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Historical Review of WIG Vehicles

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Introduction

THE feasibility of the development of a vehicle based on wing-in-ground (WIG) effect principles has intrigued military and cargo transportation planners for nearly 20 years. These vehicles could be developed for antisubmarine warfare (ASW) or transportation roles. In the U.S. several studies were conducted in the late 1950's and early 1960's to determine the feasibility of developing large transoceanic cargo transport vehicles. However, the decision to develop the Lockheed C-5A large jet cargo transport curtailed these activities. In the 1970's, interest in the WIG phenomenon was revived primarily in response to the need to identify new modes of transportation that would provide an energy-efficient, cost-effective transport vehicle. This requirement was highlighted by the energy crisis of 1973.

The Soviet Union has maintained a continuing interest in WIG vehicles since the 1960's. In the early 1960's, the Ministry of Ship Building conducted extensive studies of WIGs as transportation vehicles and several experimental vehicles were built. The most recent Soviet experimental designs have been suggested as search-and-rescue vehicles in river and coastal waters.[1-3]

This paper is an historical review of WIG vehicles. Experimental and proposed designs are described. Some comparisons are made betweeen these vehicles and more conventional transport vehicles. Some conclusions are drawn as to the future of WIG technology and its application to military and civilian vehicle requirements.

Background

The term wing-in-ground effect applies to a vehicle that is designed to fly at very low altitudes, typically less than one-half of the wing span, to take advantage of the increased aerodynamic lift and reduced drag that occurs when a wing is in ground effect. The improved lift and decreased drag that occurs in ground effect allows greater loads to be carried over longer distances with lower power requirements and lower fuel consumption than when flying out of ground effect. Another advantage of WIG-type vehicles is that they can move over water and land surfaces, including ice cover. They can operate in shallow water and move easily from water onto land or ice cover and back. This capability coupled with moderately high speed and large load capacity suggests a number of possible civil and military transportation roles.

Flight in ground effect can be achieved in two ways. In the first method, the vehicle is supported on a cushion of air created solely by aerodynamic lift of its wings and other lifting surfaces. This is illustrated by flying a conventional aircraft very close to the ground or by the ram-wing concept with low-aspect-ratio wings utilizing end plates. In the second method, the vehicle is supported by a combination of aerostatic lift, created by directing all or part of the thrust from its propulsion unit downward, and of aerodynamic lift from its wings and other lifting surfaces. Examples of this concept are the channel flow wing which combines a peripheral jet air cushion principal with the ram wing, and the power-augmented ram wing (PAR-WIG). In this concept, propulsors are located forward of the ram wing and their exhaust is deflected under the wing to create a high-pressure area under the wing to lift the vehicle off the water.[4-6]

In the Soviet Union the terms *ekranoplan* and *ekranolet* are used to describe vehicles that fly in ground effect. The composite word *ekranoplan* is based on *ekran,* a screen or curtain, and *plan,* the lifting surface of an airplane. *Ekranoplan* is used to describe a vehicle that is supported by aerostatic lift created by its propulsion unit and aerodynamic lift created by its movement in ground effect. *Ekranolet,* which literally means "screen flyer," is used to describe a vehicle that is supported on a cushion of air which is created solely by aerodynamic lifting surfaces as the vehicle moves in close proximity to the surface.[7] Some analysts state that *ekranolets* also have the capability to fly out of ground effect as well, while the *ekranoplans* cannot. Also, some analysts define *ekranoplan* as a vehicle which operates only over water in ground effect and, finally, call amphibian WIG vehicles *ekranokhods.*

Early History

The phenomenon of wing-in-ground effect has been documented since the early days of aviation. Probably the best remembered use of the favorable influence of the ground effect phenomenon was the operation of the Dornier DO-X seaplane. The DO-X seaplane was a large (56-ton) aircraft

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constructed by the Dornier Co., Germany, in 1929. It was used in transatlantic service in 1930-31 and utilized ground effect to increase its payload and range during these flights.

However, investigations of the beneficial aspects predate this. At the turn of the century, C. Ader, a French aviation pioneer, conducted experiments with winged launches for the French government. In 1897, after an unsuccessful demonstration of his "Avion-3," financial support was withdrawn. However, he continued on his own and patented the concept in England in 1904.[1]

During the development and testing of their early manned gliders in 1900, the Wright brothers flew in ground effect as often as they could. There are descriptions of glides in which they apparently flew some distance only a foot or so off the ground.[8]

The first successful ram-wing ground effect machine was developed by a Finnish engineer, Toivo Kaario, in 1935. He had been experimenting since 1932 to develop a high-speed snow sleigh.[1,4] More details on this vehicle and on other experimental vehicles are contained in the next section of this paper.

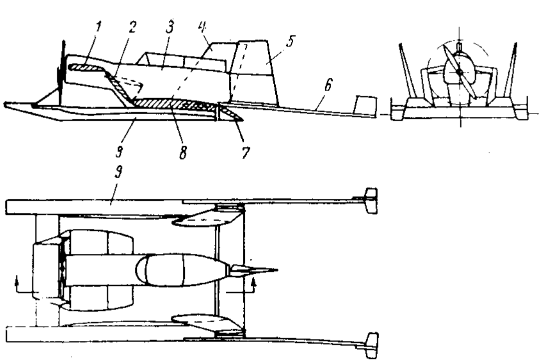
Experimental Wing-In-Ground Effect Vehicles

The initial successes in the development of wing-in-ground effect vehicles occurred in Finland, Sweden, and the northern United States where innovators were trying to develop vehicles capable of skimming over snow-covered countryside, swamps, marshes, and open water. The Soviets also began to develop vehicles to provide high-speed transportation in undeveloped sections of the country. These experimental vehicles are described in the following paragraphs.

North European Developments

As has been noted previously, the first successful wing-in-ground effect vehicle was an experimental, ram-wing snow sled developed by Toivo Kaario in Finland in 1935. It was powered by a 16 hp engine and carried a man over the snow at speeds up to 12 knots. He continued to work on this concept up to and after World War II. In 1962, he developed the Aerosani No. 8, a two-man sled capable of speeds of 43 knots. A three-view drawing of this sled is shown in Fig. 1. Note the long trailing rods which were used to stabilize the sled. Its principal physical characteristics are listed in Table 1.[1]

In the late 1930's, I. Troeng of Sweden experimented with a 3 ton and with a 500 kg waterborne, wing-in-ground effect vehicle. The vehicles were developed with government funds and the program was stopped when the vehicles became unstable during tests. The vehicles were based on the "flying wing" principal and used a hydroski located aft to achieve stability. The Aeroboat is shown in Fig. 2 and its known characteristics are listed in Table 1.[1]



Key: 1—forward wings; 2—articulated controlling wings; 3—hull with driver cockpit; 4—side stabilizers; 5—rudder; 6—tail stabilizing beams with planes; 7—flap; 8—main lifting wing; 9—skis

Fig. 1 T. Kaario's surface-effect vehicle Aerosani No. 8.[1]

GEM-3

The next significant development effort of the wing-in-ground effect concept took place in the late 1950's and early 1960's. Dr. W. R. Bertelson of Neponset, Ill., developed a series of ram-wing vehicles in this period culminating with GEM-3 in 1963. The vehicles were designed to aid him in visiting his homebound patients in his rural medical practice. GEM-3 was a four-seat vehicle capable of speeds up to 95 knots over snow or water. This vehicle is shown in Fig. 3 and its characteristics are listed in Table 1.[1]

Dr. Bertelson is still developing air cushion vehicles, but has discarded the ram-wing concept in favor of a gimballed ducted fan to control lift of the vehicle.[6]

