DESIGN AND ANALYSIS OF MICRO GAS TURBINE

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ABSTRACT

The objective of this project is to design a micro gas turbine and too make a static analysis on its turbine and compressor and to find out the results of maximum stress and total deformation in the turbine and the compressor. This project does not include a CFD analysis on the turbine and compressor which is necessary to optimise the design. Only a mean line design process is discussed in this project.

Keywords: Turbine, blades, nozzles and centrifugal compressors

1. INTRODUCTION

To develop a design methodology for a low pressure ratio centrifugal compressor, nozzle and axial turbine.

Scope of the project:

- *Design of centrifugal compressor*
- *Design of nozzle*
- *Design of axial turbine*
- *Static analysis and of axial turbine and centrifugal compressor.*

The project deals with the design methodology for the design of a Centrifugal Compressor. The 1D design gives an initial design solution on the basis of which it can be decided if a complete CFD analysis of the compressor is required.

The objective of this project is to design a micro gas turbine and too make a static analysis on its turbine and compressor and to find out the results of maximum stress and total deformation in the turbine and the compressor.

This project does not include a CFD analysis on the turbine and compressor which is necessary to optimise the design. Only a mean line design process is discussed in this project.

2. LITERATURE SURVEY

In 1922, the American engineer and teacher Harvey N Davis had patented an expansion turbine of unusual thermodynamic concept. This turbine was intended to have several nozzle blocks each receiving a stream of gas from different temperature level of high pressure side of the main heat exchanger of a liquefaction apparatus.

First successful commercial turbine developed in Germany which uses an axial flow single stage impulse machine. Later in the year 1936 it was replaced by an inward radial flow turbine based on a patent by an Italian inventor, Guido Zerkowitz.

India has been lagging behind the rest of the world in this field of research and development. Still, significant progress has been made during the past two decades. In CMERI Durgapur, Jadeja developed an inward flow radial turbine supported on gas bearings for cryogenic plants. The device gave stable rotation at about 40,000 rpm. The programme was, however, discontinued before any significant progress could be achieved. Another programme at IIT Kharagpur developed a turbo expander unit by using aerostatic thrust and journal bearings which had a working speed up to 80,000 rpm. Recently Cryogenic Technology Division, BARC developed Helium refrigerator capable of producing 1 kW at 20K temperature.

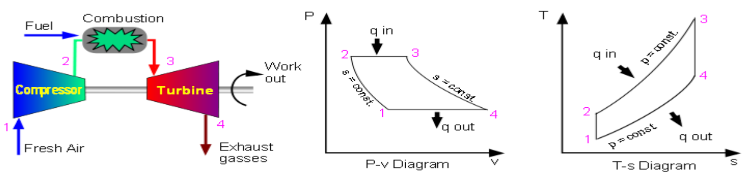
3. INTRODUCTION TO DESIGN PROCESS

The classical turbo-machinery design process begins with mean line performance modelling calculations, once a cycle specification has been set freezes the design flow, speed and stage pressure ratio or head rise.

When basic mean-line velocity triangles have been suitable optimized then blading methods are used to design the required blade shapes. They may involve, either direct or inverse computational methods or they should involve both flow solvers and fundamental design rules.When appropriate passage contours and blade shapes, are obtained it is reasonable to go for final levels of design optimization

4. GAS TURBINE

A gas turbine is a rotating engine that extracts energy from a flow of combustion gases that result from the ignition of compressed air and a fuel (either a gas or liquid, most commonly natural gas). It has an upstream compressor module coupled to a downstream turbine module, and a combustion chamber(s) module (with igniter[s]) in between. Energy is added to the gas stream in the combustor, where air is mixed with fuel and ignited. Combustion increases the temperature, velocity, and volume of the gas flow. This is directed through a nozzle over the turbine's blades, spinning the turbine and powering the compressor Energy is extracted in the form of shaft power, compressed air, and thrust, in any combination, and used to power aircraft, trains, ships, generators, and even tanks.

