Proceedings of the International Conference on Aerospace Science and Technology
26 - 28 June 2008, Bangaloire, India

INCAST 2008-109

DESIGN AND DEVELOPMENT OF AN INDIGENOUS 55 HP WANKEL ENGINE

K.Monickavasagom Pillai, A.J. Steve Mithran, V.K. William Grips, K. Satish Kumar, Umesh Kumar Sinha, M.N. Varadarajan, J.J. Isaac and Y.V.S.Murthy[1]
National Aerospace Laboratories, Bangalore, India, kmpillai@css.nal.res.in
(Council of Scientific & Industrial Research, India)
[1]Aeronautical Development Establishment, Bangalore.

ABSTRACT: *During the last decade, a number of developmental projects have been initiated both in civil as well as military aviation, for Powered Hang Gliders for aerial spraying of pesticides, Small Aircraft, Pilot-less Target Aircrafts and Unmanned Aerial Vehicles. The requirements for all these applications are similar in that the power to weight ratio should be high, specific fuel consumption (sfc) should be low, noise and vibration levels must be low, thermal efficiency must be reasonably higher and maintenance and serviceability should be acceptable. A prominent contender that can meet all the above requirements is the Wankel engine. In recent years, they are found increasingly in roles where their compact size and quiet running is important, notably in Unmanned Aerial Vehicles (UAVs).*

At present, the National Aerospace Laboratories is involved in the indigenous development of Wankel engines to support the nation's UAVs program. A 55 hp single rotor, liquid cooled, Wankel engine was designed, developed and the 1st Proto type (PT1) was successfully tested. This paper describes the developmental work carried out on the Wankel engine and the performance validation of the engine.

1. INTRODUCTION

Aerospace propulsion demands a power plant with the minimum weight possible without sacrificing on torque and power. Out of the various possible options, the Wankel engine has been actively considered for powering light aircraft and UAVs. This is because of its salient features like high power to weight ratio, good anti knock properties and smaller size when compared to a piston engine of the same class. NAL has acquired the necessary expertise in design and development of rotary combustion engine over many years due to the developmental work carried out on an air-cooled 35hp Wankel engine. Due to the expertise gained over the years, NAL was entrusted with the design and development of a 55hp liquid cooled Wankel engine for a UAV application.

2. INDIGENOUS ENGINE DESIGN

2.1 Design Methodology

The brief specifications of the indigenous 55hp Wankel engine is given in Table 1. The first step in any engine design is sizing the engine i.e. deriving the basic parameters of the engine.

Table 1 Brief specifications of the proposed 55 hp engine

Type	Single rotor Wankel engine
Cycle	Otto cycle
Power	55 hp (41 kW) @ 8000 rpm at ISA-sea level (without exhaust muffler)
Compression ratio	9.2
Housing Cooling	Water-Glycol mixture
Rotor cooling	Air
Lubrication	Total loss forced lubrication system
Ignition	CDI system
Carburettor	Diaphragm type
Specific fuel consumption	335 to 365 g/ kWh (0.55 to 0.60 lb/ hp h
Engine weight	35.6 kg

The following three step design methodology has been followed for the present 55 hp Wankel engine development.

i.From first principles

The thermodynamic cycle analysis and design of the engine components have been derived from first principles.

ii.Knowledge base available

Since NAL had gained expertise in developing a 35hp air cooled engine, the knowledge base was utilised for the present development.

iii.Reference to the proven engines

A survey was made to analyse proven designs of rotary combustion engines close to the required power output range and with modifications of the geometry and/or other parameters in order to obtain the required power output and performance.

2.2 Basic Parameters

The basic parameters[1] of a rotary combustion engine design are displacement, eccentricity, rotor radius, rotor radius and chamber width. These parameters were calculated [5,6] to meet the power output of the 55 hp engine and are given in Table 2.

Table 2 Summary of geometric parameters of the 55 hp engine

Sl No.	Parameter	
1.	Eccentricity (e)	11.6 mm
2.	R/e	6.12
3.	Rotor radius (R)	71 mm
4.	Trochoid profile shift (a)	0.5 mm
5.	Chamber width (w)	75.2 mm
6.	Displacement (V_s)	324 cm^3
7.	Recess volume	15.82 cm^3

2.3 Thermodynamic Cycle Analysis

After arriving at the above basic parameters to make sure that above parameters could develop the required power and to also design the cooling system, a detailed thermodynamic cycle analysis of the engine was carried out using the Wankel engine cycle analysis program exclusively developed for analysing the Wankel engines[4]. This confirmed that the selected parameters could produce the specified power.[5,6]

2.4 Major Components of the Wankel engine

The major components of the Wankel engine are shown in the exploded view (fig 1). A detailed design and analyse of all the major components were made.