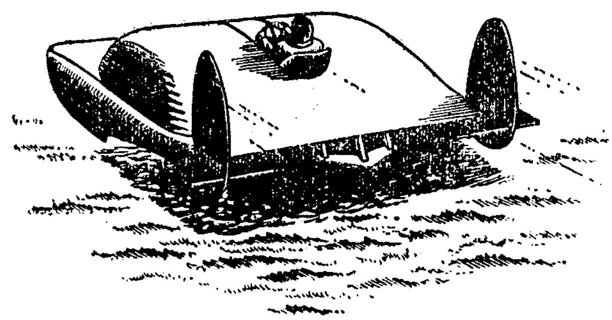


Fig. 2 Swedish water-borne WIG vehicle (Aeroboat) developed by Troeng in late 1930's.[1]

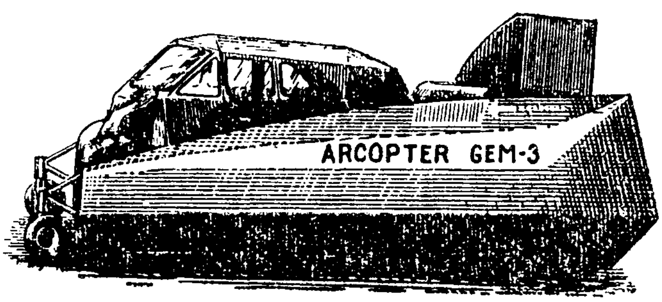
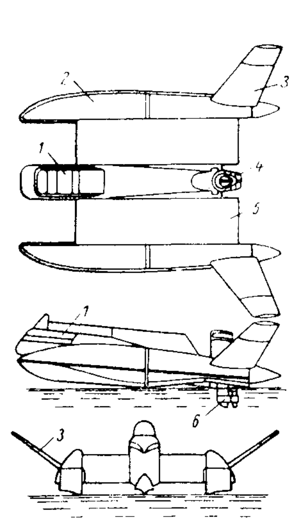


Fig. 3 Four-seat ram-wing vehicle built in 1963 in Illinois by Bertleson.[1]



Key: 1—hull with crew cabin; 2—floats; 3—stabilizer with controlling surfaces; 4—outboard engines; 5—lifting wing; 6—propeller assembly

Fig. 4 Kawasaki KAG-3.[1]

Table 1 Experimental WIG vehicles

Name	Aerosani	Aerosani No. 8	Aeroboat	GEM-3	KAG-3	X-112	X-113	OIIMF-2	ESKA-1	An-2E	CLST 2-seater
Designer/ manufacturer	T. Kaario	T. Kaario	I. Troeng	Bertelson	Kawasaki	A. Lippisch/ Collins	A. Lippisch/ RFB	Budnitskiy/ OIIMF	Ye. Grunin/ CLST	Ye. Grunin/ CLST	Ye. Grunin/ CLST
Country	Finland	Finland	Sweden	USA	Japan	USA	USA/FRG	USSR	USSR	USSR	USSR
Date	1935	1962	1938	1963	1963	1963	1970	1965	1973	1973	1974
Length, m	2.44	8	...	7.33	5.88	7.6	8.55	5	7.55	18.65	...
Breadth/span, m	1.83	3	...	2.39	6.14/2.68	5.0	5.89	3.2/2.8	6.9	15.75	...
Height, m	...	1.7	...	1.68	1.63	1.9	2.4	...	2.5	8.1	...
Wing area, m^2	4.5	10.35	...	17.5	9.6	10.2	13	13.2	13.85	94	...
Gross weight, kg	...	500	600	1140	690	327	345	450	450	7000	1460
Useful load (passengers),[a] kg	80 (1)	160 (1 + 1)	100 (1)	320 (1 + 3)	150 (1 + 1)	160 (1)	90 (1)	80	220 (1 + 1)	...	...
Empty weight, kg	...	340	500	820	540	170	255	370	230	...	...
Power plant: number, type, and output	1,16 hp reciprocating engine/propellor	1,50 hp reciprocating engine/ propellor	1,60 hp reciprocating engine/ propellor	1,150 hp reciprocating engine/ propellor	1,80 hp marine outboard engine	1,25 hp reciprocating engine/ propellor	1,40 hp reciprocating engine/ propellor	2,18 hp Izh-60K motorcycle engine/ propellors	1,30 hp reciprocating engine/ propellor	1,1000 hp Shvetsov Ash 621R reciprocating engine/ propellor	1,210 hp Walter "Minor VI" reciprocating engine/ propellor
Range, km	...	...	...	...	40	...	...	...	300-350	...	...
Cruise velocity, knots	12	...	...	70	21-32	68	...	54-65[b]	60	...	...
Maximum velocity, knots	...	43	...	95	46	77	76	...	66	...	...
Cruise altitude, m	...	0.15	...	0.5	0	1.2	1.5	...	0.3-1.5	...	...
Maximum altitude, m	...	...	...	...	0	...	> 100	...	50	...	...
Wing loading, kg/m^2	...	48	...	65	72	32.7	26.9	40	32.5	74.5	...
Power loading kg/hp	...	10	10	7.6	8.6	13.1	8.65	12.5	15	7	...
Lift-to-drag ratio (ground effect)	...	...	...	...	11.4	25	30	8	25	...	...
Mission	Experimental	Experimental	Experimental	Experimental	Experimental	Experimental	Experimental	Experimental	Experimental	Experimental	Experimental sea rescue
Vehicle type	Ram wing	Ram wing	Flying wing	Ram wing	Flying wing	Ram wing	Ram wing	Tandem flying wing	Ram wing	Ram wing	Ram wing

[a] (1 + 1) = 1 pilot and 1 passenger. [b] Designed but never reached.

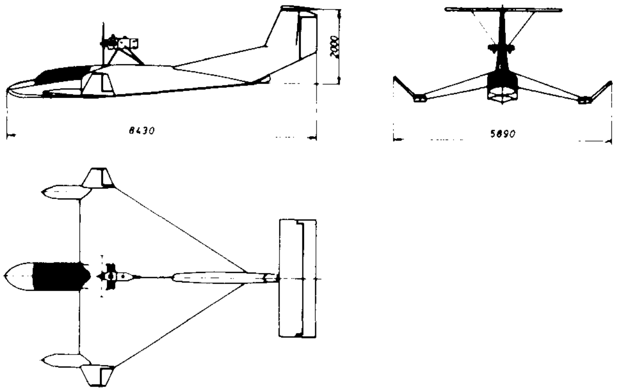


Fig. 5 General arrangement of RFB X-113 AM aerofoil boat.[10]

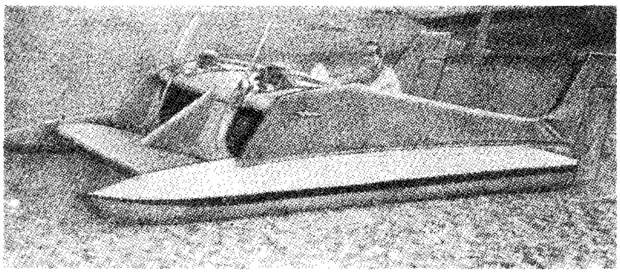


Fig. 6 OIIMF-2 single-seat wing-in-ground effect research craft.[1]

KAG-3

In 1963, the Kawasaki Corporation of Japan began testing the KAG-3 catamaran waterborne craft. Because it was powered by an outboard marine engine, it was not capable of leaving the water surface. Kawasaki conducted a series of systematic experiments to determine the performance and stability characteristics of this vehicle based upon the "flying wing" principal. The project was abandoned in the mid-1960's. Figure 4 shows a three-view drawing of the KAG-3; its characteristics are listed in Table 1. The Soviets reported extensively on this effort in the marine technical literature.[1,9]