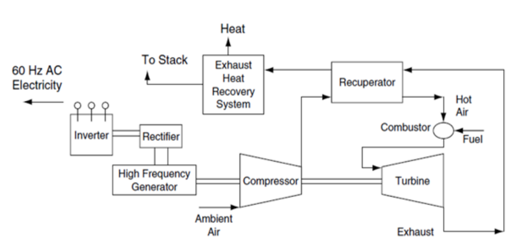


Idealized Brayton Cycle

4.1 Micro turbine

Micro turbines are small combustion turbines which are having output ranging from 2 kW to 500 kW. The Evolution is from automotive and truck turbochargers, auxiliary power units (APUs) for airplanes, and small jet engines. Micro turbines are a relatively new distributed generation technology which is used for stationary energy generation applications. Normally they are combustion turbine that produces both heat and electricity on a relatively small scale. A micro (gas) turbine engine consists of a radial inflow turbine, a combustor and a centrifugal compressor. It is used for outputting power as well as for rotating the compressor. Micro turbines are becoming widespread for distributed power and co-generation (Combined heat and power) applications. **They are one of the most promising technologies for powering hybrid electric vehicles**. They range from hand held units producing less than a kilowatt, to commercial sized systems that produce tens or hundreds of kilowatts. Part of their success is due to advances in electronics, which allows unattended operation and interfacing with the commercial power grid. Electronic power switching technology eliminates the need for the generator to be synchronized with the power grid. This allows the generator to be integrated with the turbine shaft, and to double as the starter motor**. They accept most commercial fuels, such as gasoline, natural gas, propane, diesel, and kerosene as well as renewable fuels such as E85, biodiesel and biogas.**

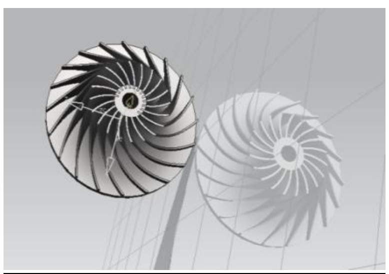
4.2 Thermodynamic Heat Cycle

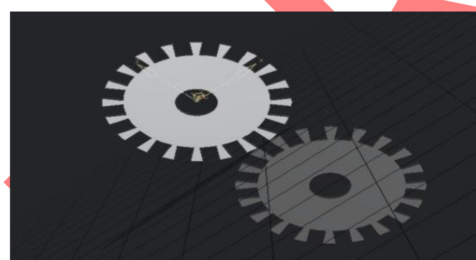


Microturbine based combined heat and power system

Pressure ratio is considerably lower when a recuperator is used. Consequently, for good power and efficiency, it is advantageous to operate the expansion turbine at the highest practical inlet temperature consistent with economic turbine blade materials and to operate the compressor with inlet air at the lowest temperature possible. The general trend in gas turbine advancement has been toward a combination of higher temperatures and pressures. However, inlet temperatures are generally limited to 1750°F or below to enable the use of relatively inexpensive materials for the turbine wheel and recuperator. 4:1 is the optimum pressure ration for best efficiency in recuperated turbines.

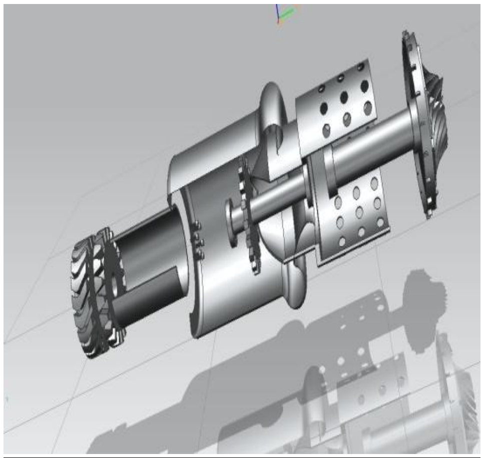
5. MODELLING OF A CENTRIFUGAL COMPRESSOR

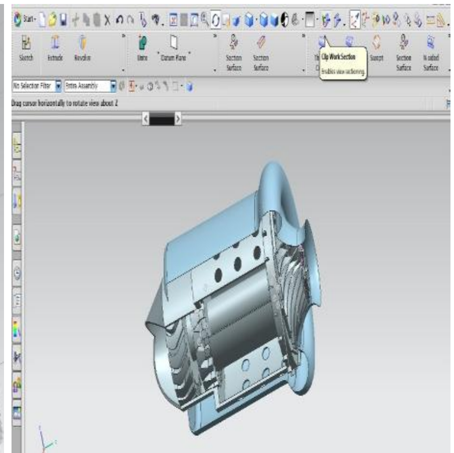




A circle is drawn on the x-z plane and is extruded along the y- axis about a distance of 3mm.A datum plane is created on the surface of the disk thus produced.

