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Gas Turbine Builders Association

Code of Practice for the Safe Operation of Model Gas Turbines

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Contributors

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Foreword

This Code of Practice has been prepared by members of the Gas Turbine Builders Association and is submitted in good faith to promote the safe design, building and operation of small gas turbines. The content of the Code is drawn from the collective knowledge of those individuals who, from the inception of the GTBA in 1995, have amassed significant experience in designing, building and operating gas turbines intended for a wide range of applications, including model aircraft, boats, land vehicles and auxiliary power generation.

Whilst every effort has been made to avoid errors and omissions, the authors cannot be held responsible for any eventuality arising from the application of this code. The safe operation of any gas turbine must remain the sole responsibility of the operator / remote pilot.

Definitions

Persons complying with the requirements of the Code must be aware that throughout the Code there are certain words which have specific meanings, defined as follows:-

'must' - Indicates an absolute obligation to comply. There are no circumstances under which the requirement could be relaxed.

'should' / 'strongly recommended' - Indicates an obligation to comply so far as is practicable but allows a relaxation of the requirement under exceptional circumstances. There has to be a very good reason why the requirement is not complied with.

'may' / 'highly recommended' - Indicates a preferred course of action, based on collective experience. Non-compliance is not expected to result in an unsafe situation.

Introduction

The guidance given in this document is presented in a form relevant to members of the GTBA, as well as the needs of individuals and groups (such as model clubs). Topics are presented here in a logical order for the achievement of the safe and competent design, building and operation of gas turbines and gas turbine powered application, whether on land, water or in the air.

Additional guidance and examples, in respect of the clauses detailed in this Code of Practice, are provided in the Appendix to The Code of Practice Issue No.10.

Information about hazardous materials as well as specific guidance on safety issues relating to different gas turbine engine arrangements are also covered in the Appendix to The Code of Practice Issue No.10.

Where appropriate, notes recommending referral to the Appendix to The Code of Practice Issue No.10, for further guidance and information, are included against relevant clauses.

Individuals keen to learn more about the safe design, construction and operation of model gas turbine engines are highly recommended to join the GTBA. Joining information can be found at https://www.gtba.co.uk/ and then click on the 'Apply for Membership' tab.

Gas turbine engines and models powered by them share many of the safety issues of conventional model power-plants. Those embarking upon the construction of a gas turbine, or a model powered by such an engine, should first make themselves familiar with conventional model power-plant safety issues, as detailed in (for example) the BMFA handbook relating to model aircraft. Specific safety issues relating to gas turbines in particular are as follows: -

a) Danger of burns or damage caused by hot exhaust gases.

b) Danger of fire after a crash, ignited by hot components and made more serious by the relatively high fuel loads commonly carried.

c) Danger of fire caused by overheating as a result of poor start-up procedures or engine failure.

d) Danger of fire or explosion caused by mishandling of liquid propane or similar fuels.

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e) Dangers relating to the relatively large size, power and wing loading, in the case of turbine powered model aircraft. These dangers are of course shared with many other large, powerful models.

f) Problems of ground handling relating to the relatively high idle thrust of some gas turbine engines.

g) Risk of injury caused by engine parts that may be ejected at high velocity after engine failure.

h) Risk of hearing damage to persons in either close proximity to operating engines over prolonged periods or as a result of regular exposure.

i) Risk of the ingestion of body extremities (fingers, long hair) and loose clothing though the engine intake when a gas turbine is running.

To prevent or minimise risk from all of these possibilities there are seven approaches.

i. Ensure that operators and/or remote pilots have a high level of skill, knowledge, and experience to enable them to avoid dangerous situations.

ii. Ensure that failures and incidents happen as infrequently as possible by paying detailed attention to reliability issues and by careful, systematic design procedures, operational procedures and maintenance.

iii. Provide fail safe and cut-off mechanisms whenever practicable to ensure that failures follow a "low risk" path.

iv. Run the engine at a conservative maximum operating power rating to provide a safety margin in case of over-speed or over-temperature.

v. Design the outer casing of the engine to provide containment in the event of disintegration of the rotating parts.

vi. Pay attention to where and when you operate gas turbine powered models (or engine on a test stand) to ensure the safety of people, property and the environment.

vii. Ensure anyone in close proximity to a running gas turbine wears appropriate clothing and safety protection equipment - e.g. close fitting garments and ear defenders.

