SECTION 5

DUTIES AND MAINTENANCE

5.1 DUTY CYCLE

The engines driving the lift fans of a hovercraft have to run at a high proportion of their maximum output for most of their running time. The level of power demanded of the propulsion units will depend on the type of hovercraft operation. In general, maximum power will be needed at the beginning of every sortie to get through the hump. The level of cruising power will vary according to the operator but in general will be between half and maximum cruise power. This is in contrast to most automotive applications where the average power demanded will be well below half maximum output. Engines should, therefore, be capable of operating for most of their life at close to their maximum power or maximum cruise rating. In particular cases, for example when a craft is used for rescue, ambulance or other emergency services full power is needed in the shortest possible time after start up, and this may be in low ambient temperature, for example in Canada or Scandinavia.

Gas turbines can accommodate these two requirements, continuous operation at high power and minimum warm up time, better than other types of engines. In the case of reciprocating piston engines, especially automotive units, there is the choice of running at a power close to the maximum output with overhauls and possibly replacement of major parts, at relatively frequent intervals, or of maintaining a reasonable overhaul life and setting the maximum continuous power rating relatively low in relation to maximum output. This naturally has an adverse effect on specific engine weight (weight per horse power), which should, of course, be as low as possible.

The absence of reciprocating parts and the reduction in the number of wearing parts, as compared with equivalent four-stroke piston engines, suggests that the Wankel engine is less likely to suffer from stress failures in the upper performance range. Wear is primarily confined to the apex seals, and depends greatly on the matching of the apex seal materials to the materials of the epitrochoidal surface. In fact, acceptable seal wear was achieved with several material combinations some years ago, though the lowest wear rates were measured with hot pressed silicon nitride type apex seals early in 1970.

It is a peculiarity of the Wankel engine that it is safe to run the engine under full load as soon as it may be safely assumed that satisfactory apex seal lubrication has been ensured, which is quite independent of engine temperature. Since the lubricant for the apex seals is carried by the charge, these engines can be put on load very quickly after starting up.

Engine response to rapid throttle movement has also proved to be very good.

The rotary engine therefore offers improvements over the automotive piston engine in terms of continuous operation in the top half of the power range, negligible warm up time and better response. It also shows to advantage in power/weight ratio, bulk and frontal area.

Some of these points are illustrated in Table 5.1, in which the NSU KKM 612 rotary engine is compared with four typical automotive piston engines.

As compared with the gas turbine, it offers a lower specific fuel consumption, especially under part load conditions.

The idling speed of a rotary engine may have to be set higher than that of a piston engine to ensure smooth running, but any effect on operating costs for duties involving a high proportion of idling time, such as relatively short runs, is likely to be secondary. The engine could, of course, be shut down, provided normal precautions were taken against vapour locks, etc., in hot climates, but at the risk of increased maintenance due to the more rapid wear which results from frequent engine stops and restarts.

TABLE 5.1

Comparison of NSU KKM 612 (Ro80) Rotary and Petrol Piston Engines of Similar Output

Engine Type	Net Dry Weight lb Excluding Radiator	Block Frontal Area,* in.^{2}	Power hp			Weight per Max. Cont. hp lb/hp	Frontal Area per Max. Cont. hp in.^{2}/hp	Max. Cont. per Max. Output hp
			Max. Cont. DIN	Overload (Intermittent) DIN	Max. Output SAE			
Ford 2604E 4 Cyl.	416	726	99	128	144	4.2	7.34	0.69
Ford 2603E 4 Cyl.	414	726	77	96.5	119	5.38	9.42	0.65
Ford V8, 330 in.^{3}	720	836	115	135	154	6.26	7.26	0.746
B.M.W. 411	320	620	115	115	130	2.46	4.76	0.885
NSU Rotary KKM 612	296	513	113.5	113.5	128	2.69	4.67	0.86

* Excluding radiators.

5.2 MAINTENANCE – FREQUENCY OF WORK

Observations must of necessity be based on the comparatively few types of engine in production. The experience gained from these shows that for engines subjected to long continuous running periods, requirements for major maintenance are minimised but there must be a frequent check on ignition timing, carburettor and metering pump settings as these are more critical in the rotary engine (for example, the sparking plug and contact breakers operate more frequently than in a four stroke engine running at the same speed).

Maintenance will also be affected by the smaller number of parts, particularly wearing parts, compared with piston engines, as shown in 2.3.

