According to the statistic material, the proportion of turn over of passenger water transport in the total passenger transport turn over was dropped down from 9.7% in 1952 to 2.1% in 1994. The water transport of China is really facing to the serious crisis of existence.

It is obvious, that the low speed, bad equipment, poor comfortable condition of passenger ships, etc seriously influence on the development of Chinese water passenger transportation, even on the route of Yang- Zi , Pearl , Xie Jaiang , Helongjiang River etc, and also on the coastal line. Taking the Yang-Zi River Route as an example, it will take about 6 day and night from Shanghai to Chong Cheng for a ship, 51 hours for the train, and only 1-2 hr for the airplane. Therefore, in order to get larger passenger flow, shipping companies are obliged to drop down the ticket fare. Even in such case, the average occupation is often lower than 50%.

Therefore, it is not strange that the shipping companies demand the policy with " travelize" for long range passenger route, and "increasing speed " for short range.

According to the statistical data in the first half of 1995, total number of high speed passenger crafts for the regular route in China is in excess of 190 (seats larger than 40, and speed higher than 23 kn), with increasing rate as high as 38%. Hundreds of high speed craft with various types operated on four big inland inland water system (Yang-Zi River, Yellow River, Pearl River, and Helongjiang River) and on the coastal line along the Bo Hai Sea, Yellow Sea, Eastern Sea, and Southern Sea.

There are more than 50 main high speed water transport passenger routes in China, about 25 routes among them on the delta area of Pearl River (10294 seats), occupied 52.3% of total; 7 routes on the delta area of Yang-Zi River (3052 seats), 15.4 %; 8 routes on mid and upper stream of Yang-Zi River, 21.1 %; 3 routes on Helongjaing River, 599 seats, 0.4% (due to the freezing in winter season). Only one route on Da-Lian Yen-Tai route in Bo Hai Bay, with 1595 seats. (1)

The above mentioned statistic data did not cover Hong Kong , and Taiwan area. According to the unperfect statistic data of 1994, there were 838 high speed crafts in the world (not including the Independent t of Common wealth, and main land of China), among them 113 crafts on Hong Kong area. If taking into account 190 crafts on mainland, then the total crafts in the China were 300, i.e. about one third of the total crafts in the world!

At present, the high speed passenger water transport has been almost saturated in the developed countries, such as western European countries, north America, and Japan etc. They are try to take steps to develop high speed car passenger ferry ship and cargo ship with big size, as well as apply novel technology to the HSC for improving performance, economy, and comfortable of the crafts.

However, in China, the transaction for the high speed water transport is still at the initial stage. In order to catch more passenger flow and profit, some shipping companies take a serious of temporary steps to purchase various type of second hand CAT, HYC, MH , and modern high speed CAT with hydrofoil and wave piercing craft from foreigners, as well as China made HSC.

Nevertheless, owing to the booming economy, wide domestic market, large passenger flow, and extraordinary geographic condition, it can be predicted that the worldwide market of high speed craft might be transferred partly to the China.

With respect to the military HPMV, it should be noted that they will always be emphasized by naval staff of various countries due to a serious of specific functions of them, and which will be used as landing craft, minesweeper, guide missile craft, and patrol boat etc.

2. Dynamic Air Cushion Wing in Ground Effect Craft (DACWIG)—The Orientation of the High Speed Passenger Water Transportation Tool in the 21st Century

2.1 Seeking the suitable high-speed water transportation tool for satisfying the domestic requirements

The suitable navigation time for up dated high-speed crafts on coastal line is about 2-3 hr for satisfying the comfortable standard ISO263 for passengers. That means the endurance for anti-fatigue for passengers of crafts operating in sea is about 2-3 hr, and 4-5 for inland water routes. Otherwise passengers will complain for the continuous high vibration and noise level in the crafts, except provided with special berth equipment.

Taking a HSC with speed of 30-40 kn for an example, the max range for the sea route will be 80-120 n.mile, and 250-350 km for the inland water way. However, the range of some domestic navigation routes are far in excess of such limit, and demonstrates that the conventional HSC are unsatisfied for the requirements.