X-112 and X-113 Aerofoil Boats

Dr. Alexander Lippisch, the famous German aircraft designer, devoted much of the last 15 years of his life to the development of a ram-wing ground effect vehicle. Migrating to the U.S. after World War II, he began working on experiments for a WIG vehicle at the Collins Radio Company, Cedar Rapids, Iowa. In 1963, he and his coworkers successfully tested the X-112 vehicle in and out of ground effect. They had designed a vehicle which was stable in both free flight and ground effect. After this initial success, lack of interest in its development by the U.S. government caused Lippisch to seek support elsewhere. In 1967, he began a program with the West German government and Rhein-Flugzeugbau. The X-113 was constructed under this program and its first flight was in October 1970. The vehicle underwent extensive testing during 1971-72 to collect data on sea states with waves approaching 1 m and winds up to 25 knots. The information obtained in this program led to the design and development of the six-seat X-114 vehicle now undergoing testing. Figure 5 is a three-view drawing of the X-113. The characteristics of the X-112 and the X-113 are shown in Table 1.[10]

OIIMF-2

In the early 1960's the Soviets undertook several programs to develop high-speed transportation vehicles. The OIIMF-2 was one of a series of ram-wing ground effect vehicles constructed by students at the Odessa Engineering Institute of the Merchant Fleet under the direction of Y. Budnitskiy. According to Belavin, this experimental vehicle was underpowered and another vehicle, OIIMF-3, was to have been built and tested in 1966-67; however, no reports were ever issued on the success of this program. The design of the OIIMF-2 vehicle was strongly influenced by the results of the Kaario and Bertelson vehicles. The OIIMF-2 is shown in Fig. 6 and its characteristics are listed in Table 1.[1]

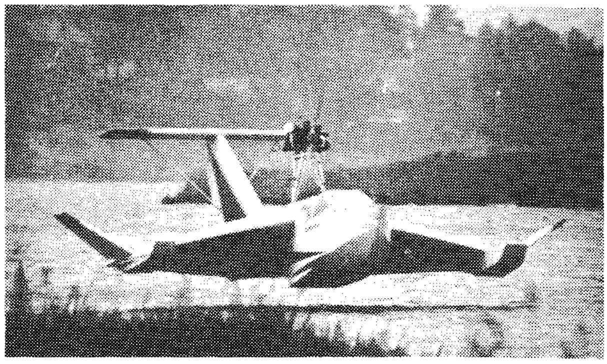


Fig. 7 ESKA-1, experimental aerodynamic ram-wing vehicle.[16]

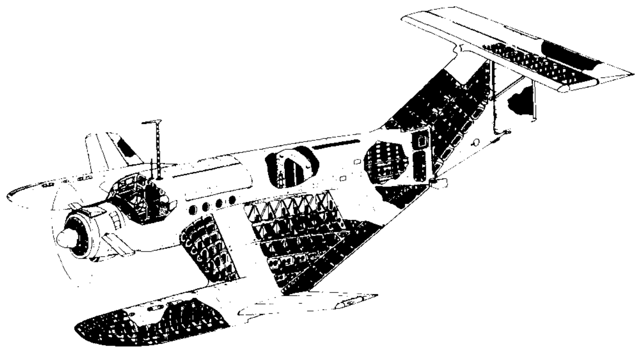


Fig. 8 An-2E, Antonov An-2W modified by CLST.[3]

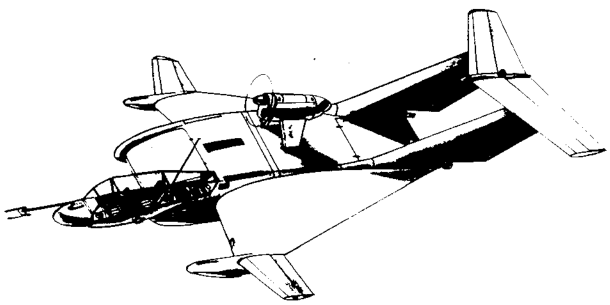


Fig. 9 CLST Ekranoplan two-seater employed for light liaison duties with Soviet fishing fleet.[3]

CLST Experimental Vehicles

The Central Laboratory of Rescue Techniques (CLST), a division of the Rescue Organization for Inland Waters (OSVOD) of the Russian Soviet Federative Socialist Republic (RSFSR), has been experimenting with aerodynamic ram-wing vehicles since 1971. Exploiting the success of the Lippisch concept, the CLST has constructed and tested several experimental vehicles, including the E-120, which has a circular planform; the ESKA-1 (ESKA stands for Ekranolyestiny Spasatyeling Kater-Amphikya surface effect amphibious lifeboat) and derivatives; the An-2E, a modification of the Antonov An-2W 12-passenger utility aircraft; and the CLST two-seater. The characteristics of the ESKA-1, An-2E, and CLST two-seater are listed in Table 1. Figures 7-9 indicate the general features of these vehicles.

Table 2 Large WIG vehicle concepts

Name	Large craft	Flying wing	Low Boy	RAM-1	RAM-2	Aerofoil boat	Cygne 10	Cygne 14	WSEV-C	Hybrid airship	WIG transport
Designer/ manufacturer	Weiland	B. Blinov	Boeing	Research Affiliates	Research Affiliates	A. Lippisch	J. Bertin	J. Bertin	Water Research Co.	D. Calkins	Lockheed-Georgia
Country	USA	USSR	USA	USA	USA	USA/FRG	France	France	USA	USA	USA
Date	1963	1965	≈ 1965	≈ 1965	≈ 1965	1970	1969	1973	1974	1975	1977
Length, m	213.4	23	...	12.2	4.6	91.5	45	53	92.7	97.6	72.5
Breadth/span, m	152.4	125	52	18.3	7.6	42.7	108	115	76	82.9	32.9
Height, m	7.6	...	...	6.1	2.28	18.3	...	...	...	25.3	...
Wing area, m^2	...	28.75	220	92.9	25.5	2200	3860	4070	3792	2296	914
Gross weight	1000 ton	...	125 ton	22,000 kg	4,990 kg	300 ton	1000 ton	1400 ton	1000 ton	1000 ton	700 ton
Useful load (passengers)	300 ton (3000)	550 ton	6.8 ton	11,360 kg	2,270 kg	(200-300)	350 ton	700 ton	220 ton	347 ton	220 ton
Empty weight	...	...	52 ton	...	1,750 kg	...	450 ton	533 ton	490 ton	321 ton	163 ton
Power plant: number, type, and output	4,200,000 hp turboprops	6, turboprops	4, turbofan jet-engines	2,000 hp	3,000 lb thrust jet engine	6, turboprops 50,000 hp	8, 15,000 hp turboprop engines	8,25,000 hp ducted fan engines	1,80,000 hp ducted fans	2, P&W FT9 35,000 hp ducted fan engines	4, turbofans 95,600 lb thrust each
Range, km	≈ 8000	5000	12,300	2900	300-1000	...	8,000	8000	5500	5900	6400
Cruise velocity, knots	100	215	160	86	...	300	200	260	215	150	262
Maximum velocity, knots	...	325	210	100	250	...	...	...	250	...	...
Cruise altitude, m	6	2000	≈ 5	0.6	...	21.3	25	25	...	13.7	1.2
Maximum altitude, m	...	...	...	7000 ft	...	...	100	100	...	...	...
Wing loading, kg/m^2	...	...	568	237	196	136	259	335	263	396	666
Power loading, kg/hp	10	...	...	11	...	6.0	8.3	7	5.5	13	10.5
Lift-to-drag ratio (ground effect)	...	...	...	...	...	...	20	20.6	15.5	≈ 25	15.6
Mission	Passenger/ cargo transport	Cargo transport	ASW	ASW, cargo	Assault vehicle	Cargo transport	Cargo transport	Cargo transport	Cargo transport	Cargo transport	Cargo transport
Vehicle type	Tandem flying wing	Flying wing	Flying wing	Flying wing and ACV	Flying wing and ACV	Ram wing	Flying wing	Flying wing	Ram wing	Flying wing	PAR-WIG