An indication of reliability is that although, in view of the growing number of Wankel engines in use in this country, it was thought opportune by a group of engineers to form a company suitably equipped for the general overhaul of this type of engine, it was found from conversations with importers and distributors that there would be no demand for this kind of service.

It would also seem that the Wankel engine is less liable to major damage due to failure of internal parts than the piston engine. There is, of course, no possibility of crank case damage caused by connecting rod failure, nor can a broken valve damage a piston and cylinder head. This is borne out by the importers and distributors referred to above, who reported that they had had to change very few epitrochoidal housings as a result of failure due to operating conditions or other external causes. The only known case of an epitrochoidal housing failing on test occurred during a run for several hundred hours at 7500 rev./min. under severe knock conditions. The cause was an apex seal failure, part of the seal being trapped between the rotor and the epitrochoidal bore.

5.2.1

The achievement of the Fichtel & Sachs range of small engines is very good. The Hoverhawk, which is now equipped with their standard engines, not marinised, is the only hovercraft known to be fitted with Wankel engines as a production machine and it is too early for any substantial evidence of its operational performance. The following statement was obtained from the manufacturers of the craft:-

"1. Power to weight ratio (installed in craft)

4.3 lb/bhp Wankel
4.9 lb/bhp Velocette Viceroy.

2. Engine power curve is very flat at top end and it is easy to match fan power curve to this engine. Also, engine does not go off tune as easily as most two stroke engines.

3. The thermal efficiency of this engine is not very good and exhaust temperature is very high (950°C) at manifold. Fuel consumption 0.68 lb/hp hr.

4. Engine runs very smoothly at high rev./min., i.e. above 3,000, but will not idle below 2,000, also below 2,000 rev./min. torque pulsing becomes very apparent.

5. Engine cooling is very good but we have had problems in lift engine bay with vapour locks due to high engine bay temperature.

6. Magneto ignition on this engine is very good.

7. Starting, temperamental when hot (this problem has been resolved to some extent).

8. Fitted with micronic air cleaner, engine performs very well under all conditions.

9. Engine can be fully marinised but this is very costly, all alloy castings would need to be coated with epoxy paint. This can be done by Fichtel & Sachs.

10. Engine is very robust in construction and no problems have been encountered on this score.

11. Maintenance of this engine is very simple and only one specialised tool is required to do a major overhaul."

Commenting on this statement, it is known that the basic Fichtel & Sachs unit was found to be very nearly right for this installation and needed minimal modification. The engines referred to in item 1, above, are the Fichtel & Sachs KM 914 unit and the Velocette 'Viceroy' piston engine previously used in these craft. The reference to thermal efficiency in item 3 may be misleading; the fuel consumption quoted is the standard for these small engines (see Appendix IV), and the exhaust temperature of a Wankel engine is normally higher than for a piston engine (see 2.1).

5.2.2

For the NSU KKM 612 engine, used in the Ro80 car, long term information is not available, but indications from those motor cars in circulation are that they show very good mileages between maintenance, other than those cars being used by doctors or as taxis, where stop/start running is normal. The original problem of apex seal wear and breakage has been overcome and, with the newly developed silicon nitride seals by B.S.A. Research Group (not yet available in production quantities), appears to be virtually eliminated, and an overhaul life of 70,000 to 100,000 miles or more is being achieved.

This order of mileage is confirmed also by Daimler-Benz on their M 950 engines, but it is acknowledged that this is achieved on motor cars operating under normal conditions with characteristically relatively short periods of maximum cruise or full throttle power. Not one of these three companies would commit themselves to a definite equivalent hours life under the conditions of hovercraft service but considered that 500-1,000 hours was possible and perhaps 2,000 hours with reasonable routine maintenance.

5.2.3

The observations of engineers at NSU (G.B.) Ltd. might be of interest, since they have already had experience of the operating problems of the NSU Ro80 motor cars in the U.K.

They say that generally the rotary engine is more reliable from major trouble aspects than the piston engine in that there are fewer vulnerable parts, no valves, fewer bearings, etc.

However, top maintenance is more important and the overall costs involved tend to be higher than for conventional car engines. Each rotor being, in effect, a separate engine with its own carburettor, correct tuning of the carburettors is required, whilst attention to the oil metering pump which injects oil directly into the induction system is essential. The engine having a total loss oil system has to be checked to ensure adequate oil is in the sump, though no oil changing is required. (Oil consumption is approximately 200 miles – 5 hours – per pint, the sump refill capacity being 8 pints.) To summarise, maladjustment of ancillaries causes similar problems to those of a piston engine, e.g. overheating, etc. As a result of experience, NSU insist on the use of Glysatin antifreeze.

