ENGINEERING NOTE

QUALIFICATION OF A WANKEL ROTARY ENGINE FOR UAV APPLICATION - AIRWORTHINESS CHALLENGES

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Abstract

An indigenous Wankel Rotary Engine of 40 kW class has been developed for Unmanned Aerial Vehicle (UAV) application. It should be capable of flying flawlessly for long duration at designated altitude and carrying the payload intended for the mission. The engine has to withstand high shock loads during launching from a mobile launcher and has to climb to the designated altitude within a specified time. To meet these requirements the engine needs to deliver required power while operating at its maximum speed during take-off and climb. Therefore qualification of a Wankel rotary engine for this type of application is a great challenge and needs thorough study of its component durability and engine performance and reliability. This paper presents the various qualification tests stipulated on the components, systems and on engine to establish its performance, integrity and reliability. The paper also highlights the basis of clearing the engine for its first flight. Engine made its maiden flight successfully on an UAV platform exhibiting satisfactory performance.

Introduction

Wankel Rotary Engines are widely used all over the world since the middle of 20th century for automobiles. Because of its advantages like low vibration level, high power weight ratio and fewer moving parts compared to conventional four stroke reciprocating engine, it has become a popular choice to power Unmanned Aerial Vehicles (UAV) [1]. The present study deals with a 40 kW rotary engine developed indigenously for UAV application. It should be capable of flying the UAV for specified mission profiles within its designated flight envelope. The take-off weight may include some logistic payloads or scientific equipments required for any specific mission. The UAV is generally launched from mobile launchers and engine has to withstand the high shock loads during launching and it has to climb to the designated altitude within a specified time. To satisfy these flight requirements, the engine needs to deliver full power while operating at its maximum speed for a considerable time covering take-off and climb. Therefore it is a great challenge to qualify the engine in ground and based on its performance and reliability clearing the engine for the first flight. This paper presents the various qualification tests stipulated on engine components, its various systems and finally on the full engine to validate its design and to establish its performance and reliability. The engine has undergone about 100 hours of ground tests and its performance in terms of power output, exhaust gas temperature and coolant temperature has been satisfactorily demonstrated. The engine prototypes are also subjected to about 50 hours of endurance runs, which the engine has successfully completed without any failure and problem. The tests also include 6 cycles of mission profile of the proposed first flight. The consistency in performance and reliability of the engine components during these endurance tests has become the basis for qualifying the engine for the first flight. Subsequently the engine has made its maiden flight successfully on an UAV platform being airborne for over 30 minutes and exhibiting satisfactory performance.

Engine Configuration

The Wankel engine under study is a four-stroke, spark ignition, rotary combustion, single rotor with liquid-cooled housings and air-cooled rotor internal combustion engine. The engine displacement area is about 325 cc with a compression ratio of 9.2 and is designed to develop 41 kW power at max speed at sea level condition. The external view of the engine is shown in Fig.1.

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Fig.1 View of the Wankel Engine

Fig.2 Engine Cross-Sectional View

The major components of a rotary Wankel engine are rotor a triangular shaped piston which houses apex and face seals and transmits power to the crankshaft through an off centerline pressure force, eccentric crankshaft which accepts the transmitted torque from the rotor to a purely rotational torque outside of the endplates [2]. The rotor housing is an epitrochoidal shaped internal housing that, when mated with the trochoidal rotor, contains and separates the intake stroke, compression stroke, ignition, power stroke and exhaust. The rotor gear is housed within the rotor which serves to maintain engine timing through meshing with the rear gear and contact at each of the apex seals with the housing. The traditional Wankel engine contains both apex seals and some configuration of face seals on the side of the rotor. The primary purpose of the seals is to separate the three chambers, contain combustion, and to insure adequate compression ratio.

Apex seals span the rotor from end-plate to end-plate at all three tips of the rotor. These seals are typically spring backed and are the primary sealing mechanism for rotary type engines. The engine also comprises of various systems and accessories like ignition system, fuel system, and lubrication pump and drive system for pump, radiator and thermostat, drives for blower and coolant pump etc. The engine cross-sectional view is shown in Fig.2.

Engine Qualification

Component/System Level Tests

Component level or system level testing plays an important role in the process of engine qualification. It is pre-requisite to the engine testing in any engine development program. These are intended for evaluation of performance, structural integrity and reliability of components, sub-systems and systems to fulfill preliminary flight rating test (PFRT) requirements, which may not be possible during engine tests [3]. In the present case, performance tests of radiator, thermostat, ignition system; oil pump and fuel pump were carried out in stand-alone mode at design and off-design conditions and found satisfactory.