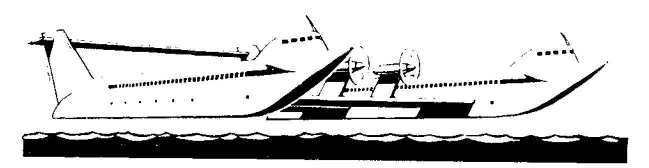


Fig. 10 Large tandem-wing transoceanic WIG vehicle proposed by Weiland in 1963 (3000 passenger, 1000 ton).[12]

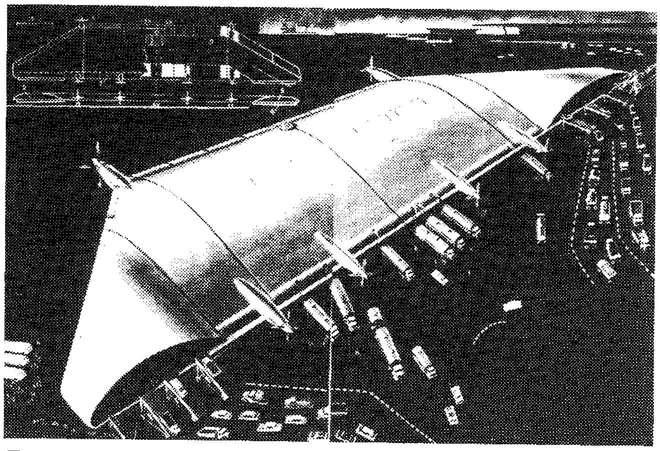


Fig. 11 Large Soviet WIG vehicle ("Flying Wing" cargo transport) conceived by Blinov in 1965 to carry 550 tons.[13]

These vehicles are intended for use as rescue vehicles on rivers, lakes, and coastal waters. The An-2E has been proposed as a passenger and cargo transport. Only the ESKA-1 has been displayed in public.[3,11]

Large WIG Vehicle Concepts

During the past 15 years, several projects have been proposed to develop large WIG vehicles to transport hundreds of tons of cargo at high speeds over transoceanic distances. Also, several vehicles have been proposed for military missions such as ASW, amphibious assault, and mine laying. The cargo transport concepts nearly always address the threshold of the 1000 ton or 2 million lb vehicle; however, concepts with gross weights as low as 300 tons are considered here. Initially, the large vehicles were attractive from a cost viewpoint (shipping costs per ton-mile were low). In recent years, both costs and fuel savings were considerations. These conceptual vehicles are described in the following paragraphs.

Weiland's Large Craft

In the early 1960's, several ground effect vehicles were conceived as cargo transports including the "Columbia" by Scott Rethorst of the Vehicle Research Company, and concepts by Lockheed, General Dynamics, and others. Probably the largest vehicle concept was the 3000-passenger, 1000 ton transoceanic craft proposed by H. Weiland, a Swiss engineer, in 1963. He worked on this concept in the U.S. The vehicle was a tandem wing design; a sketch is shown in Fig. 10. Its technical characteristics are listed in Table 2. A scale model of this vehicle was built in 1964 and crashed during its initial tests.[1,12]

Soviet Vehicles

B. Blinov of the Moscow Aviation Institute presented a concept for a "Flying Wing" cargo transport in 1965. The aircraft was designed to transport 550 tons over 5000 km at an altitude of 2000 m. The aircraft is shown in Fig. 11 and its technical characteristics are listed in Table 2. Blinov stated that the "pockets" located on the wing tips would provide a ram-wing effect to reduce takeoff and landing power and

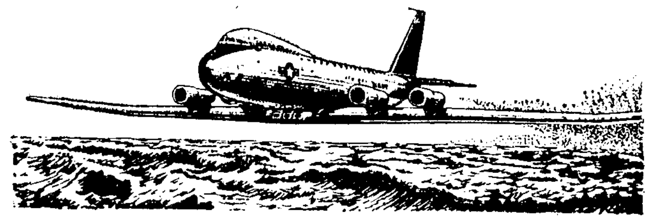


Fig. 12 Boeing concept of ASW aircraft, mid-1960's.[16]

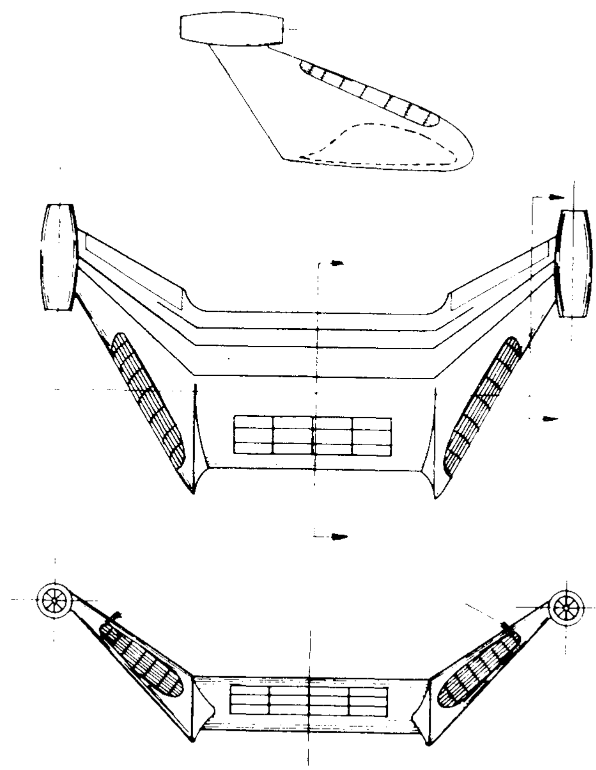


Fig. 13 Long-range RAM 1 GE-STOL vehicle, proposed in about 1965.[18]

distances. Several small radio control models were constructed and flight tested to verify the concept. The author claimed that the vehicles were stable; however, no additional information has been released on this concept.[13]

The Soviets, according to reports in western technical journals, have built a large WIG vehicle. Sketches of the vehicle indicate that it is a power-augmented ram-wing vehicle. It is estimated to weigh 500 tons and could be used as a troop transport or a ASW vehicle.[14,15]

Low Boy

In the mid-1960's, the Boeing Company, Seattle, Wash. published a study for a concept of a wing-in-ground effect ASW aircraft. It is shown in Fig. 12 and its technical characteristics are listed in Table 2. This concept was unusual because the vehicle had a wing aspect ratio of 12, much greater than conventional WIG's with aspect ratios of 1-5. Also, the wings did not have end plates.[16]

RAM-1 and RAM-2

Research Affiliates, Potomac, Md., proposed two ram-wing vehicles in the mid-1960's for naval missions such as ASW, amphibious assault, and cargo transport. RAM-1 was designed for long-range missions (up to 3000 km) and RAM-2 for short-range missions (270-925 km). Two methods were conceived for producing lift; the first was a combined aerodynamic lift and ground effect machine (CAL-GEM) and the second was an aerodynamically augmented air cushion