The profile for nozzle is drawn on this plane and this is extruded onto the circle and the material is removed, using Boolean subtract. This extrude is performed 1mm more than the required.An associative copy is then made of this feature (circular array) and we obtain the number of nozzles we require.Then a circle with the inside diameter of the nozzle is drawn, extruded and united with the previous circle.A hole is made on this nozzle for mounting it on the shaft using air bearings or magnetic bearings.





6 RESULTS AND DISCUSSIONS

Titanium Alloy

TABLE 1: Geometry

Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	E:\Project\compressor 2.igs
Type	Iges
Length Unit	Meters
Element Control	Program Controlled
Display	Part Color
Style	
Bounding Box	
Length X	50. mm
Length Y	15.005 mm
Length Z	50. mm
Properties	
Volume	9990.5 mm³
Mass	4.6156e-002 kg
Scale Factor Value	1.

Statistics	
Bodies	1
Active Bodies	1
Nodes	37739
Elements	20508
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No
Named Selection	No

Processing	
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\Amar\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure	Yes

and Symmetry Processing	

TABLE 2
Model (A4) > Geometry > Parts

Object Name	*Part 1*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Material	
Assignment	Titanium Alloy
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	50. mm
Length Y	15.005 mm
Length Z	50. mm
Properties	
Volume	9990.5 mm^3
Mass	4.6156e-002 kg
Centroid X	-5.2581e-004 mm
Centroid Y	4.0649 mm
Centroid Z	-2.2049e-003 mm
Moment of Inertia Ip1	5.4201 $kg \cdot mm^2$
Moment of Inertia Ip2	9.6012 $kg \cdot mm^2$
Moment of Inertia Ip3	5.4164 $kg \cdot mm^2$
Statistics	
Nodes	37739
Elements	20508
Mesh Metric	None

TABLE 3
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*

State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. mm
Origin Y	0. mm
Origin Z	0. mm
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

TABLE 4

Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size	Off
Function	
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Fine
Minimum Edge Length	0.652250 mm
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside	Program Controlled

Nodes	
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	37739
Elements	20508
Mesh Metric	None

TABLE 5: Static Structural (A5) Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS
	Mechanical
Options	
Environment Temperature	22. °C
Generate Input Only	No

TABLE 6
Model (A4) > Static Structural (A5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large	Off

Deflection	
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	E:\Project\Compressor analysis_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	nmm

TABLE 7
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Pressure*	*Pressure 2*	*Pressure 3*	*Pressure 4*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geomet	1 Face				

ry		
Definition		
Type	Fixed Support	Pressure
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System
X Component		0. MPa (ramped)
Y Component		-0.2 MPa (ramped)
Z Component		0. MPa (ramped)

Model (A4) > Static Structural (A5) > Pressure

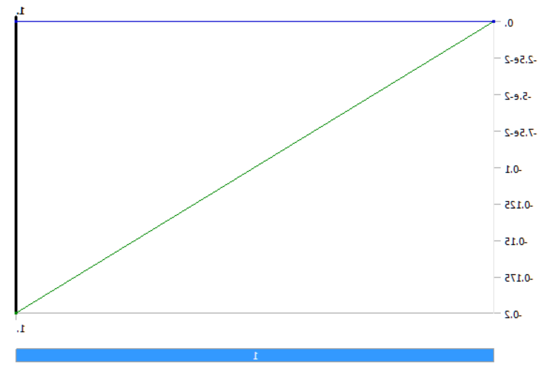


FIGURE 15
Model (A4) > Static Structural (A5) > Pressure 4

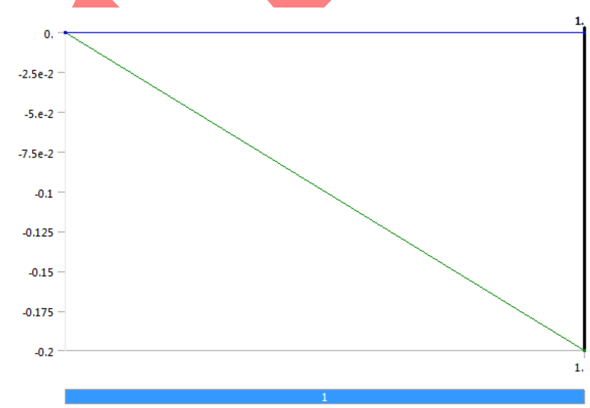


TABLE 8
Model (A4) > Static Structural (A5) > Loads

Object Name	*Pressure 5*	*Pressure 6*	*Pressure 7*	*Pressure 8*	*Pressure 9*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				

