APPENDICES

APPENDIX I

HISTORY OF WANKEL DEVELOPMENT

The search for positive displacement rotary piston machines dates back several centuries and actually pre-dates the invention of the reciprocating piston principle. James Watt, while working on reciprocating machines, also sought purely rotary solutions. Over the years literally thousands of patents on rotary piston machines, including engines, were filed in this country alone.

Felix Wankel, starting in the thirties, worked out a classification of rotary machines*, and went on to evolve the engine considered in this report, when he was sure that he had developed effective methods of sealing quite complicated rotary combustion machines.

As mentioned in the introduction to Section 2, Wankel started work in 1954 on an engine consisting of a three sided rotor in a two lobed housing, both of which rotated in an outer casing about different centres and at different speeds, and which represented a practical method of obtaining variations in the volumes of the three chambers formed between the rotor and the housing, which complied with the requirements of the Otto cycle. This engine, which had a maximum chamber volume of 125 cc, went on test early in 1957 and eventually developed 29.6 bhp at a rotor speed of 11,330 rev./min. and a housing speed of 17,000 rev./min., thus proving the feasibility of the basic concept.

It was realised that the design could be inverted to the planetary rotation type, with stationary rotor housing, which was simpler but presented potentially greater problems for achieving satisfactory linear sealing, as yet unproved, of the apex seals. Dr Ing. Walter Froede of NSU, with whom Wankel had joined forces, preferred the planetary rotation machine and the first such engine, (the Wankel engine as we know it now), ran early in 1958. Prototype engines of this type and of various sizes were designed and built: in due course and at a very early stage, one of these engines was fitted to a small car, but it was not until the NSU Spider that a Wankel engined car became available to the public in limited quantities to gain experience of the practical problems encountered. Until about 1964 perhaps the most serious one was associated with apex seal behaviour; wear, and chatter marks in the housing bore which affected engine life. Other areas needing attention included oil sealing, combustion phenomena and reduction of manufacturing cost. Sometimes more than one solution was found for specific problems due to development being carried out in a growing number of centres with the increasing number of licensees. It is understood that licensees now number 21 spread over Europe, America and Japan. For example, engines are in use giving satisfactory service with

* Wankel, F., Rotary Piston Machines.

quite different combinations of apex seal and housing bore surface materials. Most work to date was confined to petrol engines, though from 1961 onwards licences were also granted for diesel engines. Rolls-Royce have very recently announced progress towards the development of a two stage compression-ignition engine, but no significant results have been disclosed by other licensees in this field.

Besides the companies holding licences from Wankel-NSU, research is being carried out in many parts of the world but especially in Germany and Japan. Activity in the U.K. is confined to Rolls-Royce's work on a diesel version and to the B.S.A. Group Research Centre, who appear to have produced the best apex seal material to date and are working on small engine developments.

As yet there are relatively few applications – two makes of cars in commercial quantities, three outboard motors; small engines are also used for military and industrial applications, for agriculture and in snowmobiles, etc. The worldwide interest is rapidly growing and the Wankel engine has a very important future.