Note that none of these approaches should be taken too far, as it may compromise other factors. For example an over engineered and conservatively rated engine for use in a model aircraft could well result in an model with a poor thrust to weight ratio and a high wing loading, which would be more likely to stall and crash - perhaps causing injury. The total safety approach is therefore a compromise between each of these factors, although (vi) remains the most critical.

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The Gas Turbine Builders Association

Code of Practice

1. Design

1.1 All engines, however designed, must be subject to rigorous testing before operation in public, to establish a service history and to ensure that all components will sustain the stresses arising from the engine's operation. *(see Appendix1 A1.1 for guidance)*

1.2 All materials must be suitable for the use to which they will be put. *(see Appendix1 A1.2 and Appendix 2 for guidance)*

1.3 Where a design has been published or an engine is being manufactured commercially, no inferior materials should be substituted for those specified, nor modifications made to any component that is subject to significant stress, before seeking the designer's or manufacturer's approval.

2. Engine Protection and Control

2.1 Engines under development must be rigorously tested and during such testing must be protected against exceeding design parameters, especially those of speed and temperature.

2.2 Engines must be prevented from exceeding safe operating speeds and temperatures by limiting the maximum fuel flow by appropriate fail-safe methods. *(see Appendix 1 A2.2 for guidance)*

2.3 Under-speed protection should be incorporated in the engine control system. *(see Appendix 1 A2.3 for guidance)*

2.4 Engine control systems should be designed to prevent engines operating beyond permissible temperatures during normal operation. *(see Appendix 1 A2.4 for guidance)*

2.5 Engine protection systems should, wherever possible, return engines to safe operating conditions and only shut engines down completely when no other option remains.

2.6 Start up and static running

Where engines are being run statically, on a test bench or during start-up procedures in a model aircraft, boat or land vehicle, a manual fuel shutoff mechanism must be provided. This mechanism may take any suitable form, such as a fuel valve or electrical switch to cut power to the pump, but must be independent of the normal throttle control. Where a fuel valve is used in a liquid fuel system, it should be located in the low pressure part of the fuel line, between the tank and the pump. In a self pressurised (gas) system it should be located as close as possible to the engine to ensure a rapid shutdown. *(see Appendix 1 A2.6 & A2.7 for guidance)*

2.7 Operation under remote control

The following paragraphs apply only to engines that are operated remotely, such that the manual control, referred to in (2.6) above, is inaccessible.

2.7.1 **Shutdown mechanisms.** *(see Appendix 1 A2.6 & A2.7 for guidance)*

The control system must incorporate two independent fuel shutdown mechanisms, both of which must be capable of being remotely operated independently of each other. One of these will be the valve or pump speed controller, connected to the throttle control channel.

The other could be a servo operated valve in the fuel line, in which case the considerations with regard to positioning given in (2.6) above will apply. Alternatively a relay or additional transistor in the pump circuit may be used.

Activation of the second shutdown mechanism should be via a separate channel to that controlling the throttle, unless the second shutoff mechanism is specifically incorporated in an Engine Control Unit (ECU) or Full Authority Digital Engine Controller (FADEC) by means of a fuel shutoff servo or relay output.

2.7.2 Failsafe operation. *(see Appendix 1 A2.6 & A2.7 for guidance)*

Due to the high fuel load and the fact that gas turbine engines have a continuously lit flame in the combustion chamber when operating, there is a very high risk of fire in the event a model crashes.

Gas turbine powered models must incorporate a radio failsafe which will shutdown the engine (preferably via both of the mechanisms described in (2.7.1) above) in the event of loss of signal. It is acceptable for there to be a short delay (of between one and three seconds) between loss of signal and failsafe activation.

A failsafe function is incorporated in most modern radio control systems. This failsafe must be correctly programmed and under no circumstance should it be left at the default setting.

Where both fuel shutoff mechanisms are incorporated in a single control unit, such as an ECU or FADEC, then this unit should be configured so that an internal failure of the unit will activate at least one of the shutdown mechanisms.

The settings and correct operation of failsafe devices must be checked prior to each operating session, as well as following any changes made to the remote control system.

2.7.3 Kill switch *(see Appendix 1 A2.6 & A2.7 for guidance)*

Radio transmitters used for the control of gas turbine powered models must incorporate a control that will instantly shut the engine down when operated. This control should be easily accessible and must operate in a single action, independently of the throttle lever.