It is interesting to note that internal troubles, usually seals or seal springs, affect engine performance at low rev./min.; one indication of damaged seals may be a tendency for the engine to stall. Once high revs are attained, little difference is apparent because the gas loading on the seals is the most important factor.

Overhaul is quick on the Ro80. NSU (G.B.) Ltd. have been able to make complete engine changes, with all adjustments, and road tested the car within 2 hours. They reckon that a trained fitter is able to complete 1½ engine rebuilds per day. In their opinion, the top servicing is more difficult than internal work, and anyone capable of carrying out servicing could quite easily cope with engine internals.

So far as we have been able to find out from discussions with local garages servicing NSU cars, these observations of the NSU engineers appear to be confirmed in practice.

5.2.4

One important point to remember in the NSU and Mazda engines, which will presumably apply to the Daimler-Benz M 950 engine, is that adjustment of the ancillary equipment, points, ignition timing, oil metering pump, carburettors, etc., must be to the makers' recommendations.

Should anything be amiss, a fall-off in engine power will be noticed. This then necessitates a thorough examination of carburettors, timing, plugs, lubrication controls, etc. Continuing loss of power, especially at low speeds (5.2.3), points to seal trouble. The motor should be shut down and stripped as soon as possible to replace damaged parts.

5.2.5

In practical terms and based on NSU Ro80 experience, a typical general maintenance programme would be (subject to correction for hovercraft against motor car use and provable only by trials) as follows:-

(a) When convenient between operations, carry out ancillary equipment checks in three stages:

  (i) At 80 hours: check ignition timing and carburettor setting, change plugs. Approximately one hour's work.

  (ii) At 160 hours: check ancillaries, change plugs. Approximately 2 to 2½ hours' work.

  (iii) At 240 hours: thorough ancillary equipment check, all adjustments, timing, etc., change plugs. Approximately 3 hours' work.

(b) Et seq. up till major overhaul at car 30,000 miles equivalent, say 1,000 hours, when it would be expected to change seal elements, renew gaskets, various minor parts, e.g. control bearings. This would involve some 10 to 12 hours' work and (at present costs ex local agents), some £50 in parts. A new rotor and chamber unit would cost approximately £105 if required.

For the Mazda engines the quoted mileage intervals between services are better by some 25%.

Note: When a Wankel engine is installed in a closed, possibly pressurised, compartment, differences in temperature, humidity, etc., from the automobile condition combined with the type's apparently greater sensitivity to tuning, extra care may be needed in obtaining the correct initial settings.

5.2.6

An average costing for the above maintenance schedule, based on NSU (G.B.) Ltd. charges for the Ro80 would be of the order of

(a) At 80 hour intervals, averaged = £12 to £15.

(b) At 1,000 hour overhaul allow £80.

both including labour taken at £2 per hour and current materials cost ex agent. It is considered that these costs are rather high.

No costing figures are available from Daimler-Benz, who will not quote as they are not in production. However, some estimate was needed for the calculation of running costs and Hoverprojects estimate that on the basis of the NSU charges and assuming that the 80 and 1,000 hours schedules apply, costs might be of the order of:

(a) At 80 hour overhaul = £25–£30

(b) At 1,000 hour overhaul = £160.

5.2.7

Some observations by Industria Ltd., the Toyo Kogyo concessionaires in the U.K., regarding the Mazda R 100:-

"As with the Ro80 engine, top ancillary adjustment is critical, with checks and plug changes at 10,000 miles, and complete overhaul quoted at 40,000 miles, although Industria's, who have been dealing with the R 100 for a year, have not yet had to do a full service, or make any major repair on any car they have supplied in that time. Rebuild takes about one day."

Fuel is supplied to the engine through a four barrel, two stage carburettor and consumption of petrol is 20/22 mpg and of lubricating oil is 300/500 miles per pint (10 hrs/pt).

Engine coolant uses any standard antifreeze to B.S. 3151. The engine has good torque characteristics at low speeds, possibly due to the use of side inlet ports, and the car is capable of pulling away in top gear from 15 mph. The standard generator has the fairly low output of 33 amps at 12 v.