Acceptance test procedures are strictly followed to qualify the structural components like various engine housings, rotor and eccentric shaft. Selection of material to achieve the design power to weight ratio is very critical. The components manufactured should be of high quality aeronautical standard and manufacturing processes need to be evaluated stage-by-stage and freezed finally. Various inspection techniques should be followed to ensure the quality such as chemical analysis to confirm the chemical composition of the material, metalography to ensure freedom from micro/macro structure abnormalities and ultrasonic or radiographic tests to detect internal cracks or defects prior to clearance for assembly. For proper functioning of the engine, fits and clearances should be formulated for different sub-assemblies and assemblies and assembly procedures and techniques should be evolved. The engine should adhere to the permissible overall dimensions for its fitment to the intended platform.

Engine Tests

Performance Test

This is the first phase of testing for qualification of the engine. During this phase engine compression check, motoring test, dynamometer test and running-in tests are carried out. The developmental engine is subjected to run with all its accessories and systems at different engine speeds. Design deficiency if any or engine malfunction due to component mismatch are identified at this stage and are addressed before proceeding further. Wankel engines generally encountered failures in bearing and its mounting, apex seal and springs [4][5]. Selection of better bearing and improvements in fits and tolerances prove very effective in eliminating these problems. Engine is then subjected to performance evaluation tests and exhibited satisfactory performance.

Endurance Test

This contains various test requirements and their schedule such as compression check test, motoring test, dynamometer test, engine running-in tests and endurance test. A typical endurance cycles defined for this engine is shown in Fig.3. In subsequent cycles, the cycle duration is increased to 160 minutes with dwell period at max speed progressively increasing.

Mission Cycle Test

The proposed mission for first flight is presented in Fig.4. Based on this flight plan and mission profile of targeted UAV, endurance mission cycle was defined for the Wankel engine as shown in Fig.5. The engine was subjected to 6 such cycles at test bed prior to its clearance for first flight.

Clearance for Maiden Flight

Provisional flight clearance for Wankel rotary engine is issued based on its performance and reliability and successful completion of all tests as per the compliance matrix given in Table-1.

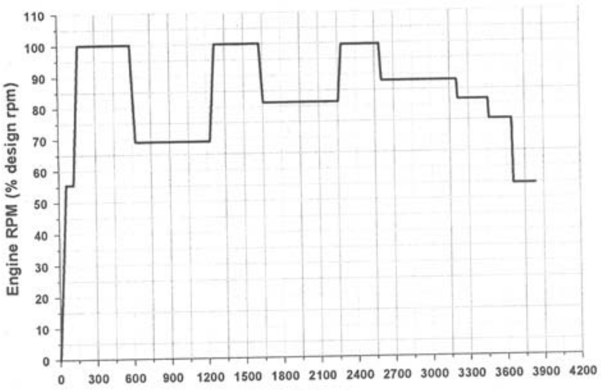

Fig.3 Typical Endurance Test Cycle

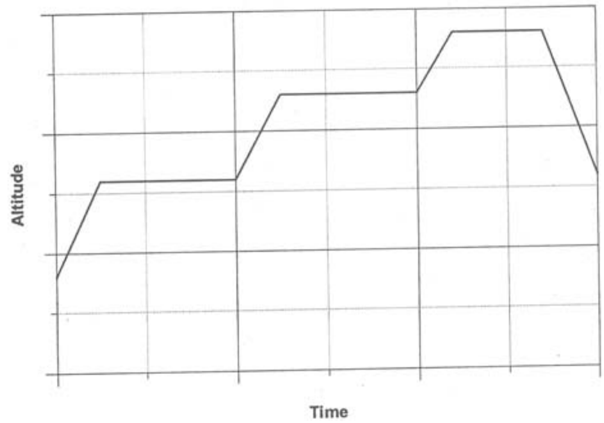

Fig.4 Mission Profile for First Flight

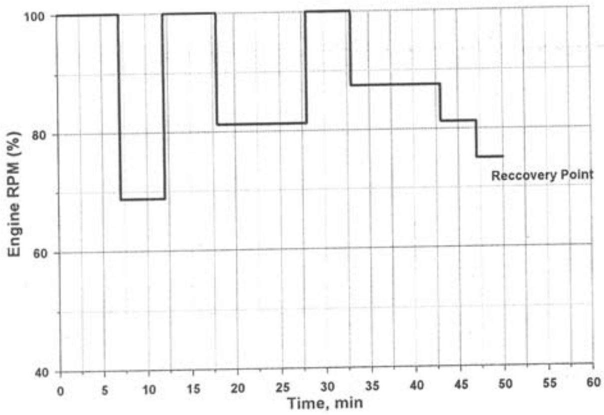

Fig.5 Mission Cycle Test of Wankel Engine

Performance

The engine prototypes have run for about 100 hours prior to its first flight. The engine performance parameters such as power output and EGT are satisfactorily demonstrated during ground test bed trials as presented in Figs. 6 and 7. The power output is very satisfactory while EGT is well within the specified limit [6]. The coolant temperature being a critical parameter has also been demonstrated to be within the specified limit on ground as shown in Fig.8. The non dimensional temperatures are expressed as the ratio of measured temperature to the specified limit by the designer.