It is highly recommended that a guard or fence be installed around or over the switch, to prevent inadvertent activation, potentially leading to a dangerous situation arising. The guard or fence must not limit the operators ability to rapidly activate the switch in the event of an emergency.

3. Fuel Systems

3.1 Where possible fuel tank(s) should be located in a separate compartment from the engine. The tank(s) must be protected from the heat of the engine.

3.2 The fuel tank(s) and fuel system components must be adequately secured and protected to minimise the risk of rupture in the event of a crash.

3.3 The use of flexible fuel tanks, including plasma bags, are not recommended. If such tanks are used they must be placed in a separate compartment from the engine, to eliminate the possibility of ingestion, or in a protective ‘shell’, the construction of which shall not compromise the integrity of the tank, and be leak-proof and be fitted with a drain to route spilled fuel overboard.

3.4 Fuel lines, connectors and associated equipment must be tested to show the ability to withstand the pressure imposed without leakage or failure when the engine is operating at maximum safe speed. A drainage hole should be made in every part of the model where fuel could collect as a result of a leak. *(see Appendix 1 A3.4 for guidance)*

3.5 Fuel lines and associated equipment must be made from materials suitable for the intended service and which can adequately cope with the environmental conditions of the installation. For example, silicon tubing must not be used for fuel lines, because it rapidly degrades when in contact with kerosene (jet fuel). *(see Appendix 1 A3.5 & A4.8 for further guidance)*

3.6 Separate feed lines for starting gas and liquid fuel should be used to avoid the dangers of migration of the starter gas back into the liquid fuel system. *(see Appendix 1 A3.6 for guidance)*

3.7 The fuel tanks of liquid fuelled engines should not be subjected to any form of high pressure pressurisation. Low pressure pressurisation is permitted, in systems of a suitable pressure rating, up to

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a maximum of 5 psi (0.35 bar) for the purpose of aiding fuel movement between tanks and the fuel pump(s). *(see Appendix 1 A3.7 for further guidance)*

3.8 Tanks for gaseous fuel are pressure vessels and must be certified as such.

3.9 All tanks and fuel lines should be regularly checked for deterioration and renewed where necessary, paying particular attention to the possibility of hardening of flexible pipes and seals in the vicinity of joints that are subjected to high pressures

3.10 Only clean, filtered fuel should be used and measures taken to prevent contamination of fuel systems. It is strongly recommended that fuel be filtered when filling the storage vessel. Filters should also be fitted between the storage vessel and model's tank, as well as between the model's tank and the engine. *(see Appendix 1 A3.10 & A4.6 for further guidance)*

4. Lubrication Systems

There are two commonly employed lubrication systems. The first is to mix a small quantity of lubrication oil into the liquid fuel. Some of this fuel/lubricant mix is diverted, via a flow restrictor, to the bearings, whilst the rest is delivered direct to the combustion chamber.

The alternative, is to use separate lubrication and fuel systems where, typically, neat lubricant is contained in a small reservoir and pressure fed to the bearings. The fuel for combustion is contained separately in the main fuel tank and only delivered to the combustion chamber by the fuel pump.

4.1 For separate lubrication systems, the oil reservoir should be positioned so that the oil level can be quickly and easily determined.

4.2 Whether separate or mixed, the lubrication system must be designed, or measures taken by the operator, so that, when not in use, oil cannot migrate, due to siphoning or thermal expansion, into the engine.

4.3 Whether separate or mixed, the reservoir or tee junction and flow restrictor should be positioned in close proximity to the engine, or the oil line to the engine should be primed, to minimise delay in establishing the lubrication supply during starting.

4.4 For aircraft applications, the lubrication system should be able to maintain a continuous supply, or keep interruptions, arising from aircraft manoeuvres, to a minimum.

4.5 Whether separate or mixed, the oil flow must be controlled to give the appropriate oil consumption, as specified by the designer or manufacturer. *(see Appendix 1 A4.5 for guidance)*

4.6 A suitable filter should be fitted upstream of any restrictor or flow regulator. *(see Appendix 1 A3.10 & A4.6 for further guidance)*

4.7 An appropriate oil suitable for use in gas turbines should be used. The grade of oil used should be that specified by the designer or manufacturer. Special oils designed for full size aviation gas turbine operation, may contain hazardous chemicals such as organophosphates. *(see Appendix 2 for guidance)*

4.8 Oil lines and associated equipment must be made from materials suitable for the intended service and which can withstand the environmental conditions of the installation. Checks must be made periodically to ensure that lines and equipment are not subject to degradation by ageing. *(see Appendix 1 A3.5 & A4.8 for further guidance)*

4.9 Oil lines and associated equipment must be able to withstand the maximum operating pressure of the lubrication system without leakage or failure.