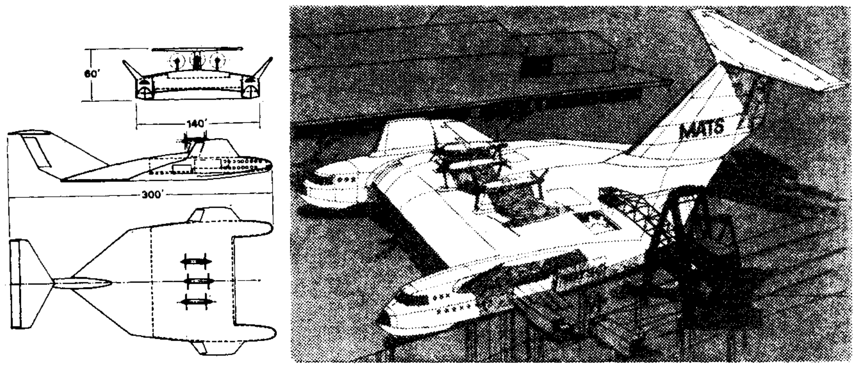


Fig. 14 Ocean-going surface-effect ship conceived by Lippisch Research Corp. which would weigh 300 tons.[14]

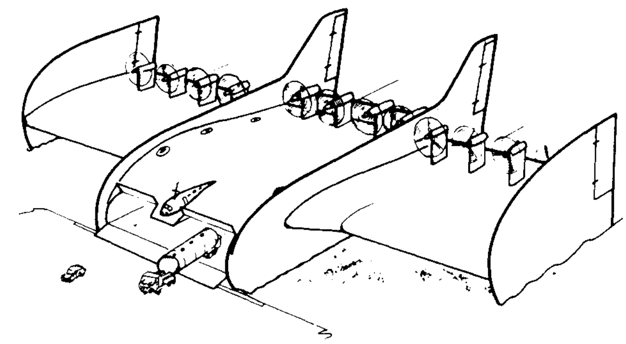


Fig. 15 Cygne 10, large air freight carrier conceived by J. Bertin Co., France, 1969.[17]

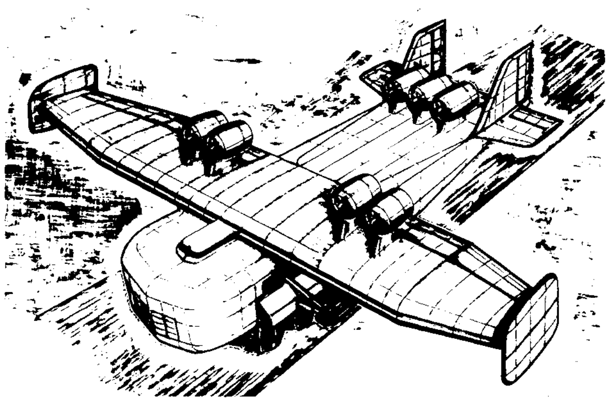


Fig. 16 Cygne 14, large air freight carrier conceived by J. Bertin Co., France, 1973.[17]

vehicle. Both vehicles were to operate in and out of ground effect. Figure 13 is a three-view drawing of the RAM-1; the vehicle technical characteristics are listed in Table 2.[17]

Aerofoil Boat

In 1970, Dr. A. Lippisch presented his concept for a large transoceanic transport using his ram-wing design. He envisioned a vehicle 91 m long with a span of 42.7 m to transport passengers and cargo across the Atlantic at speeds up to 320 knots. Figure 14 gives both a three-view drawing and a perspective of the craft. Its principal technical characteristics are listed in Table 2.[14]

Cygne 10 and Cygne 14

The Cygne 10 and Cygne 14 are envisioned as large air freight carriers as designed by the J. Bertin Co., Plaisir, France. The Cygne 10 is a flying wing concept using a flap system to contain the bleed air from the engines to build up an air cushion for takeoff. The Cygne 14 is a flying wing concept which uses the patented Bertin air cushion system as its

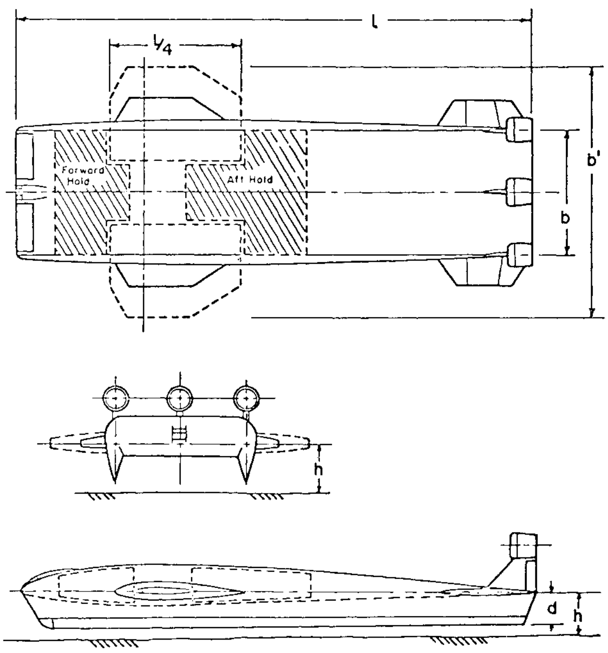


Fig. 17 Proposed layout of winged surface-effect vehicles (WSEV), Water Research Company, 1974.[17]

landing gear. The Cygne 10 is a 1000 ton vehicle. It is shown in Fig. 15 and its principal technical characteristics are listed in Table 2. In 1974, Bertin estimated its construction costs at 172 million francs (approximately $35 million). The Cygne 14 is a 1400 ton vehicle. It is shown in Fig. 16 and its technical characteristics are listed in Table 2. Its construction cost was estimated at 238 million francs (approximately $50 million).[18,19]

WSEV-C

The Water Research Company, Phoenix, Ariz., in 1974 conceived a series of Winged Surface Effect Vehicles (WSEV) as part of a design study for large Navy transport vehicles. They were designed to transport cargo and transport landing craft to the battle zone. The vehicles had gross weights of 200, 500, 1000, and 2000 tons, respectively. They were designed using the flying wing and catamaran concepts. The general layout of the vehicles is shown in Fig. 17. The technical characteristics of a representative vehicle, the 1000 ton WSEV-C, are listed in Table 2.[18]

Hybrid Airship

D.E. Calkins of the University of California presented the results of a feasibility study of a transocean hybrid cargo airship operating in ground effect in 1975. The author sought to combine the attributes of the airship and ground effect in the design of an energy efficient transatlantic cargo vehicle.

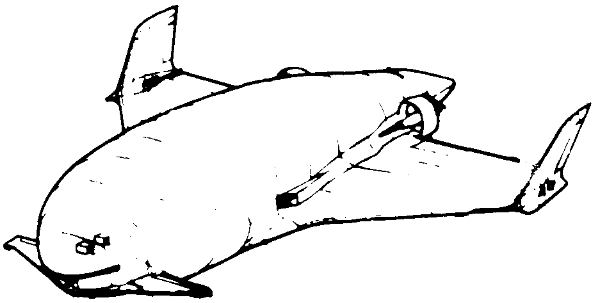


Fig. 18 Transoceanic hybrid cargo airship proposed in 1975 by Calkins.[20]

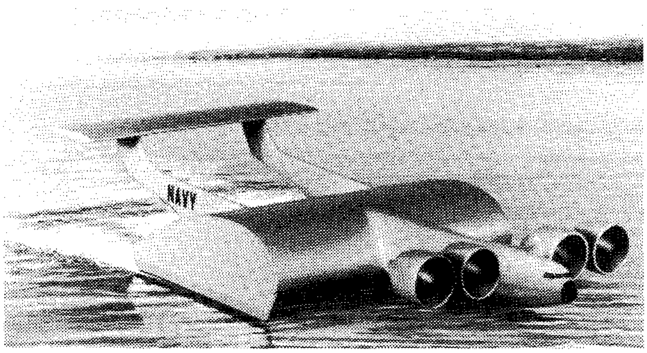


Fig. 19 WIG cargo conceived by Lockheed-Georgia for Navy, 1977.[14]

