FTD-ID(RS)T-0765-86

FOREIGN TECHNOLOGY DIVISION

A REVIEW ON THE AVIATION PISTON ENGINE POWER ASSEMBLY FOR THE AIR
CUSHION BOAT

by

Zhu Jianzhang

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FTD-ID(RS)T-0765-86   25 September 1986

MICROFICHE NR: FTD-86-C-002233

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English pages: 15

Source: Chuanbo Gongcheng, Nr. 5, 1985, pp. 42-46

Country of origin: China
Translated by: FLS, INC.
                F33657-85-D-2079
Requester: AFWAL/FIEM
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i

A REVIEW ON THE AVIATION PISTON ENGINE POWER ASSEMBLY FOR THE AIR
CUSHION BOAT

Zhu Jianzhang
Chinese Institute of Ship and Oceanic Engineering Design

I. Preface

In the early development of the air cushion boat, its power
assembly was started with an aviation piston engine in many countries;
for instance, the Soviet small air cushion boats the "RADUGA" and
"BREFZE". The air cushion boats 711, 711.II, 711.IIA, 716, etc.
developed in our country from the early 60's to late 70's all selected
aviation piston engines as their main power. This situation has been
maintained for nearly 20 years, and the primary reasons for it are as
follows:

1. The aviation piston engine has a suitable power rating. The
weight of the air cushion boat developed early was rather small, mostly
ranging from 2-4 tons. The power rating of the air cushion boat is
about 100-135 horsepower/ton. According to this, a single engine's
power rating ranges from 200-500 horsepower. It is well known that

1

this is exactly the most common power rating of an aviation piston engine (and an air-cooled diesel engine). (Table 1).

Table 1. Several models of piston engines which can be selected for use in the air cushion boat.

(1)机　　型	额定功率 (2)马力	(3) 燃料牌号	(4)油耗率 克/马力·小时	(5)机组重 公斤	(6) 单位马力重 公斤/马力	第一次大修期 小时 (7)
(8)航空活塞机 M11-ФP	140	(10)航空汽油 70°	260	180	1.125	400
604-1	270	(10)航空汽油 70°	260	200	0.74	250
АШ-82	1530	(10)航空汽油 95/130°	285	936	0.612	250
(9)风冷柴油机 F6L912	95	(11)0°轻柴油	163	410	4.32	~6000
BF6L913	135	(11)0°轻柴油	162	485	3.59	~6000
BF12L413F	428	(11)0°轻柴油	154	1360	3.18	~6000

Key: (1) Model No.; (2) Rated Power, Horsepower; (3) Fuel No.; (4) Fuel consumption rate, g/horsepower.hour; (5) Weight of engine assembly, kg; (6) Weight per unit horsepower, kg/horsepower; (7) Time for first major overhaul Hours; (8) Aviation Piston engine; (9) air-cooled diesel engine; (10) aviation gasoline; (11) light diesel.

2. The aviation piston engine has a markedly light unit horsepower weight. The unit horsepower weight for an air-cooled diesel engine with a modern standard is 2.18-5.74 kg/horsepower, yet it is only 0.33-0.80 kg/horsepower for an aviation piston engine with the same power rating, which is about 1/6 of that of the air-cooled diesel engine. Thus, the effective load of the boat is increased. Figure 1 shows that the effective load of the 711.IIA boat, which is equipped with an aviation piston engine, exceeds that of the API-88 boat, which is equipped with an air-cooled diesel engine, when fuel consumption is taken into consideration.
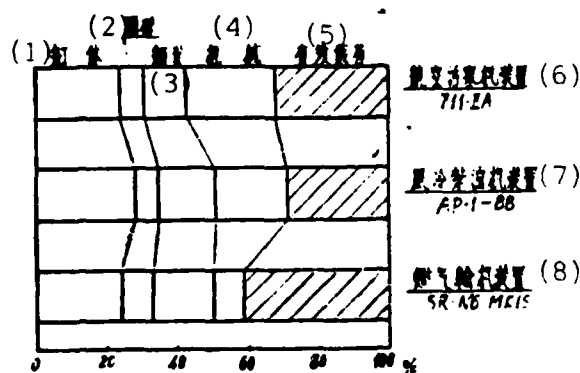
Fig. 1. Comparison of weight classes for boats equipped with a different power assembly.
Key: (1) boat body; (2) apron; (3) dead weight; (4) machinery; (5) effective load; (6) aviation piston engine assembly; (7) air-cooled diesel engine assembly; (8) steam engine assembly.