APPENDIX II

GENERATION OF AN EPITROCHOID

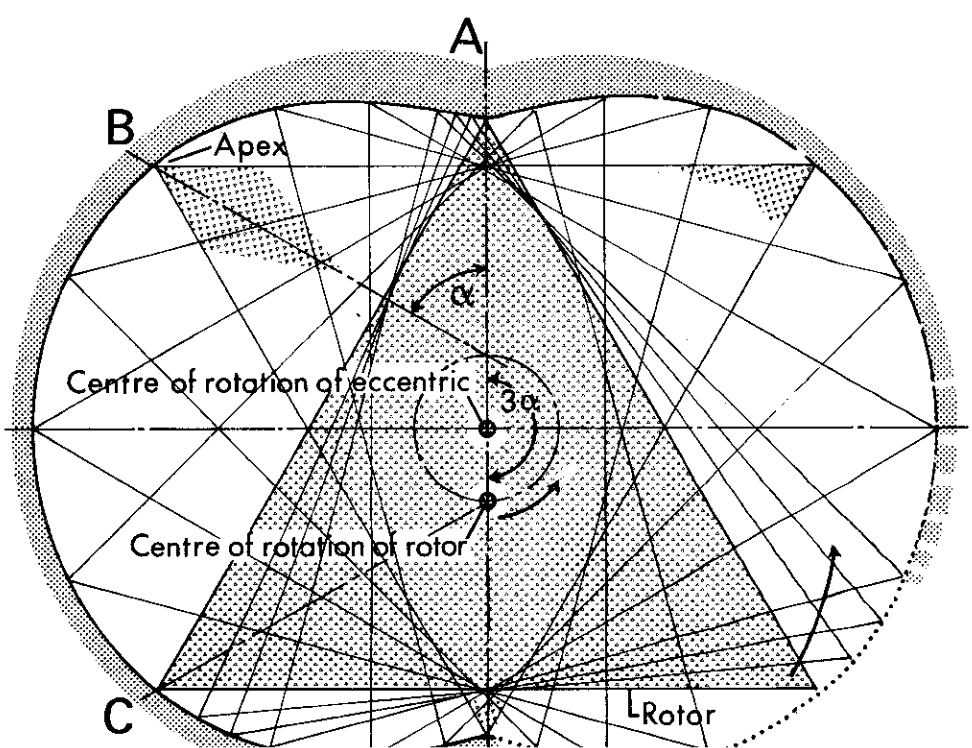
(Using a Triangular Rotor)

Assume an equilaterally triangular rotor with one side horizontal, forming a base and free to rotate about its centroid.

This centre of rotation is itself on an eccentric which revolves about a main centre at three times the speed of revolution of the rotor (via gearing not shown). Therefore for motion through α° of the rotor, the eccentric will always move $3\alpha^\circ$. This is shown on the figure. Whilst the eccentric has rotated from Bottom Dead Centre to Top Dead Centre, i.e. 180°, the apex has rotated 60° about its centroid, the apex travelling a path, or locus, from A to B. Similarly, whilst the eccentric rotates from Top Dead Centre to Bottom Dead Centre the rotor apex has rotated a further 60°, the apex following a locus from B to C.

The centre of rotation of the rotor, i.e. the eccentric, has now traversed a circular path through 360° whilst the rotor itself has rotated but one third of this, i.e. 120°. Thus the former top apex has now arrived at the position of the original left had base apex, and the centre of rotation of the rotor on the eccentric is also at its original position, and the cycle can re-commence.

The apices therefore follow a similar locus throughout one complete engine cycle since this is composed of 3 identical motions of the eccentric and rotor.



APPENDIX III

BRIEF DATA ON TYPICAL EXAMPLES OF VARIOUS TYPES OF ENGINE

Manufacturer	Type	Cooling	Cruise hp/ Output rev./min. (continuous)	Fuel	Fuel Consumption lb/hp hr	Weight lb	Approx. Cost £	Weight/ Cruise hp lb/hp	Cost/ Cruise hp £/hp
AUTOMOTIVE TYPE PETROL ENGINES									
Volkswagen (1)	124A	Air	40/3,000	Petrol	0.53	235	222	5.9	5.6
Ford (2)	2604E	Liquid	99/4,000	Petrol	0.60	400	200	4.03	2.01
B.M.W. (3)	411	Liquid	130/5,400	Petrol	0.55	335	990	2.58	7.6
Chrysler (4)	440	Liquid	300/3,200	Petrol	0.49	668	355	2.22	1.17
General Motors	427	Liquid	430/5,800	Petrol	–	600	1,500	1.4	3.5
LIGHTWEIGHT AND AUTOMOTIVE DIESELS									
Dorman	6DAT	Air	95/1,800	Diesel	0.37	1,100	515	11.6	5.41
Ford (5)	2704ET	Liquid	135/2,400	Diesel	0.4	1,005	625	7.78	4.62
Cummins (6)	V6-215-M	Liquid	158/2,600	Diesel	0.46	2,325	3,375	14.7	21.4
Daimler-Benz	OM403	Liquid	275/2,200	Diesel	0.35	2,050	1,800	7.46	6.55
Cummins (7)	VT8-370-M	Liquid	270/2,600	Diesel	0.38	2,775	4,760	10.3	17.6
Dorman	8JVT	Liquid	300/-	Diesel	0.38	2,000	1,700	6.7	5.66