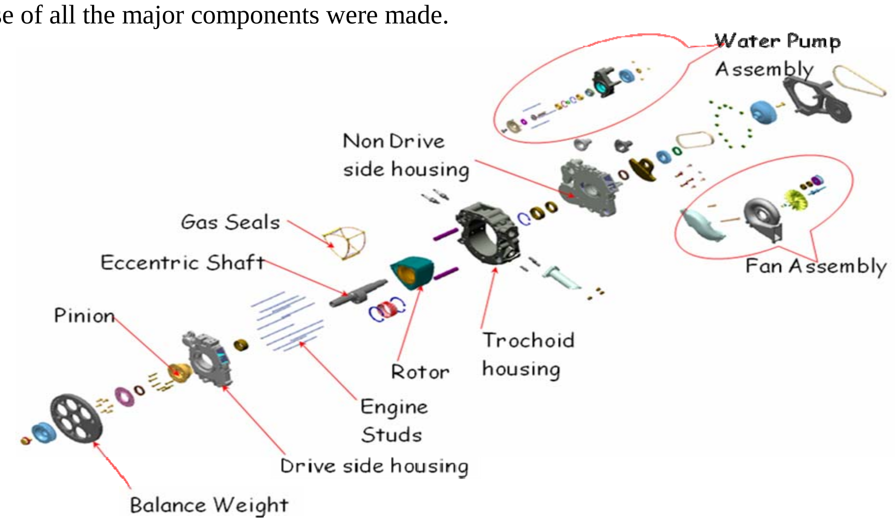

Fig. 1 Exploded view of the 55 hp indigenous Wankel engine

3. ASSEMBLY AND TESTING

The core engine has the following sub-assemblies:
Drive side housing assembly, trochoid housing assembly, eccentric shaft assembly, rotor assembly, non-drive side housing assembly, water pump assembly, fan assembly.
All the components for the PT1 engine were indigenously manufactured to accomplish the above sub-assemblies. The complete engine assembly was made at the Rotary Engines and Ceramics Application Laboratory (RECAL) in the Propulsion Division. After satisfactory motoring trials of PT1 on the motoring rig, the engine was shifted to the dynamometer test bed. Components like carburettor, ignition system, radiator and lube oil pump were provided by the Aeronautical Development Establishment (ADE), Bangalore since they were not in the scope of NAL for the present development program. After precise alignment of dynamometer shaft with the engine shaft, the performance tests were conducted.

4. EXPERIMENTAL SET UP

The following line diagram (fig 2) shows the experimental set up for the performance test and the various parameters to be measured during the testing.

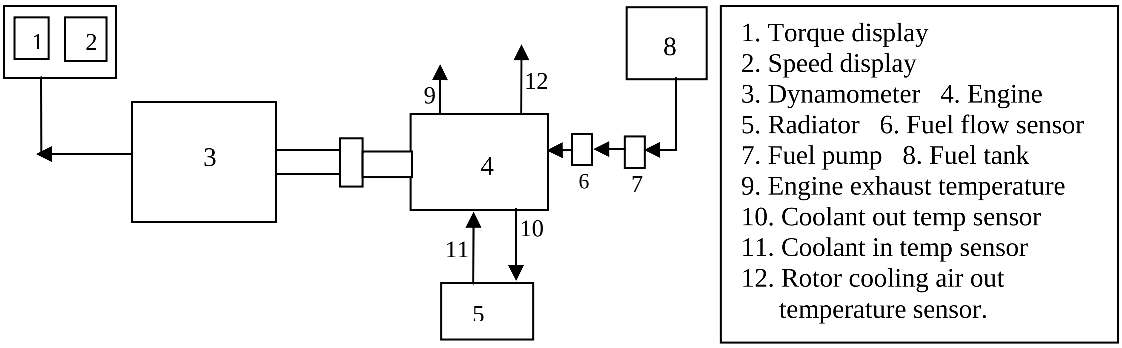

Fig. 2 Schematic of the experimental set up

Figure 3 shows the engine mounted on the dynamometer test rig before the performance test.