When the fuel consumption is taken into consideration, the total weight of the power device differs as the requirement for sustained cruising time changes. The critical point of the weight benefit time for the two power assemblies is T_k

$$T_k = \frac{W_{gD} - W_{gA}}{g_{eA} - g_{eD}}$$

where g_{eA} and g_{eD} are the fuel consumption rates (kg/horsepower·hr) of an aviation piston engine and an air-cooled diesel engine, respectively; W_{gA} and W_{gD} are the unit horsepower weights (kg/horsepower), respectively.

The typical values for g_{eA} and g_{eD} are 0.27 and 0.15 kg/horsepower·hr, respectively, and 0.74 and 3.18 kg/horsepower for W_{gA} and W_{gD}, respectively. T_k is about 20 hours obtained from using these values. The sustained cruising time for small and medium air cushion boats is about 4-8 hours. It is suitable to use an aviation piston engine for this type of limited cruising distance.

3

3. The aviation piston engine has excellent assembly integrity. About 80% of its assembling parts can be directly, or after modification, used on an air cushion boat, and this is significant in shortening the manufacturing cycle of an air cushion boat.

In addition, there are plenty of aviation piston engine supply sources. By the 60's, the development of aviation engines were such that the piston engines were gradually replaced by turbo engines. Yet, the piston engine production lines were still in operation, plus there were plenty of retired and stocked piston engines during this period of time, thereby providing a sufficient power resource for the air cushion boat industry which had just been started in the 60's.

II. Example of a Power Assembly - 711.IIA

The 711.II full-floating type air cushion boat was successfully built in 1966 in our country. Then, on this basis, it was modified to the 711.IIA boat which weighed 6 tons and carried 20 passengers with a speed of 70 km/hr. It is 11.74 meters long and 5.1 meters wide and is equipped with two model "604-1" aviation piston engines. The rated power of the single engine is 270 horsepowers (2250 rpm) (1 hour sustained cruising time) burning No. 70 aviation gasoline. Its fuel storage capacity is 450 kg and the sustained cruising distance is 250 km.

Each engine has its own propeller with an absorption power of 186 horsepower. The free end of the propeller housing is equipped with a modified output axle connector, which is exclusively designed

4

for the use of the air cushion boat. The out put shaft, through two pairs of universal joints with bending angles $16°42'$ and $9°59'$, respectively, a hydraulic clutch, and finally the coupled axle gear box to conduct power branching and partial axle coupling and drive a model "4-76" centrifugal lift fan which is 1.8 meters in diameter and turns at 780 rpm. Figure 2 shows the layout of its power assembly.
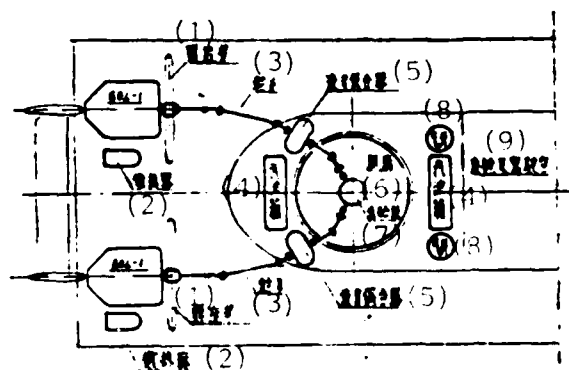

Fig. 2. Power assembly of 711.IIA.
Key: (1) propeller; (2) Heat dissipator; (3) axle system; (4) gasoline tank; (5)hydraulic clutch; (6) fan; (7) gear box; (8) gas vapor well; (9) cabin and control room.

Since this boat adopts the double-engine with coupled axles, propeller-fan joint motion and variable blade distance change technologies, it possesses excellent maneuverability and the possibility of interchanging the power of propulsion and lift. Several groups of reasonable power matches can be obtained under different H/D and rpm n (Fig. 3).

Fig. 3. Operational characteristics of double-engine coupled axles and propeller-fan joint motion.

aa_1, bb_1 - power supplied to the fan by each engine and fan power characteristics, respectively.

dd_1, ee_1 - rated power characteristics of single and double engines, respectively.

xx_1, yy_1, zz_1 - characteristics of certain part of the double engines, respectively.