The range of some navigation routes of China can be listed in following table:

Navigation Route	Shanghai to Tsin-Dao	Shanghai to Wen-Zhou	Xia-Men to Gao-Xiong	Fu-Zhou to Kei-Lon	Hai-ko to Hong Kong	Tian-Jin to Da-Lian

			(Taiwan)	(Taiwan)		
Range (n.m)	408	281	165	149	280	218
Navigation	Wu-Han to					
Route	Nan-Jin					
(n.m)	395					

Since the speed of China made WIG and Russia made civil WIG is about 80-150 kn, the navigation time of the route using such transport tool can be limited in 2-3 hr. For example: in case of using WIG with the speed of 150 kn, the navigation time between Shanghai and Tsin-Dao will be 2.75 hr, and 4.2 hr for the inland river route from Nan-Jin to Wu-Han by WIG with speed of 100kn. Thus, it will extend greatly the applicable range for the HSC so as to cause more interest of passengers.

China is still a developing country with the features of large passenger flow (3-4 million person-time for Shanghai to Chong-Min Island), and poor economical and technical condition.
We have not enough airplanes, helicopters, and express high way for cars, for passengers as the transport tool. We still have to fully make application of the high-speed water transport tool to instead partly of aviation and ground transport, and it is no doubt that the WIG is a reasonable transport tool.

2.2 The characteristics of the Dynamic Air Cushion Wing in Ground Effect Craft (DACWIG)

At present, there are two basic kinds of WIG in the world. They are:

(1) **Power Augmented Wing in Ground Effect Craft (PARWIG)**

Fig.4 shows the Russian PARWIG type Orlyonok.

The features of the PARWIG are:

- Very high speed (> 150 kn), it is due to larger aspect ratio of the wing, and taking special aerodynamic configuration.
- Very good seakeeping quality of the craft post take-off, due to the large flying height on such operation mode;
- With the ability to fly beyond the ground effect zone in a short time period, as to possesses larger maneuvering space;

However, they have some disadvantages as follows:

- Even though there are bow thrusters and water ski for improving the take-off, and seakeeping quality (pre take-off), the craft does not possess amphibious due to its aerodynamic configuration. The craft is able to land only on the prepared landing base with special landing equipment;
- The larger aspect ratio, and wing span , which affects on the maneuverability of the craft, and make the craft difficult to operate on the narrow water way, to operate alongside with other craft and wharf;
- The take-off speed and distance is larger due to the specific aerodynamic configuration, which also affect on the craft performance at low speed, and difficult to loiter in narrow sea.

- Since the craft may fly beyond the ground effect zone, the complicated automatic control system is necessary, apart from special aerodynamic configuration;

Due to the characteristics above mentioned, the craft is difficult to use as passenger craft just as the description in (6), (7). In case of applying such craft to the passenger transport, more navigation equipment have to be equipped both on board and landing base, in addition, the special operational zone, special landing base, etc are also have to prepared (2), (6), (7).

May be this is why no passenger PARWIG used in Russia so far, since the largest WIG so called "Caspain Sea Monster" in the world so far (weighing 544 t) completed in former USSR 30 years ago.

(2) Dynamic Air Cushion Craft (DACC)

In Former USSR, the founder of Hydrofoil craft and WIG, Prof. R.Y. Alexeev at his senior age after 30 years of research and development of PARWIG, did realize that the PARWIG are very difficult to apply to the passenger transportation on the condition of former USSR. With his colleagues he developed a type of WIG with simple version named "Volga 2" as a water passenger transportation tool. Apart from the advantage of high speed, they also possesses following advantages:

- Since the craft will operate basically skimming on the water surface with strong surface effect, the craft is with fine stability, and needn't any automatic control system. The craft is with low cost both for construction and maintenance.
- Owing to the special aerodynamic configuration, the craft possesses the function of dynamic air cushion , amphibiouness and landability. That means the craft is able to land on the unprepared beach, ramp, slope, and operate on the grassland , ice surface, and tidal region, etc.
- Since the craft has no excess of wing span, and with function of static air cushion, the craft can operate on cushion borne, just as an air cushion vehicle. Therefore, the navigation equipment, and selection of navigation route, as well as the handling technique are similar as that on ACV.

The disadvantage of the craft are:

- The aerodynamic property will be lower than that of PARWIG due to the lower aspect ratio. The speed of the craft is not very high, about 70-150 kn;
- The seakeeping quality of the craft might be lower due to the lower flying height, and operation skimming on the water surface. For this reason, the "Volga-2" is suggested to be operated on inland river.

We think the ACEG type of Germany, and Russian Volga-2 are including to such type of WIG.