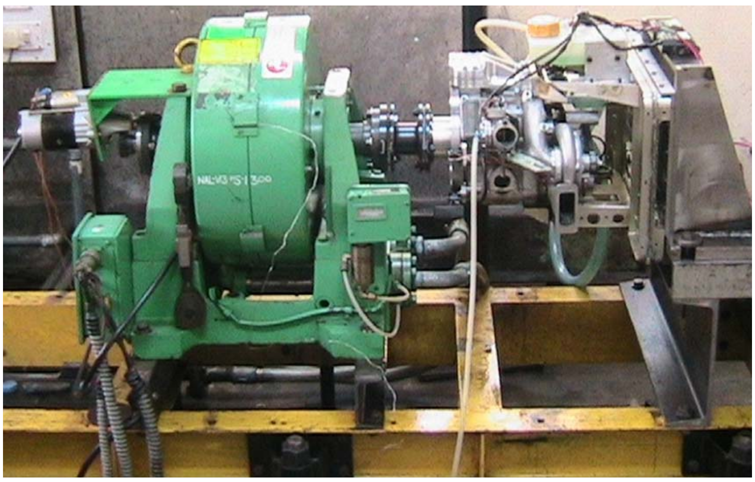

Fig. 3 PT Engine mounting on the dynamometer bed

The dynamometer specifications are given below:
Make: SAJ, Pune, Capacity: 80 kW, Type: Eddy current
The dynamometer is equipped with a non-contact type speed pick up to measure the speed and the load cell to measure the engine torque. Through the dynamometer control system the load acting on the engine could be varied. The cooling water inlet and outlet temperature and the rotor cooling air temperature were

measured by RTD (Pt 1000) sensors. The engine exhaust gas temperature and intake air temperature were measured by thermocouples.
The fuel flow rate was measured by a volume flow meter.
100LL AVGAS was used as fuel for the testing.
The dynamometer and all the instruments were calibrated before testing PT1engine.

5. RESULTS AND DISCUSSIONS

The dynamometer test results are given in the table 3. Since the engine was tested at Bangalore conditions, the brake power output from the engine was corrected to sea level condition as per the Indian Standard 10000[2]
Test conditions: Ambient pressure = 910 mbar, Ambient temperature = 26 ^{o}C, Relative humidity = 48.5%
Inlet air temperature = 50 ^{o}C

Table 3 Dynamometer performance test results of the 55 hp indigenous PT1 Wankel engine

Sl No.	Speed	Torque	EGT	Fuel flow	Brake Power		sfc	Corrected parameters at ISA conditions		
								Brake Power		sfc
	RPM	N m	^{o} C	Lit /h	kW	hp	kg/ kW h	kW	hp	kg/ kW h
1	4500	32.0	630	10.53	15.08	20.24	0.50	19.72	26.44	0.47
2	5000	33.4	656	11.33	17.49	23.47	0.46	22.87	30.67	0.44
3	6000	35.5	727	14.43	22.31	29.94	0.46	29.17	39.11	0.44
4	6500	36.5	772	16.04	24.84	33.35	0.46	32.49	43.57	0.44
5	7000	37.0	798	16.82	27.12	36.41	0.44	35.47	47.56	0.42
6	7500	36.6	827	17.81	28.75	38.58	0.44	37.59	50.41	0.42
7	8000	36.0	856	18.06	30.16	40.48	0.43	39.44	52.89	0.41
8	8101	35.8	870	18.32	30.37	40.77	0.43	39.72	53.26	0.41

Figure 4 shows the variation of brake power and sfc with speed at the Wide Open Throttle (WOT) condition.

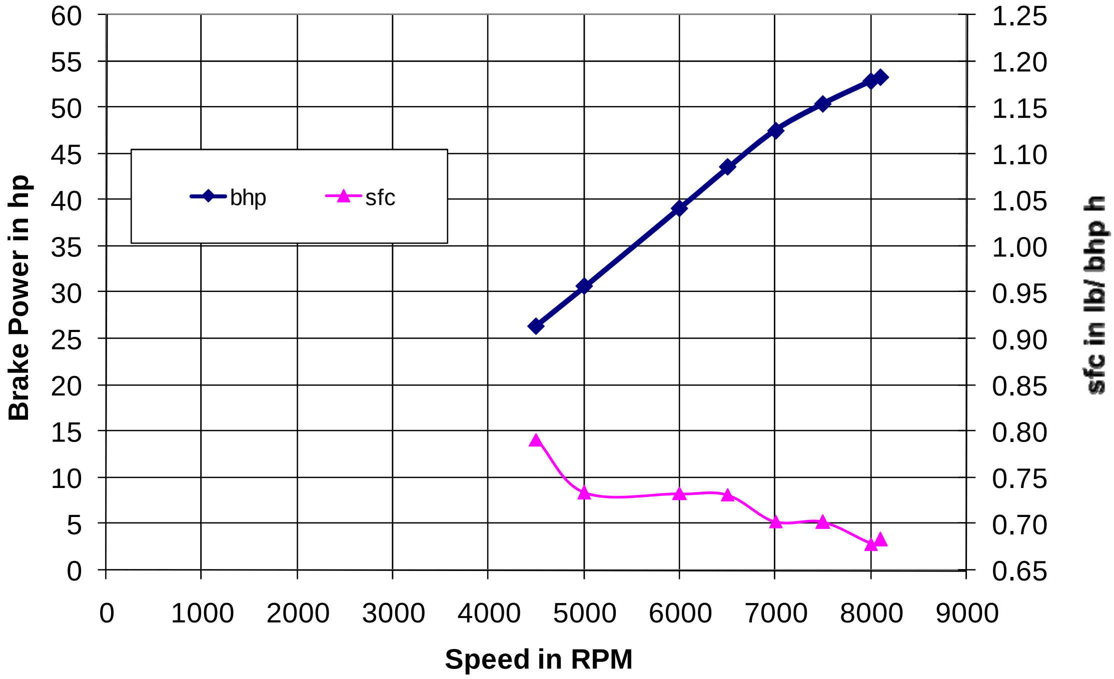

Fig. 4 Variation of power with engine speed at Wide Open Throttle (WOT) condition