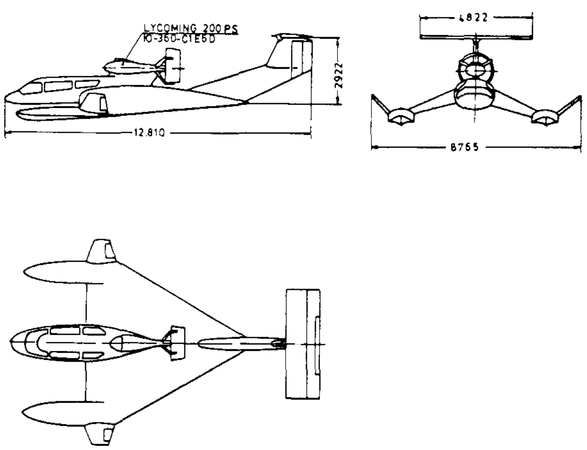


Fig. 20 X-114 aerofoil boat developed in 1977 by Rhein-Flugzeugbau GmbH (RFB).[21]

The concept employed most of the current energy-saving devices, including aerodynamic winglets, blended wing-fuselage, an active control system, shrouded propellors, and advanced composite materials. The vehicle would cruise at 150 knots at an altitude of 13 m. Figure 18 is a sketch of the vehicle. Its principal technical characteristics are listed in Table 2.[20]

WIG Transport

As part of the U.S. Navy Advanced Naval Vehicle Concepts Evaluation Program (ANVCE), the Lockheed-Georgia Co. in 1977 conducted a point design study of a 700 ton Wing-in-Ground Effect Vehicle. The vehicle was designed as a cargo transport. It is based upon the powered-augmented ram-wing concept known as PAR-WIG. The vehicle is intended to operate as a cargo transport or as a long-endurance ASW vehicle. Figure 19 is a sketch of the vehicle. Its principal technical characteristics are listed in Table 2.[14,15]

Current Experimental Programs

There are at least five WIG vehicle development programs under way in the United States and Europe. The most notable is the continuing effort to exploit the Lippisch concept by the Rhein-Flugzeugbau GmbH (RFB) in the Federal Republic of Germany. This program is funded by the German government. An examination of these programs indicates that ram-wing and powered ram-wing concepts are now favored; however, one tandem-wing skimmer is also being developed.

X-114 Aerofoil Boat

The X-114 Aerofoil Boat was developed by the Rhein-Flugzeugbau GmbH (RFB), a subsidy of the VFW-Fokker. The vehicle is shown in Fig. 20 and its principal characteristics are listed in Table 3. The X-114 evolved from the X-113 and is approximately four times the size of the X-113. Construction was completed in 1977 and the flight trails, which began in April 1977, are continuing through this year. Fiberglass-reinforced plastics and other advanced composite materials were used extensively in its construction. It is powered by a 200 hp Lycoming IO-360 engine driving an RFB ducted fan. The X-114 is designed to operate in the ground-effect mode over waves up to 1.5 m which, according to RFB, permits it to operate in the Baltic Sea during 80% of the year and 60% of the year in the North Sea. It also can fly like an aircraft with an increase in fuel consumption.

The six-passenger X-114 amphibious vehicle is suitable for air-taxi along coast lines, surveillance activities, and search-and-rescue missions. RFB estimates that a 18,000 kg vehicle could be constructed without any significant additional research.[6,21]

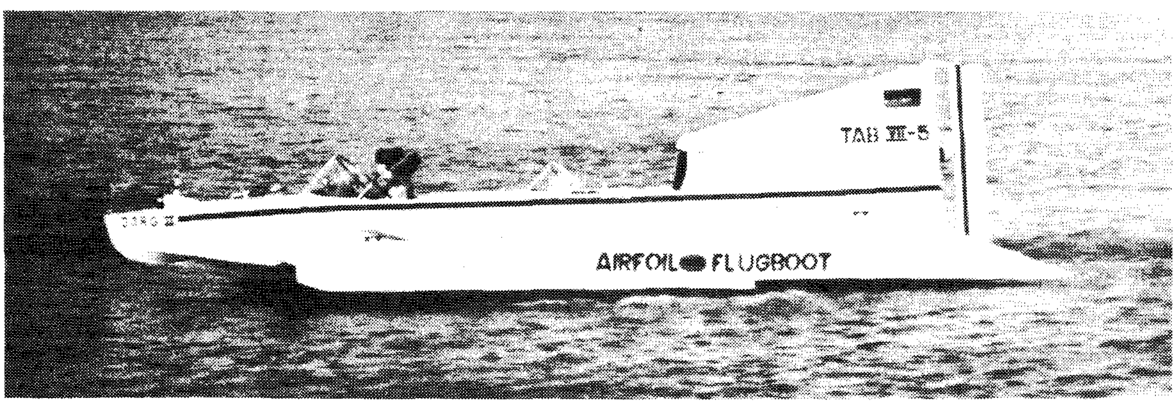


Fig. 21 TAB VII-5 airfoil boat developed by Jörg, Federal Republic of Germany.[22]

Table 3 Current experimental WIG vehicles

Name	X-114 Aerofoil boat	TAB VII-5	SEABEE	PSI 575 Flying boat	PAR-WIG R/C model
Designer/manufacturer	Lippisch/RFB	Gunter Jörg	R. Bourn/HFL-Sea Glide	G. Hennebutte	NSRDC
Country	West Germany	West Germany	England	France	USA
Date	1977	1976	1972-1976	1977	1978
Length, m	12.8	8.3	5.2	5.7	3.05
Breadth/span, m	8.8	3.28	4.6	10	1.27
Height, m	2.9	1.75	1.75	1.7	0.76
Wing area, m^2	29.1	19.2	10	...	0.74
Gross weight, kg	1350	740	502 (1 + 1)	...	16.4
Useful load (passengers)[a]	500 (1 + 5)	200 (1 + 1)	... (1 + 2)	... (1 + 2)	0
Empty weight, kg	850	540	...	...	...
Power plant: number, type and output	1, Lycoming IO-360 200 hp ducted fan	1, Fiat-Abarth 70 hp propellor	1, Rolls Royce 240A 93 hp propellor	1, RFB SG85 50 hp Wankel ducted fan	2,1 hp ducted fan model aircraft engines
Range, km	2100	200	322-400	400-500	...
Cruise velocity, knots	70	54	Less than 100	...	20
Maximum velocity, knots	108	70	120	75	30
Cruise altitude, m	≈ 1.5	0.3	≈ 1	5	0.012
Maximum altitude, m	...	...	...	...	...
Wing loading, kg/m^2	46.4	38.5	50	...	22.2
Power loading, kg/hp	6.75	10.6	5.4	...	8.2
Lift-to-drag ratio (ground effect)	20	...	...	...	...
Mission	Experimental	Experimental	Experimental pleasure craft	Experimental sea rescue, pleasure	Experimental radio-controlled model
Vehicle type	Ram wing	Tandem wing	Ram wing	Ram wing	PAR-WIG

[a] (1 + 1) = 1 pilot and 1 passenger.

TAB VII-5 Airfoil Boat

The TAB VII-5 Airfoil Boat represents a 13-year research and development program by Günther Jörg of the Federal Republic of Germany. Figure 21 shows the boat skimming over the Rhein River and its principal characteristics are listed in Table 3. It is a tandem airfoil boat (TAB) designed to operate in ground effect only in relatively calm rivers and sheltered lakes. Since it operates in ground effect only, it does not require the T-tail configuration necessary for vehicles that operate in and out of ground effect. The vehicle achieves directional stability through the use of an aerodynamic rudder and underwater spoilers. It has retractable landing gear to give it amphibian capability.