Numbers in brackets refer to engines used in hovercraft, see p.III-4

BRIEF DATA ON TYPICAL EXAMPLES OF VARIOUS TYPES OF ENGINE (Continued)

Manufacturer	Type	Cooling	Cruise hp/ Output rev./min. (continuous)	Fuel	Fuel Consumption lb/hp hr	Weight lb	Approx. Cost £	Weight/ Cruise hp lb/hp	Cost/ Cruise hp £/hp
AIRCRAFT GAS TURBINES									
Budworth	Puffin	N/A	200/10,000	Kerosene	0.88	100	3,000	0.5	15
United Aircraft (8)	PT6 A	N/A	450/6,500	Kerosene	0.71	250	18,000	0.56	40
Turbomeca (9)	Astazou	N/A	502/6,000	Kerosene	0.65	270	N/A	0.54	—
INDUSTRIAL AND AUTOMOTIVE GAS TURBINES									
Rover	IS/90	N/A	107/3,000	Some Distillates	1.38	140	1,600	1.3	15
S.T.A.D.	IS/250	N/A	250/Various	Any Distillate	1.4	600	6,000	2.4	24
Leyland	Auto	N/A	370/3,000	Any Distillate	0.4	1,000	2,400	2.7	6.5
Ruston	TE 500	N/A	520/1,800	Distillates and gases	1.1	3,400	20,000	6.5	38.5
Centrax	CS600-2	N/A	730/1,800	B.S.2869 Classes A.1,A.2	0.74	1,600	15,000	2.2	23

Numbers in brackets refer to engines used in hovercraft, see p.III-4

BRIEF DATA ON TYPICAL EXAMPLES OF VARIOUS TYPES OF ENGINE (Continued)

Manufacturer	Type	Cooling	Cruise hp/ Output rev./min. (continuous)	Fuel	Fuel Consumption lb/hp hr	Weight lb	Approx. Cost £	Weight/ Cruise hp lb/hp	Cost/ Cruise hp £/hp
AIRCRAFT PISTON ENGINES									
Potez	4E20B	Air	75/2,450	Petrol	0.57	190	1,000	2.54	13.3
Continental	0-240	Air	98/2,550	Petrol	0.58	246	1,650	2.52	16.9
Continental (10)	I0-470	Air	195/2,450	Petrol	0.49	470	3,300	2.41	16.9
Lycoming	I0-540-E1A5	Air	220/2,350	Petrol	0.61	437	3,200	1.98	14.5
WANKEL									
Fichtel & Sachs (11)	KM 914	Air	18/5,000	Petrol	0.68	62	95	3.44	5.26
NSU	KKM 612	Liquid	113.5/5,600	Petrol	0.62	290	320	2.56	2.76
Toyo Kogyo	10 A	Liquid	110/7,000	Petrol	0.6	300 app.	300	2.7	2.7
Daimler-Benz	M 950-4	Liquid	350/7,000	Petrol	0.5	396	*	1.13	*

*Not available – see notes on Data Sheet Appendix IV

Numbers in brackets refer to engines used in hovercraft, see p.III-4

Certain of the engines included in this Appendix are used on the hovercraft indicated below:-

1.	VW.124A	Hovermarine Hovercat, Vosper VT1(M)
2.	Ford 2604E	Air Cushion Equipment Ltd. unit
3.	BMW 411	Believed contemplated for Air Bearing HC 10
4.	Chrysler 440	Believed of interest for Sealand S.H.1.
5.	Ford 2704ET	Air Cushion Equipment Ltd. unit
6.	Cummins V6-215	Hovermarine HM2
7.	Cummins VT8-370	Hovermarine HM2
8.	United Aircraft PT6 A	Cushioncraft CC-7
9.	Turbomeca Astazou	Naviplane N.102
10.	Continental 10-470	Mitsui MV-PP1. Hovercraft Development Ltd. HD-1. Vickers VA-2.
11.	Fichtel & Sachs KM 914	Hover-air Hoverhawk III