The above results clearly show that the brake power output of the indigenous PT1 engine is around 53 hp, which is very close to the initial specified power. The specific fuel consumption (sfc) was 0.41 kg/kWh (0.68 lb/bhp h) at 8000 rpm, which is higher than the specified values and this will be addressed in the next proto types. The PT1 engine ran very smoothly throughout the entire operating speed range.

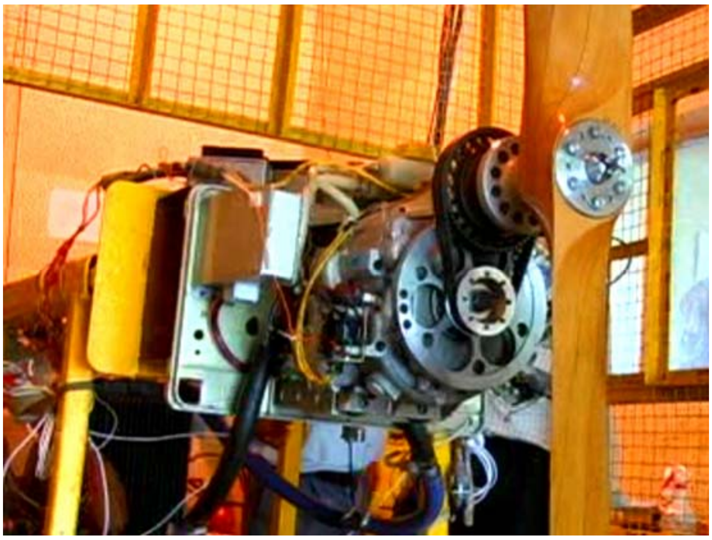

Fig. 5 PT Engine mounting on the thrust cradle

6. CONCLUSION

This is the first step in the indigenous Wankel engine development for UAV application. The indigenous PT1 Wankel engine has been tested extensively on the dynamometer test bed. The engine produced 53.3 hp at ISA condition. The performance test results were quite encouraging, since at the first attempt itself the engine produced close to the designed power. The thrust cradle measurements (Fig 5) which were done after the dynamometer tests also showed that the engine consistently produced the required thrust with the propeller of the intended UAV.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the following divisions of NAL and DRDO laboratories

i. Propulsion Systems Division, Aeronautical Development Establishment, Bangalore.
ii. Engines Division, Vehicle Research and Development Establishment, Ahmed Nagar.
iii. Failure Analysis & Accident Investigation Group, Material Science Division, NAL, Bangalore.
iv. Special Purpose Machine Shop, Propulsion Division, National Aerospace Laboratories, Bangalore.
v. Regional Centre for Military Airworthiness (Engines), Bangalore.
vi. Chief Resident Inspector (Engines), Bangalore.
vii. RECAL Project Team, Propulsion Division, National Aerospace Laboratories, Bangalore.

REFERENCES

[1] Ansdale RF. ***The Wankel RC Engine Design and Performance***. Iliffe Books Ltd, London, 1968.
[2] Indian standard IS: 10000, Methods of Testes for Internal Combustion Engines.1980 (2006).
[3] John .B. Heywood. ***Internal Combustion Engine Fundamentals***, McGraw-Hill International Editions, 1988.
[4] Monickavasagom Pillai K, Sivasankaram K and Pai BR. Thermodynamic Analysis of Wankel Engine, Paper No. B5.4., *Proceedings of the Sixth National Conference on Air Breathing Engines and Aerospace Propulsion*, Bangalore, 2003.
[5] Monickavasagom Pillai K, Satish Kumar K and Pai BR. Preliminary Design Report on Development of Technologies for Rotary Engine Systems, Project Document PR 0413, National Aerospace Laboratories, Bangalore, 2004.
[6] Monickavasagom Pillai K, Steve Mithran A.J, Satish Kumar K, Manjunath K Hiremani, Srinivas K, Roshan Antony and Rajesh M. Development of Technologies for Rotary Engine Systems – A Detailed Design Report (Revised), Project Document PR 0505, National Aerospace Laboratories, Bangalore, 2005.
[7] Yamamoto K. ***Rotary Engine***, Mazda, 1981.