Mr. Jörg has begun construction of a larger model, TAB VII-6, which will weigh 1800 kg and carry eight people. In addition, he envisions that a 30-passenger, 10 ton vehicle capable of speeds of 78 knots and skimming the water at 0.5 m could be built in the near future, and that a 300 ton vehicle flying at altitudes of 10-20% of its 36 m wing chord could transport nearly 200 ton payloads economically over trans-Atlantic distances.[22]

SEABEE

The HFL-Seaglide Ltd. of London, England, has designed and developed a three-seat aerodynamic ram-wing vehicle called SEABEE under the direction of Ronald Bourn. The vehicle makes extensive use of fiberglass-reinforced plastics. The experimental vehicle was completed in 1972 and has been tested with three engines. The first engine was a 90 hp 6-cylinder engine with a four-bladed propeller. Next a 93 hp 4-cylinder Rolls Royce 240 A engine with a two-blade propeller was installed. In July 1976, a 130 hp Turbomeca Artouste turbofan was installed. The vehicle is controlled by an aircraft-type elevon on the horizontal stabilizer and twin aerodynamic rudders. A picture of the vehicle is shown in Fig. 22 and its characteristics are listed in Table 3.

According to the designer, the three-seat vehicle could serve the following roles: pleasure craft, sea rescue and medical service, surveillance, coastguard, sea-taxi, expeditionary craft, pilot training for ground effect, and paramilitary operations. A larger craft could be a 35-seat water bus or freighter.

The vehicle has been tested in the ground effect mode only. It has not been determined if the vehicle can operate in the free-flight mode.[6]

Hennebutte PSI 575 Flying Boat

In 1971, the George Hennebutte organization of Barritz, France, which supplies inflatable dinghies to the French lifeguard patrols and Navy, began to experiment with ram-wing designs as high-speed rescue craft or pleasure craft. The latest concept, which was first shown publicly in 1977, is the PSI 575 Flying Boat, which uses one of its Espadon series inflatable dinghies as its hull. The craft has an usually large wing span and aspect ratio; however, the wings can be folded for vehicle storage and transportability.

The craft is being developed in association with the Rhein-Flugzeugbau who have supplied the wing design and the ducted engine. Figure 23 is a picture of the craft and its principal characteristics are listed in Table 3.[6,23]

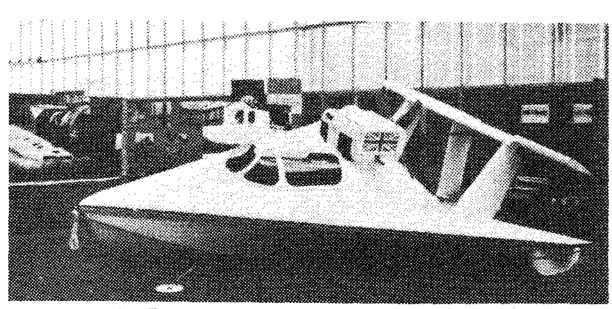


Fig. 22 SEABEE three-seat aerodynamic ram-wing prototype built in England, 1972-1976.[4]

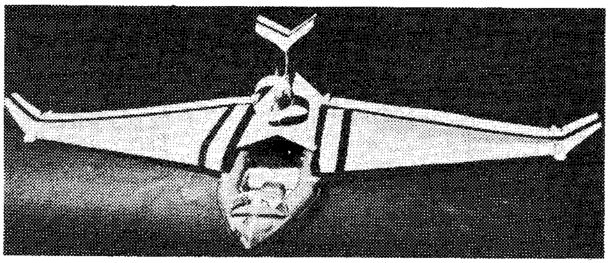


Fig. 23 Proposed Hennebutte PSI 575 flying boat, 1977.[6]

PAR-WIG Radio Control Model

In August 1978, the Aviation and Surface Effects Department of the Naval Ship Research and Development Center (NSRDC), Carderock, Md., began testing a PAR-WIG radio control model on a reservoir in the vicinity of Washington, D.C. The model is powered by two 1 hp model aircraft engines and cruises at an altitude of 3 in. and a velocity of 20 knots. The flaperons, rudder, horizontal stabilizer, throttle, and propulsor angle are remote controlled. A three-view of the model is shown in Fig. 24 and its physical characteristics are listed in Table 3.[24]

Analysis

Many concepts for transportation systems based upon wing-in-ground effect have been proposed. Also several prototype vehicles have been built to demonstrate technical feasibility and to develop economically practical systems. Several criteria may be used to compare the potential of these vehicles to more conventional vehicles. Three of these parameters are compared in this analysis.

Figure 25 is a plot of power vs speed. In this case, the power is the rated horsepower of the installed engines divided by the gross weight of the vehicle. The speed is the quoted cruise speed. The data show that prototype WIGs have approximately the same power requirements as general aviation aircraft moving at the same speeds. However note that the conceptual large transport WIGs have the same power requirements even when the speed is doubled or tripled.

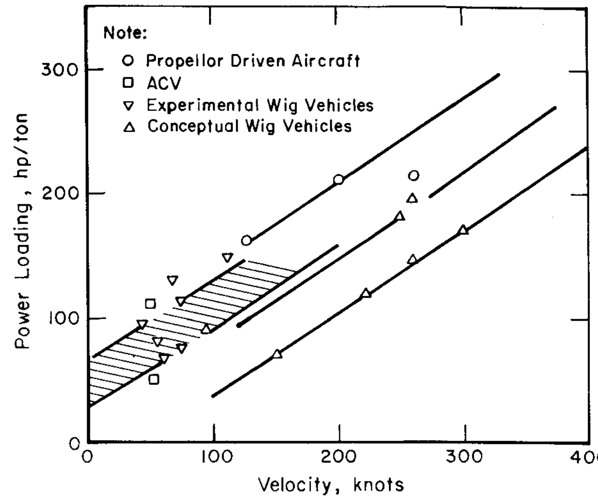


Fig. 25 Power loading for transport vehicles.

Figure 26 illustrates the effect of density loading (weight is divided by a characteristic length). In this case, the characteristic length is the square root of wing area. It has been shown that successful commercial transports have a density loading of approximately 32 kg/m^3. Most experimental WIGs have a density loading of 8-16 kg/m^3, far short of this value. The conceptual WIG vehicles also have density loadings below this value.

Figure 27 is a graph adapted from E. P. Cockshutts' study of the energy cost in transportation with WIGs added.[25] Energy cost is expressed as

$$\text{Energy cost} = \frac{\text{amount of fuel used}}{(\text{payload}) \times (\text{distance travelled})}$$

where the fuel used is expressed in its energy equivalent of foot-pounds. The graph shows that the small experimental WIGs have an energy cost less than helicopters and ACVs; however, they are not as efficient as conventional trains or trucks. The conceptual large WIG transports, especially the more recent concepts, have a lower energy cost than conventional aircraft, but travel at slower speeds.