CAC_1 - characteristics of single propeller (including N_{Fan})

B - rated design point

Under landing conditions, it is required that the flying height be small and the propulsion be large. Then, operating under rpm N_a and changing H/D along ii line, the intersection point Q on the engine external characteristic curve can be selected making an additional propulsion power $\overline{QG}$ available when compared with that of the fixed blade distance.

If large flying height and sufficiently small propulsion are required, then operation under N_e (or N_{ove}) can be selected and at this time, the H/D is reduced along, for instance, the blade distance characteristic curve gB (or fD).

6

Thus, the so-called interchange of lift and propulsion power is realized to adapt to different cruising condition requirements.

In addition, using the hydraulic clutch to couple axle, and as long as the input axle rpm is within the range of the same adjusted rpm n of the two engines, there is excellent operating compatibility; moreover, a 45° forward inclining angle is adopted in the design of the clutch for this boat (see Fig. 4). This not only decreases the effective dimension D ($D=[Me/(\gamma \cdot \lambda \cdot n^2)]^{1/5}$) due to the increase in the torque coefficient "λ" of the clutch, but also brings about excellent separatibility when there is large rpm difference between the two engines. Since at such time the low speed clutch is operating under backward inclining blades, with i=0.8 and "λ" is only about 12% of that under forward inclining operation (Fig. 5), this design effectively provides possible maneuver by using rpm difference under the coupled axles and eliminates the operation interference between the two engines, thereby improving the turning performance of the boat.
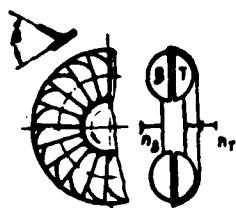

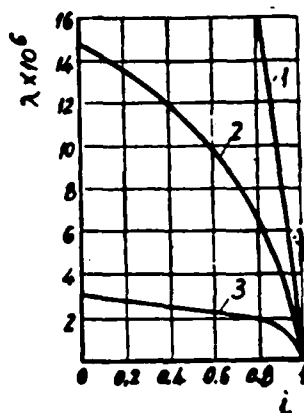Fig. 4. Forward inclining blades clutch

Fig. 5. Comparison of clutch torque coefficient "λ" for forward inclining (1) straight (2) and backward inclining blades.

III. Problems and Measures

1. Fire Prevention. The fuel for the aviation piston engine commonly used in this country are No. 70, No. 95/130 and No. 100/130 aviation gasoline. These fuels are, in addition to their poisonous combustion gases caused by the anti-knocking additive $Pb(C_2H_5)_4$, also highly volatile. The initial distillation point is only $40^\circ C$ and the 10% distillation temperature is $88^\circ C$. The high volatility can cause the light end in the fuel to decrease rapidly and form a "vapor lock" in the fuel line making startup difficult. In addition, it causes the concentration of "C-H" fuel vapor in a limited space to increase making this one of the direct reasons for casuing a fire hazard.

Figure 6 shows the explosion limit of the mixture of the fuel vapor. The gasoline, being the first grade product of petrolium, nonexplosion limit line "C-H" is below 1.3% or above 11.5%; the O_2 concentration limit line is below 9%. It is very difficult to constantly satisfy the above conditions in the engineering design,
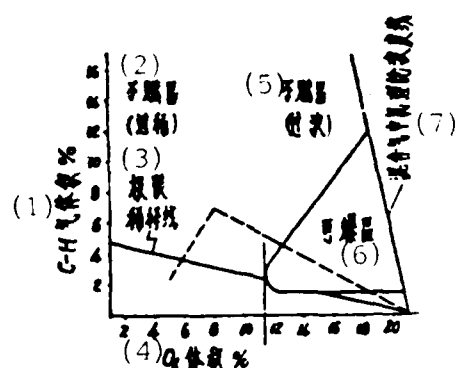
8

yet this is a necessity.

Fig. 6. Explosion limit of the C-H, O_2 and N_2 mixture.
Key: (1) C-H volume %; (2) nonignition zone (too thin); (3) limit dilution line; (4) O_2 volume %; (5) nonignition zone (too rich); (6) explosion zone; (7) Theoretical oxygen concentration line in mixture.