(3) Dynamic Air Cushion Wing in Ground Effect Craft (DACWIG)

Upon the base of crafts mentioned above, is it possible to create a novel type of craft to concentrate the merits for both crafts mentioned above for the passenger transportation both in sea and inland river? This is the aim of developing the DACWIG in MARIC for many years.

The aerodynamic configuration is designed for with higher flying height, multiple operation mode, fine amphibiouness, landability, and seakeeping quality. The advantage of such craft can be summarized briefly as follows: (2)

- Speed of the craft will be higher about 2-3 times than that of ACV/SES/HYC with same lift drag ratio. That means, lift drag ratio of the DACWIG will be close to ACV/SES/HYC, in case of 2-3 times Fn higher than that of later.
- High economy. Since the lift drag ratio of the craft is higher due to the clearing water surface operation, the fuel consumption is attractive, in addition, the construction and maintenance technology is simple, and close to ACV.
- With multiple operation mode, i.e. hull borne, cushion borne, and flying mode. Therefore, the craft can be operated not only in sea, but also in river. The craft can loiter in water surface, and alongside the ship and wharf, just as conventional HSC;
- With fine amphibiouness, landability, and low speed maneuverability;
- Good inherit stability due to operating in strong ground effect zone;
- Easy to handle, credible, and safe, without any automatic control system;
- With satisfied seakeeping quality due to a proper flying height;
- Since the craft will be operated in strong ground effect zone, i.e. the flying height is not large, the craft will be with good stealth-ability.

To sum up, the craft is neither an airplane, nor a ship, but very suitable to apply to passenger water transportation.

The disadvantages are:

- Speed less than PARWIG;
- Very difficult to design for compromising the triple performance requirements, i.e. high speed, amphibious, and sea-keeping quality.

3. Taking steps to promote the fast development of WIG in China

Since the DACWIG is very suitable to be a passenger water transportation tool, MARIC have being preferred to develop this type of WIG.

The R/D was started from the end of 70s (3), (4). A series of model tests of more than 30 air tunnel model were carried out with emphasis on the investigation of shape, and dimensions of air tunnel (main wing), as well as the relation between the jet-stream sources (bow thruster) and air tunnel. The tests were carried out in the wind tunnel of MARIC.

After some radio remote control model tests at the beginning of 80's, a manned test craft type 750 was completed in the mid of 80's.

The leading particulars of the craft type 750 are as follows: (fig. 1), (3):

Take-off weight (AUW)	745 kg
Payload	172 kg
Length overall	8.47 m
Span	4.8 m
Height	2.43 m

Take-off performance:

The craft can be taken-off at 4-5 beaufort scale of wind , and about 0.5m of wave height (in lake), with the 30 s of take-off time, 160m of distance, and 45 km/h of the speed.

Cruising speed	132 km/h
Max flying height	0.5 m
Range	130 km
Max acceleration of impact load on Emergent stop:	1.54 g

Sea-keeping quality:

The craft can be taken-off in 0.5-0.7m wave height with 4-5 wind scale, and 6 wind scale gust force in lake. It can be turned at flying speed, and running at different wind and wave direction with 0.3 deg of average pitch angle, 0.52 deg of average roll angle.

Amphibious ability:

The craft can be take-off from ground and run onto water, and vise-verse, and also flying on uneven as well as unprepared ground.

Maneuverability:

The craft can be turning at low speed and even self-turning, and also flying in a zigzag course. The circling time at high speed was about 2.5 min, with 600m of turning radius.

Hull material: GRP

The trial of the craft was completed at the end of 80's.

Since then, MARIC started to develop a passenger DACWIG type "SWAN" in 90's.

The feature of "SWAN" is as follows: (5) (fig. 2)

- Operating in strong surface effect zone, with easy handling and maintenance, safe, credible, and reasonable construction cost.
- Possessing amphibious (just like an ACV), the craft is able to land on air cushion along a slope with 5 degree of gradient, and with fine maneuverability both on ground and water. It is no necessary to prepare a special pier for the craft.
- With multiple operation mode, the craft is able to operate on hull borne, air cushion borne (0-80 km/h), and flying mode with the speed of 80-130 km/h flying height of 0-1.0 m, as well as range of 300 km.
- With max take-off weight 7.2 t, and 15-20 passengers.
- The craft can be operated, taken-off, and touched down safely in SS 2-3.

The craft is now in test.