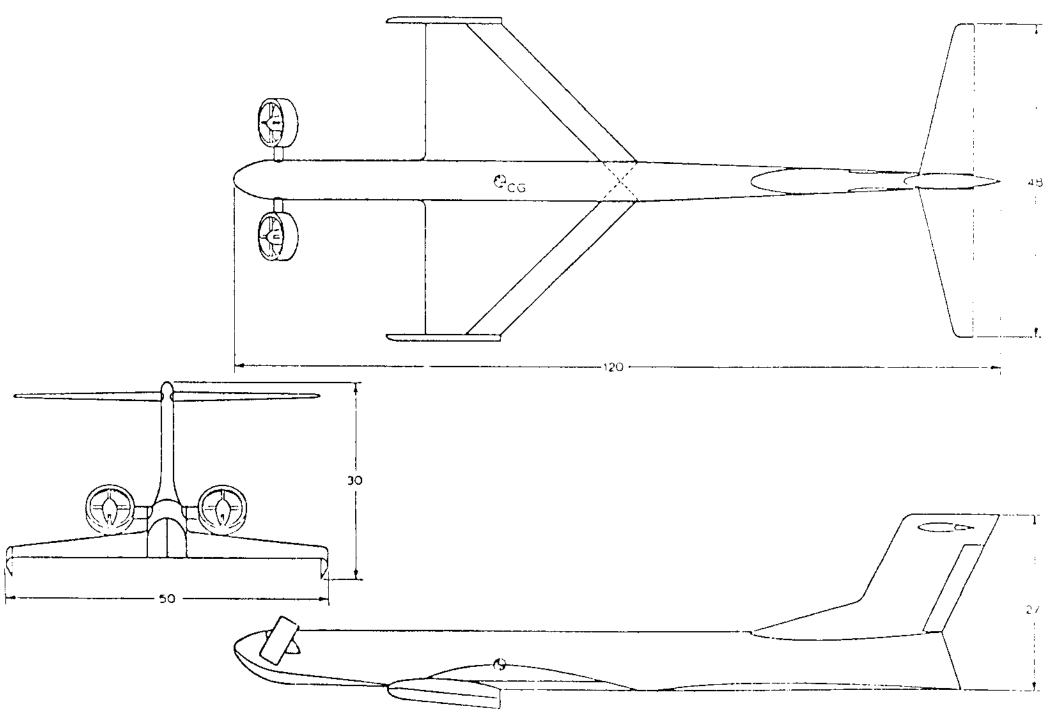


Fig. 24 PAR-WIG radio control model, 1978, NSRDC.[24]

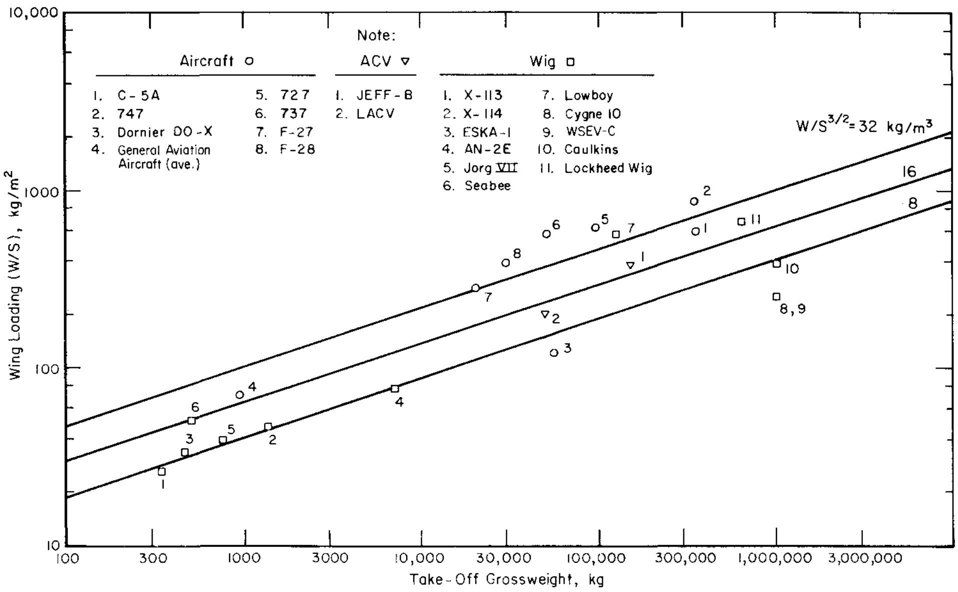


Fig. 26 Loading density of transport vehicles.

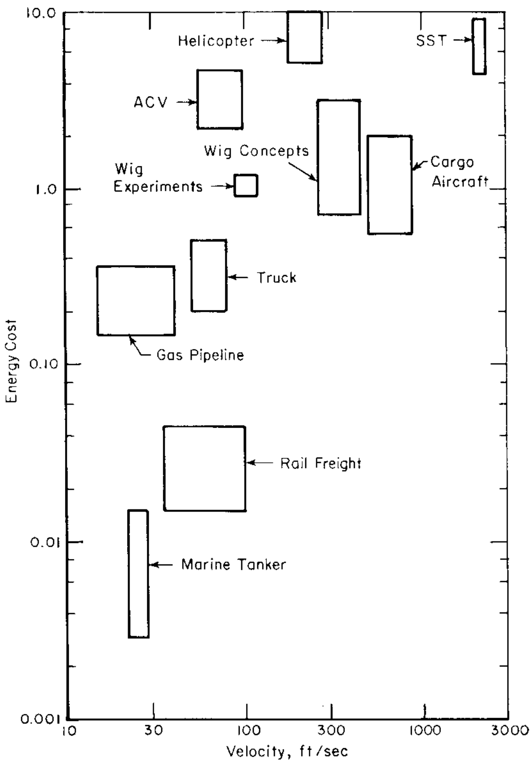


Fig. 27 Energy cost of cargo transport.

Summary

Experimenters and innovators have been investigating the beneficial aspects of ground effect since the turn of the century. Even the Wright brothers utilized it in their early manned glider experiments. The first successful ground effect vehicles were constructed in the mid- and late-1930's. World War II brought a hiatus to ground effect vehicle developments.

After the war developments resumed, first in Finland and then throughout the world. By the mid-1960's, research and development programs were under way in the U.S., Finland, Japan, Switzerland, and the Soviet Union. At this time several aerodynamic wing-in-ground effect concepts had been translated into experimental models weighing up to 4 tons and were being evaluated. Flying wing concepts (both single and tandem), ram-wing concepts, and channel-wing concepts were tested. Of these, the most promising appeared to be the ram-wing vehicles. Also during this time period, several design studies were initiated to determine the feasibility of large ground effect vehicles for trans-Atlantic passenger and cargo transport and for several Navy missions. The infantile development state of WIG vehicles combined with the successful development of the C-5A cargo military aircraft and the wide-body jets caused development work on WIGs to cease in the U.S. in the mid-1960's.

In the late 1960's the only active programs were the efforts of Dr. Alexander Lippisch, funded by the West German government, and undefined Soviet programs.

The energy crisis of the 1970's brought about a renewed interest in WIG technology because it had the promise of providing cost-efficient vehicles to serve as large, long-distance cargo transports (passenger service is no longer a viable role). Several new conceptual vehicles were proposed, but to date programs to develop these vehicles have not been funded.

Meanwhile, a new generation of experimental vehicles has been constructed, and testing is under way in the U.S., the Soviet Union, England, France, and West Germany to determine the viability of WIG technology, with the emphasis on ram-wing and powered-augmented ram-wing concepts. The experimental vehicles are small, no larger than 1500 kg, with the exception of the purported conversion of the An-2 utility aircraft in the Soviet Union. (The An-2E weighs approximately 7 tons.) Also, the immediate mission emphasis has shifted from large cargo transports to search-and-rescue craft, utility transport vehicles, and pleasure craft.

If one or more of these programs can be brought to a successful conclusion (i.e., the series production of a vehicle), then one can expect production of a vehicle, then one can expect to see in the not-too-distant future WIG vehicles on the order of 50 tons serving as transports in intercoastal waterways, inland seas, and large rivers. They also may be used in several military missions. The dream of large (1000 ton) cargo transports will have to wait for the development of moderate-size vehicles before becoming a reality.

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