Industria Ltd. are unable to supply engines even on a spare parts basis but would be amenable to allowing a mechanic to attend their school for the R 100 engine course even though engines would have to be supplied direct from Japan to a potential customer.

5.3 MAINTENANCE TECHNIQUES AND SKILL REQUIRED

Considering the three motors most likely to be available in the foreseeable future in quantity, and the expectation that these engines will be used on working craft in outback conditions with attendant maintenance facility problems, the opposed views of Daimler-Benz v. NSU and Toyo Kogyo U.K. agents have to be noted. Daimler-Benz, typically, feel that the construction of their engine is such that a workshop with skilled men is required to ensure successful assembly, compared with the NSU/Toyo Kogyo view that an average, mechanically minded hovercraft driver with training could carry out even major replacements in the field during an operational excursion.

5.3.1 Tools and Equipment

Generally simpler and fewer than those required for a piston engine, but in the case of the present Daimler-Benz engine the remarks in 5.3 apply and some special rotor case and shaft aligning equipment is necessary.

For the other Wankel engines, it should be possible for a hovercraft operating in the outback to carry all the tools necessary to effect repairs without too great a weight penalty, provided some of them are carefully designed in a lightweight form.

5.3.2 Spares

Again, generally fewer than those required for equivalent piston engines. The most frequently changed parts are belts, spark plugs and points, occasionally apex seals, oil metering pumps, oil filters and air cleaner elements and, rarely, rotors and rotor housings.

5.3.2.1 *Daimler-Benz*

The M 950 engine is not sufficiently tried operationally even to estimate a spares holding or cost.

5.3.2.2 *NSU*

The KKM 612 engine is now widely used and proven and the following spares holding are suggested by their Service Department as a basis for an operating fleet of eight three engined craft:

Operating fleet engines:	24
Spares holding:	2 complete engines allowing immediate changes to be made 5 rotor block assemblies. 6 sets of top accessories (carburettor, distributors, etc.). Various sundry items. Tools, etc.
Cost:	Total spares holding given above estimated at D.M. 30,000 to 40,000, ex works (£3,500 to £4,500 approximately).
Delivery:	Normally not more than one week to be despatched from works.

5.3.2.3 *Toyo Kogyo*

The R 100 engine would seem to be more reliable than the Ro80 but it would probably need to carry a similar spares holding. Their individual (spares) prices are approximately:

Rotor block	£125.	Rotor £25.
Trochoid	£31.	Set of top accessories £180.

5.3.3 Training Schools for Principal Engines

5.3.3.1 *Daimler-Benz*

At present do not have and do not yet contemplate a training school for instruction on their rotary engines. Training would have to be specially arranged in their experimental fitting shop where the M 950 engines are assembled and it is felt that it would take some weeks for a mechanic to be sufficiently skilled to undertake independent work on one of their engines.

5.3.3.2 *NSU*

They have an exceedingly good training school where instruction is given at no charge for the course. Accommodation, subsistence, travelling, etc., are the responsibility of the client. The NSU course is detailed in Appendix VI with some remarks. The course given by NSU (G.B.) Ltd. at Shoreham-by-Sea involves a day only on the Ro80 but this is to be extended to two days in 1971. (It is suggested that this is too short and incomplete for operators of craft working in isolation, away from a main agent – Hoverprojects' comment.)

5.3.3.3 *Toyo Kogyo*

No information is available regarding Toyo Kogyo themselves. In the U.K. training is undertaken by Industria Ltd., who have a training school at their works. The course – as NSU – is free but the engine training session is for three days and all mechanics are expected to do at least one complete engine strip and rebuild as well as adjustments and basic theory.

5.3.3.4 *Fichtel & Sachs*

Although their engines are relatively simple and backed by very good maintenance man[uals] Fichtel & Sachs are of the opinion that customers should send their mechanics to their trainin[g]

5.3.3.5

It is evident that even for good mechanics, used to piston engines, a conversion course is necessary, and in view of the fact that craft could normally be operating in out of the way areas, a complete course, preferably at the manufacturer's school, should be taken by the operator's service staff and certainly by the leading hand.

This retraining of maintenance mechanics is standard procedure within the automotive industry, even for ordinary new reciprocating piston engines.

In spite of the above statement, the engine is sufficiently simple internally for maintenance to be carried out by mechanically minded personnel who do not necessarily have previous engine experience.