Since the crafts have to be satisfied the requirements of speed performance, sea-keeping quality, and amphibious simultaneously, the design of craft is more completed. Some test facilities have to be prepared or improved for aerodynamic and hydrodynamic investigations as follows:

(1) Wind tunnel facility with moving screen

In general, there are three methods for testing WIG model in the wind tunnel. Fig.3 shows the velocity distribution of air-flow under the wings for WIG tests in wind tunnel with three type of supported rigid screen. (8).

If the wing speed is Vc (i.e. the speed of air-flow in wind tunnel), then the velocity distribution of right part in the figure is with respect to the fixed earth coordinate system, and the left part with respect to the coordinates system fixed on the wing. Obviously, (a) denotes the velocity distribution for the real moving wing of WIG model or craft, (b) the velocity distribution for in wind tunnel. Since the screen is unmoved, the influence of boundary larger on the velocity distribution is happened to both wing and screen. (c) denotes the velocity distribution on wing And screen for the method of wing image, i.e. putting a same model opposite to the original wing model for eliminating the rigid screen and the influence of boundary layer.

Fig 3-a shows the real velocity distribution of moving wing, i.e. the velocity on screen is equal to zero, and Vc on the wing. Therefore, the difference between the wing and screen is equal to Vc. However, in fig.3-b, the speed difference is zero, and in fig. 3-c, between 0 and Vc.

Therefore, (b), (c) methods do not satisfy the simulation condition of the screen bound. As a result, make not too small error on lift coefficient Cy of the wing, too small for (b), and too large for (c). Same problem also faced the authors during the test of WIG, as results, the lift coefficient of the model taken from wind test results often too small to believe, May be this is an old problem faced the aerodynamic researchers.

(2) High speed towing tank

In order to studying the speed performance, both on calm water and in waves, a high-speed towing tank with separated dynamometer have to be prepared. The separated dynamometer is used for measuring the thrust of bow thrusters so as to calculate the coefficient of thrust recovery of the bow thrusters, and lift drag ratio of the craft model.

(3) High speed turning tank

A WIG model mounted on the carriage can be turned with a high rotating velocity so as to measure the aerodynamic and hydrodynamic position / rotation derivatives of the WIG model at various Fn, and geometric parameters of the handling mechanism of the craft model.

(4) Catapult

Catapults are used for studying qualitatively the longitudinal and transverse stability, as well as the aerodynamic characteristics of the WIG models. It is most suitable for investigating the aerodynamic configuration of novel type WIG at preliminary research stage. Since the models are made of GRP with light hull and no motive engines, the test cost will be lower so as to make a large number of aerodynamic configuration for researchers' option.

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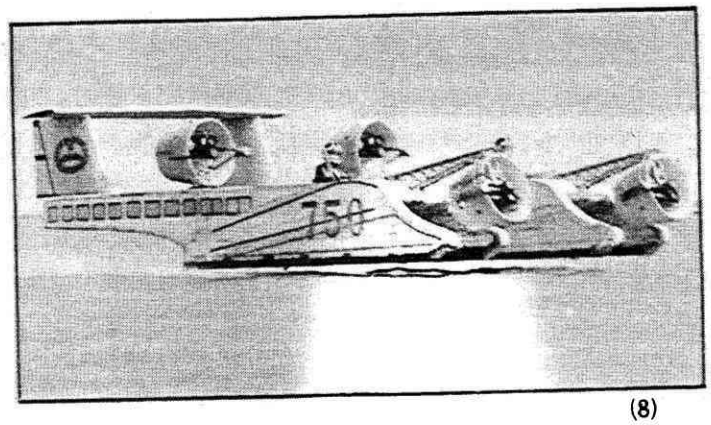

(8)