A more satisfactory fire prevention measure on an air cushion boat is the modified design extended from the fire prevention system on large aircraft. There are 4 large gasoline tanks with equal holding capacity on a certain air cushion boat. The fire prevention system is equipped with 4 CO_2 fire extinguishers with each one containing 5.7 kg liquid CO_2 under a pressure of 170 kg/m^2. When needed, the CO_2 medium is depressurezed by the double-level depressurization value in the ductwork and then slowly released as CO_2 gas under a low pressure of 1.23 kg/cm^2 through a nozzle with 0.5 mm in inner diameter into the space inside the top portion of the gasoline tank. The CO_2 gas will cover the top of the gasoline liquid surface in the tank and additional mixture will be exhausted into the atmosphere through the tank vent, thereby ensuring the quantity of O_2 and C-H gases in the mixture inside the tank to be under their limit proportion lines. Thus, safety is guaranteed. One continuous releasing time of the

above system can reach 9 hours, and therefore it satisfies the require-

ment for sustained cruising time. It is also theoretically feasible if

the CO_2 gas is, after branching, cooling and filtering, ducted directly

from the engine exhaust pipe into the tank.

2. Corrosion Prevention. In order to obtain very light unit

horsepower weight, the aviation piston engine uses a large quantity of

light alloy and premium alloy material with about 50% being light

alloy. This brings difficulties in engine corrosion prevention under

the ocean environmental conditions. According to available data, it

has been shown that the corrosion rate of metal at the shore area and

on the sea surface is related to altitude (Figs. 7 and 8). The

maximum corrosion rate for metal on the sea surface occurs at the

altitude of 0.5-1.0 meter, and the engine installed on the deck of the

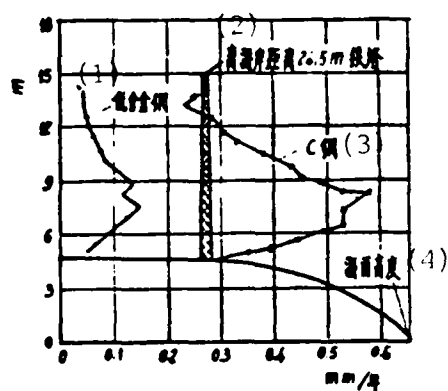air cushion boat is exactly located near that altitude.

Fig. 7. Metal corrosion rate at shore area.
Key: (1) low alloy steel; (2) Iron tower located 24.5 meter from the
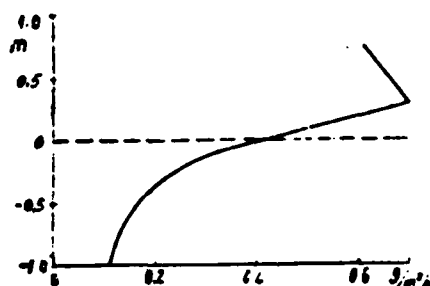shore; (3) C steel; (4) sea level altitude.

Fig. 8. Metal corrosion rate near ocean surface.

A large quantity of water mist is generated as the air cushion boat flies across the resistance peak, and even after it crosses over the peak, the mist NaCl content obtained from field measurements is still surprisingly high: it reaches 108.7 ppm in the air near the upper deck with the maximum reaching 3637.2 ppm. Yet, the NaCl content at sea surface is normally between 8-12 ppm.

It is very difficult to improve the corrosion resistance capability of the engine surface: the engine surface is of complex shape making it difficult to ensure homogeneity by electroplating, and it could even facilitate corrosion; if heat resistance organic coating is used, it obviously could affect the engine's heat dissipation performance. One feasible measure is to rinse with fresh water and then wipe dry each time after the boat returns to the harbor. The engine surface is then sprayed with a solution of gasoline and lubricant at a 4:6 ratio. This will have important effects on prolonging the usage life expectancy of the engine.

Figure 9 gives the more effective device for solving engine interior corrosion caused by air intake. Air cushion air is ducted

11

from the air cushion space, through centrifugal separation, into the main engine air intake assembly at a pressure of 20-40 milibar. There is another exclusive separator installed in the assembly (e.g., the British model "ALTAIR" separator). Even though the air that enters the engine has various resistance (flow resistnace for "ALTAIR" is $1.26xV^{2.08}$ mm H_2O), negative pressure will not occur as long as the design is proper. The volume required for air intake is only about 2% of the air cushion air flow, thus it will not affect cushion lift performance.
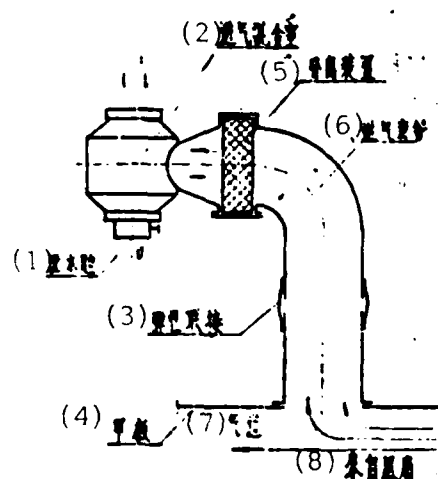