4.10 Means should be available to confirm that oil flow has been established once an engine has been started. *(see Appendix 1 A4.10 for guidance)*

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5. Installation

Model gas turbine engines induce a significant volume of air when operating and can be considered likened to a vacuum cleaner, sucking in any loose objects in the immediate vicinity of the intake.

5.1 Engines must be securely mounted and attached in a manner to ensure that they remain so for all operating regimes.

5.2 All components, such as pipes, lines, wires and control cables etc, anywhere in the vicinity of the engine intake must be adequately secured to prevent ingestion.

5.3 It is highly recommended that gas turbine engines be protected from Foreign Object Damage (FOD) by suitable screens or by virtue of the position of the air intake(s). *(see Appendix 1 A5.3 for guidance)*

5.4 Pipes, lines, wires, control cables etc., should be routed away from the hot parts of the engine or be suitable for the temperatures arising.

5.5 Until experience has been gained in operating gas turbines, engines powering aircraft or other vehicles, should be mounted externally.

5.6 For internal turbine installations, adequate heat protection from the hot exhaust gases and radiant heat from the engine body must be provided. *(see Appendix 1 A5.6 for guidance)*

5.7 The idle thrust of a gas turbine can be very high. If the model does not remain stationary with the engine at idle, positive measures must be taken to restrain it. Note that the behaviour of models may vary depending upon the nature of the runway / road / surface on which they are operating.

6. Operating Safety

6.1 Fire

6.1.1 An effective, operational, Carbon Dioxide or other suitable fire extinguisher and a trained and competent operator must be present during all engine runs. *(see Appendix 1 A6.1.1(.a to .i) for further guidance)*

6.1.2 Gas turbines must not be run if the surrounding environment presents a fire risk unless adequate precautions are taken to negate the risk. *(see Appendix 1 A6.1.2 for guidance)*

6.1.3 Smoking or other sources of ignition are prohibited within a radius of 50 meters of decanting, venting or fuelling of flammable gases. Signs designating the fuelling areas should be displayed if a gas-fuelled engine is being operated in public. *(see Appendix 1 A6.1.3 for guidance)*

6.1.4 Any venting of liquefied gas must be conducted in a safe manner, in particular venting must not be undertaken within a radius of 50 metres, and never upwind, of any other gas turbine which is running.

6.1.5 All fuels must be contained in appropriate vessels clearly marked with a description of the contents. *(see Appendix 1 A6.1.5 and Appendix 2 for guidance)*

6.1.6 Engine Fires constitute a major hazard and awareness of potential causes must be fully understood, they include:-

6.1.6.1 Residual fuel in the engine leading to a "wet start". *(see Appendix 1 A6.1.6.1 & A6.1.6.7 for guidance)*
6.1.6.2 Incorrect starting procedure.
6.1.6.3 Turbine or compressor rubbing.
6.1.6.4 Excess lubrication oil introduced during the priming of the lubrication system.
6.1.6.5 Debris partially blocking the air intake, reducing compressor performance.
6.1.6.6 Blocked fuel injectors.
6.1.6.7 Expansion of fuel into the engine after shut-down of the fuel pump. *(see Appendix 1 A6.1.6.1 & A6.1.6.7 for guidance)*
6.1.6.8 Tail-pipes pointing into wind at start-up.

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6.2. Test Running

6.2.1 A check list procedure should be used prior to and during any engine runs. *(see Appendix 1 A6.2.1 for guidance)*

6.2.2 Initial testing of prototype engines should not be conducted in a public place; only persons essential to the operation of the engine or performing safety duties should be present.