fig 1 Chinese Test [illegible] craft in flying

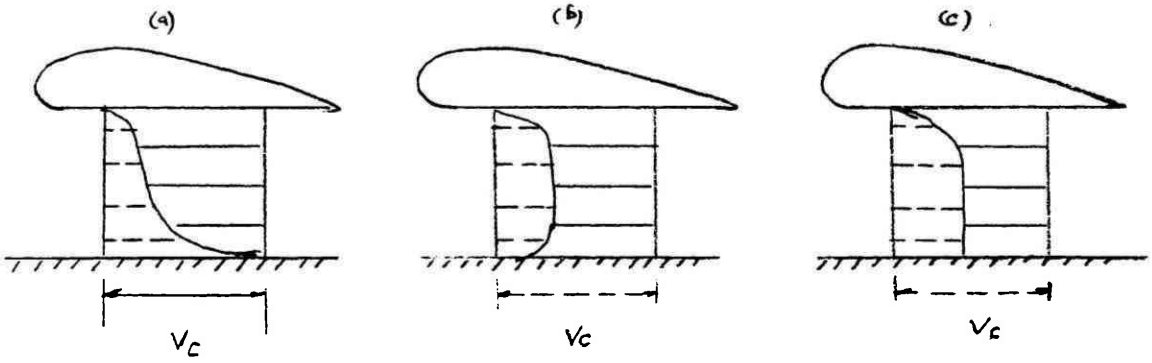

fig 3 The velocity distributions of air flow under the wings for WIG test in wind tunnel with three types of supported rigid screens. (8)