Fig. 9. Main engine air intake assembly.
Key: (1) water outlet; (2) intake air mixing chamber; (3) flexible connector; (4) deck; (5) separation device; (6) air intake elbow; (7) air duct; (8) from the fan.

3. Reasonable Selection of Design Operating Condition Point.

The rated operating condition time of the aviation piston engine is only 1 continuous hour, yet the rated operating condition for the boat

12

usually means 12 hours of continuous operation. The power reserve

in ship design or the rated power of design point under the main engine

rated rpm is reduced by 10%; or the rated rpm is increased by 3% with

the rated power unchanged. Both methods will not cause main engine

overload due to an increase in the drag of the boat body during opera-

tion.

When selecting the power design point for an air cushion boat, the

fact that the maximum power of the aviation piston engine under long-

term continuous operation is 75% of the rated power must be considered.

Therefore, the reasonable design should be such that the maximum power

design point of the propeller is at this point. And starting from

this point, the propeller is tested under the rated rpm to see if it

does have a 10% power margin.

4. Reverse Gear and Overheat. The aviation piston engine assembly

generally consists of an automatic blade distance change system and

the range of distance change is 12°-30° with no negative distance

sections. As an air cushion boat power assembly, however, the blade

initial installation angle must be changed and its range of distance

chagne increased to allow for a negative distance section so that the

maneuverability requirement of the air cushion boat can be accommodat-

ed. It must be noted that the reverse gear tends to worsen the heat

dissipation condition of the engine, and therefore its use must be

strictly limited. It is well known that one channel of heat dissipa-

tion for the aviation piston engine is passing the lubricant through

a heat exchanger, then the heat is carried away by air cushion branch

flow with a basically fixed flow rate, and another portion is dis-

13

sipated through the heat fins of the engine into the cooling air. In order to guarantee the required cooling air volume G_n for the engine under normal working conditions, the pressure head of the air flowing outside the engine must be greater than or equal to the air drag at the drag characteristic working point on the engine surface. That is,

$$\xi \rho V_0^2/2 + H_F \geq [G_n^2/(2g\gamma)]$$
$$\cdot [1/\phi_{\Sigma}^2 + (1 + \Delta T/T_H)/F_{ox}^2]$$

where ϕ_{Σ}, F_{ox}, $\Delta T/T_H$ and H_F are the cooling surface area, exhaust gas surface area, temperature rise ratio and wind velocity of the propeller air flowing over the engine surface, respectively. Or this can be explained by the experience formula of heat dissipation coefficient for the heat fins:

$$\alpha_f = 207[0.0247 - 0.00372(L^{0.8}/P^{0.4})]V_f$$

where P and L are the height of heat fins and fin distance, respectively.

At the reverse gear, the boat speed $V_o \approx 0$ and the propeller air flow is reversed. H_F is reduced causing the air flow velocity V_f through the heat fins to drop abruptly, thus both G_n and α_f are below requirements. The cooling effects are extremely bad and the cylinder head temperature rises rapidly. Therefore, the length of reverse gear must be strictly limited with each time not exceeding 5 minutes.

This example does not apply to those engines equipped with cooling fans.

IV. Conclusions

1) Since the aviation piston engine has advantages, such as a markedly light unit horsepower weight and excellent assembly integrity, although its fuel consumption is quite high, it is still a better choice from the standpoint of assembly performance. The effective load ratio and the fuel consumption ratio per seat of the 711.IIA boat are close to the level of SR.N6 with a steam engine assembly;

2) Since there are fire hazard and corrosion problems, which are difficult to overcome, as well as a defect such as short life expectancy for the aviation piston engine, it is not suitable to be used directly as the main power for passenger boat power assembly;

3) For small yachts and special duty boats, as long as attention is paid to solving the aforementioned technical problems, the modified aviation piston engine still has practical values for use.

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