6.2.3 A test bed should be used with the engine securely fixed and constrained and located in a controlled area.

6.2.4 The test area must be adequately ventilated.

6.2.5 During protracted ground running adequate eye and ear protection should be worn.

6.2.6 Mechanical abnormalities indicated at any time by vibration, unusual or excessive noise, excessive temperature, over-speed or any other unexpected phenomena must be investigated and corrected before the engine is re-started. *(see Appendix 1 A6.2.6 for guidance)*

6.2.7 During ground running, particularly in built-up areas, due regard must be given to preventing noise nuisance.

6.3. Operating in Public

6.3.1 An engine must only be run in public after the operator is fully familiar and competent with its operation.

6.3.2 All engine running must be conducted at a safe distance from non essential personnel with the jet pipe always facing away from them. When wind direction requires that tailpipes are directed towards people or property (arising from 6.1.6.8) the distance from the tailpipe to people or property must be increased to the point where jet blast and temperature effects are of no consequence.

6.3.3 No person must be allowed to stand close to an operating engine in the rotational plane of the compressor or turbine. *(see Appendix 1 A6.3.3 and Appendix 3 for further guidance)*

6.3.4 Particular attention must be paid to site husbandry and cleanliness to reduce the risk of foreign object damage to the gas turbine by ingestion and to prevent any loose articles being carried in the jet efflux.

6.4 Operating Instructions

6.4.1 The manufacturer's or designer's operating instructions must be followed at all times.

7. Maintenance *(see Appendix 1 A7 for guidance)*

7.1 Engine maintenance must be regularly performed. The frequency and detail of checks and actions will depend upon engine installation, experience and any manufacturer's instructions; and will vary between external inspections prior to starting to major dismantling and inspection of the engine at predetermined intervals.

7.2 As a minimum the following checks must be made prior to every engine start:-

7.2.1 Visual check of the fuel and oil systems for leaks.

7.2.2 Visual inspection of the compressor and turbine wheels for any signs of damage. Minor damage to a compressor blade, visible from the inlet, could indicate serious foreign object damage within the engine and must be investigated further before the engine is again operated.

7.2.3 Visual inspection of filters (if accessible and applicable) to ensure that they are contaminant free.

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7.3 As a minimum, the following checks must be undertaken at regular intervals, preferably prior to each operating session:-

7.3.1 Cleaning all fuel and oil filters.

7.3.2 Checking the fuel and oil systems for blockages.

7.3.3 Checking of the engine and systems installation for deterioration, damage and insecurity.

7.4 There are many benefits in keeping an individual engine operating log, in which would be recorded:-

7.4.1 Dates on which the engine was run.

7.4.2 Length of time engine was run.

7.4.3 Total running time accumulated to date.

7.4.4 Date and details of any service, maintenance or repair work carried out, including details of parts replaced.

7.4.5 Any other details which would be of value in creating a service history and establishing service intervals.

8. Operator Qualifications

8.1 Inexperienced gas turbine operators should, wherever possible, seek the assistance of an experienced gas turbine operator before running a gas turbine. **If in doubt - seek help.**

8.2 In order that the operator shall gain experience with the start-up procedure and the running characteristics of the engine, initial runs of any gas turbine must be carried out on a test stand. The operator must not attempt any operation of the engine in public until such experience has been gained.

9. Flying *(see Appendix 1 A9 for guidance)*

Operators and Remote Pilots in the UK must comply with the requirements of the Civil Aviation Authority publication CAP 722F “Model Aircraft Operations Policy and Guidance”.

British Model Flying Association and British Drone Flyers members may alternatively comply with the CAA issued Article 16 Authorisation “A guide to model aircraft & drone flying” but in so doing must also abide by the requirements set out in the current issue of the BMFA Members Handbook.

The Remote Pilot of a model aircraft is that person who is operating the radio control transmitter whilst an aircraft is being prepared for or undertaking flight. The ultimate responsibility for the safe operation of a model aircraft rests with the Remote Pilot.

All Remote Pilots are expected to be competent to operate their aircraft. Remote Pilots of gas turbine powered model aircraft are strongly recommended to attain a recognised standard of flying proficiency at least equivalent to the BMFA Power Achievement Scheme 'B' Certificate before attempting to fly a gas turbine powered aircraft unsupervised. Persons supervising gas turbine flying activities should be qualified to a standard equivalent to the BMFA Power Achievement Scheme 'B' Certificate.

Gas turbine operation requires that Remote Pilots must be aware of the flying characteristics which arise from the application of gas turbine power. Paying particular attention to:-

9.1 The delay in response to opening and closing the throttle.

9.2 High airspeeds that can result from the high velocity thrust generated by a gas turbine, which does not diminish with increasing model aircraft speed.

9.3 The high thrust at engine idle speed which makes for difficulties in slowing the aircraft down for landing.