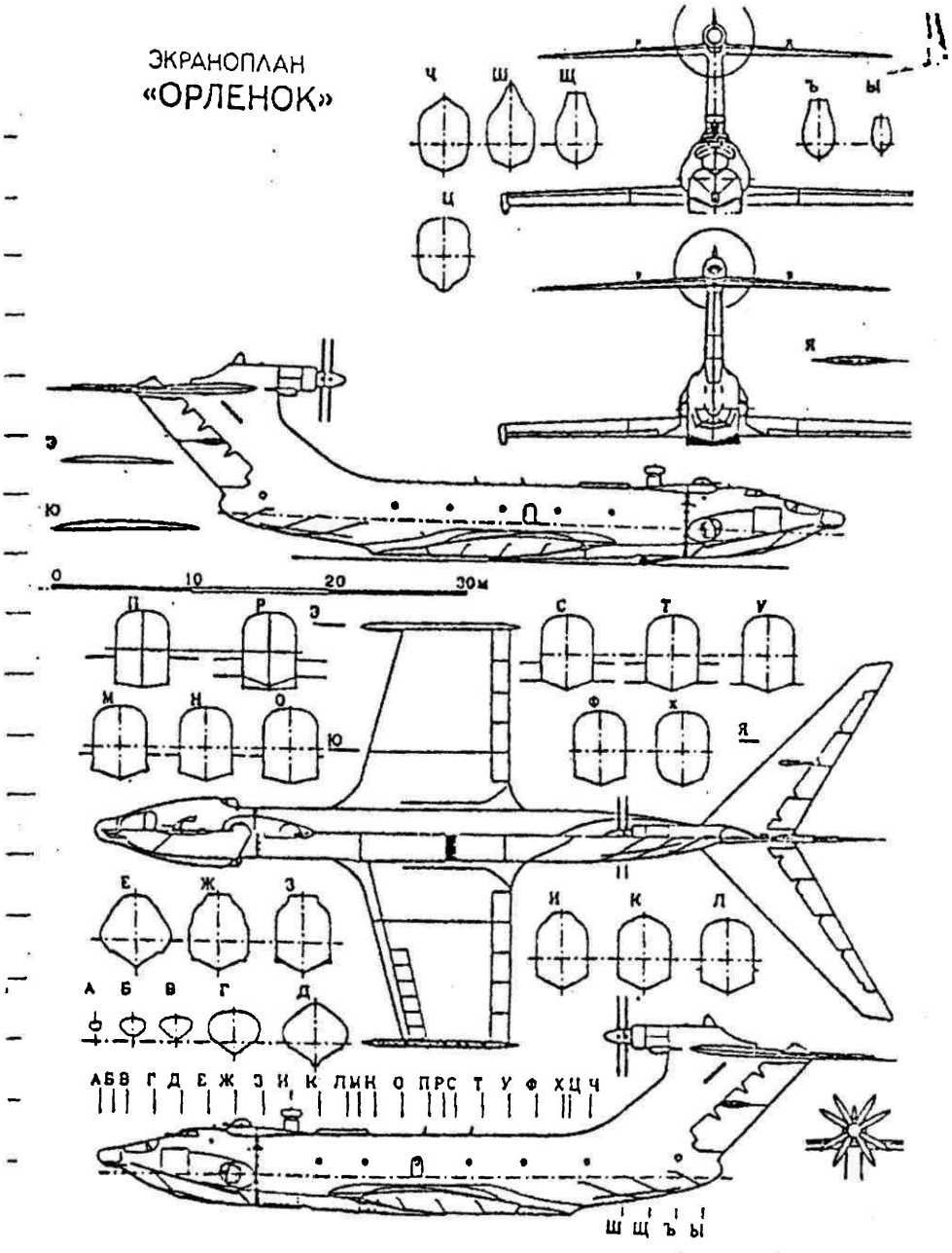

Fig. 4. Russian 140 tonne military amphibious assault Orlenok *ekranoplan. Two turbofan engines supercharge the ground cushion, intensified by deploying leading and trailing edge wing flaps. A hydroski is lowered beneath the main hull to assist lift-off from water, and to absorb impact on landing. The tail-mounted engine with contra-props is for cruising (refs 3 and 4).*

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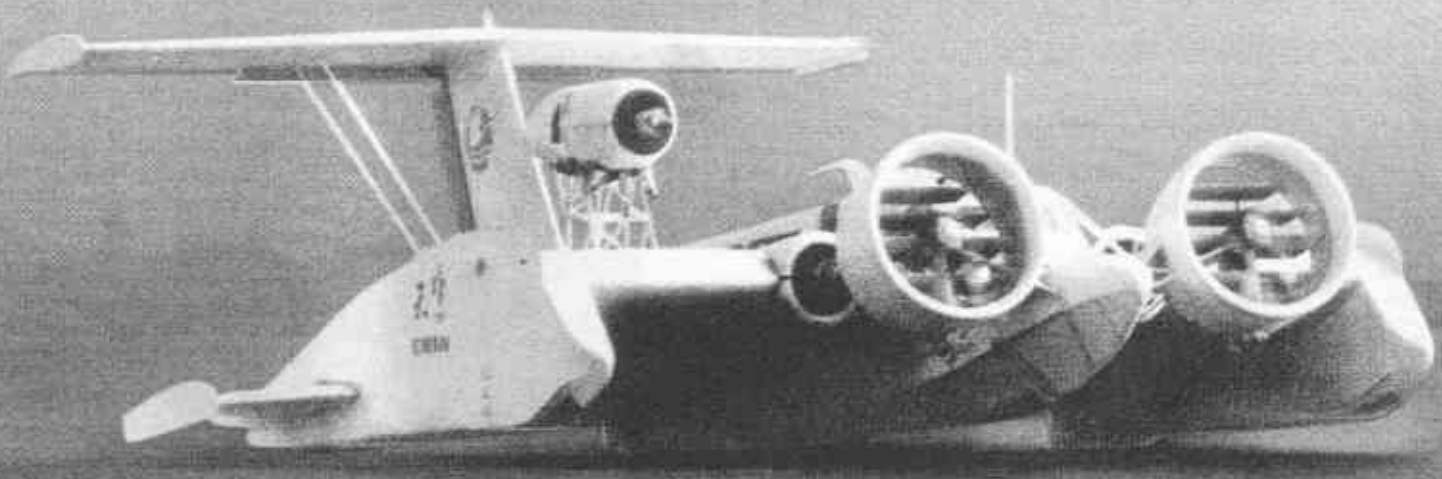

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● 最大起飞重量7.2吨，载客15~20人。

● 2~3级浪海况下起降，安全航行。

“SWAN” WIG craft is a novel type of high speed water transport tool.

* Operating in strong surface effect zone with easy handing and maintenance, safe,credible, and reasonable construction cost.

* Possessing amphibiouness(just like an amphibious hovercraft), the craft is able to land on air cushion along a slope with the gradient of 5 degree, and with fine manoevreability both on ground and water. It's not necessary to prepare a special pier for the craft.

* With multiple operation mode, the craft is able to operate on hull borne, air cushion borne(0-80km/h), and flying mode with the speed of 80-130 km/h, and flying height of 0-1.0m, as well as range of 300 km.

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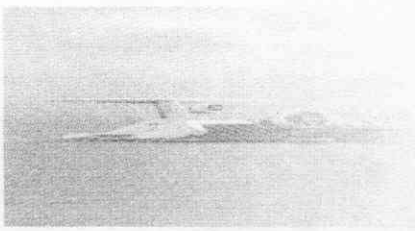

1 摇控自航模飞行试验
Remote-control free flying model test
2 模型水池试验
Model towing tank test
3 天鹅号地效翼船高速飞行
SWAN WIG flying
4 天鹅号地效翼船登陆
SWAN WIG landing