Reliability

Two engine prototypes with similar standard of preparation have undergone about 50 hours of endurance runs without any failure or problem. One of the prototypes has endured for 16 hours during its 20 hours of test. Similarly,

Table-1 : Compliance Matrix

Sl. No.	Test Requirements
1	Compression check test carried out
2	Motoring test carried out
3	Altitude performance of engine is estimated based on ground test data
4	Engine performance with flight propellor and ground propellor carried out
5	Performance test carried out at system level for Radiator, Thermostat and Ignition system at design and off-design conditions
6	RPM is within acceptable limit of 5% during Ignition drop check
7	EGT and coolant temperature within specified limit
8	Vibration survey without shcok mount is well within the limit of 10 g rms
9	Engine starting satisfactory at launch attitude
10	Engine integrity and performance found satisfactory during 50 hours of endurance test
11	Engine behavior during 6 cycles of endurance tests simulating mission profile found satisfactory
12	Engine Airframe integration check found OK

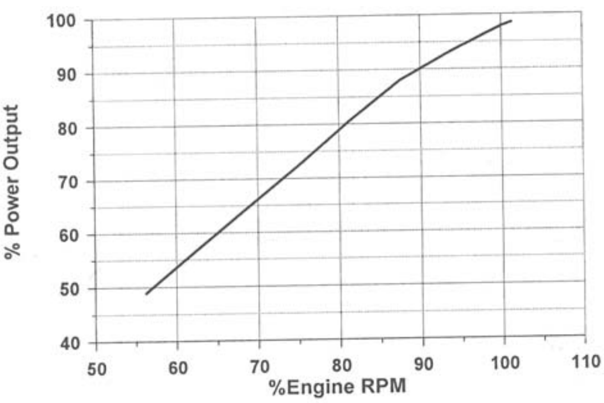

Fig.6 Engine Power Output

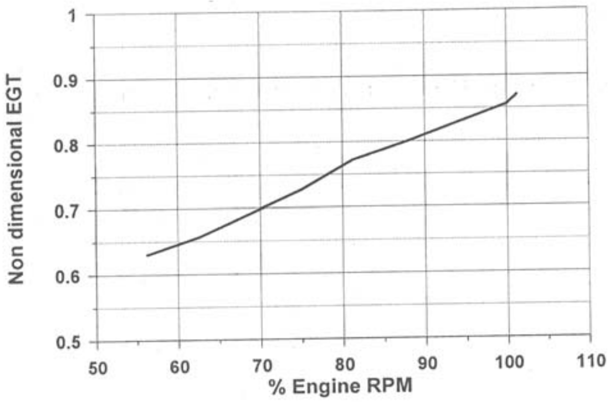

Fig.7 Exhaust Gas Temperature Measurements

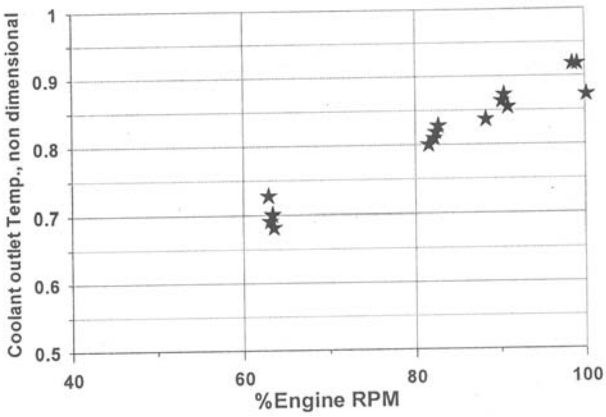

Fig.8 Demonstration of Coolant Outlet Temperature

the other prototype has undergone 34 hours of endurance tests out of which 5 hours (50 minutes x 6 cycles) simulating mission profile of the proposed first flight. The engine has dwelled at 100% rpm for 1 hour 48 minutes during the 5 hours of mission cycle testing. The consistency of performance and reliability of the engine components during these 50 hours of endurance tests has made the engine to qualify for first flight on the UAV.

Conclusion

It is a great challenge to qualify a Wankel engine for flight in UAV platform. The engine needs to demonstrate its capability and performance in a series of ground tests on its components, systems and integrated engine. The consistency of performance and reliability of the engine components during its 50 hours of endurance tests has become the basis for qualifying the engine for first flight.

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