Geometry	1 Face
Definition	
Type	Pressure
Define By	Components
Coordinate System	Global Coordinate System
X Component	0. MPa (ramped)
Y Component	-0.2 MPa (ramped)
Z Component	0. MPa (ramped)
Suppressed	No

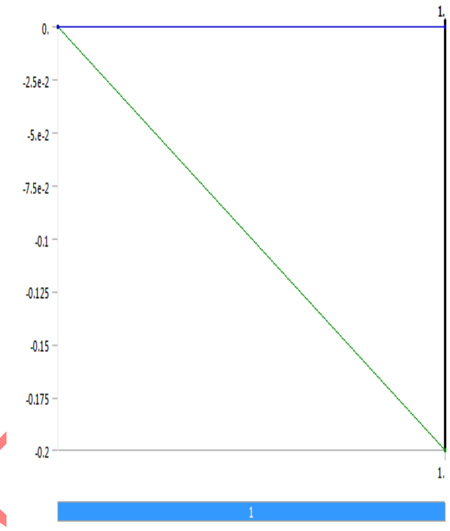


FIGURE 7
Model (A4) > Static Structural (A5) > Pressure 7

TABLE 9
Model (A4) > Static Structural (A5) > Loads

Object Name	*Pressure 10*	*Pressure 11*	*Pressure 12*	*Pressure 13*	*Pressure 14*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geometry	1 Face				
Definition					
Type	Pressure				
Define By	Components				
Coordinate	Global Coordinate System				

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System	
X Component	0. MPa (ramped)
Y Component	-0.2 MPa (ramped)
Z Component	0. MPa (ramped)
Suppressed	No

TABLE 10
Model (A4) > Static Structural (A5) > Loads

Object Name	*Pressure 15*	*Pressure 16*	*Pressure 17*	*Pressure 18*	*Pressure 19*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geometry	1 Face				
Definition					
Type	Pressure				
Define By	Components				
Coordinate System	Global Coordinate System				
X Component	0. MPa (ramped)				
Y Component	-0.2 MPa (ramped)				
Z Component	0. MPa (ramped)				
Suppressed	No				

Model (A4) > Static Structural (A5) > Pressure 15

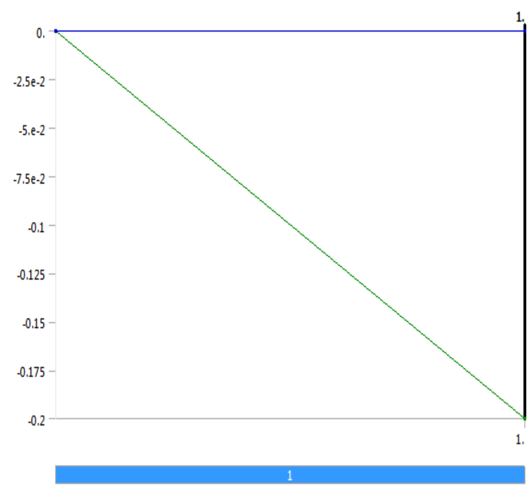

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Pressure 20*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Type	Pressure
Define By	Components
Coordinate System	Global Coordinate System
X Component	0. MPa (ramped)
Y Component	-0.2 MPa (ramped)
Z Component	0. MPa (ramped)
Suppressed	No

Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved

Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Stress*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	

Definition		
Type	Total Deformation	Equivalent (von-Mises) Stress
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Results		
Minimum	0. mm	4.2262e-002 MPa
Maximum	1.5471e-003 mm	9.4234 MPa
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	
Integration Point Results		
Display Option		Averaged

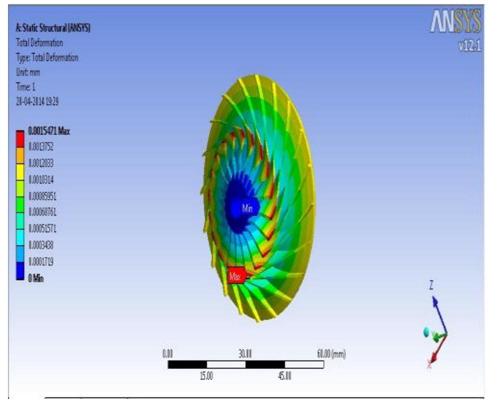

Figure 17

Compressor Total Deformation

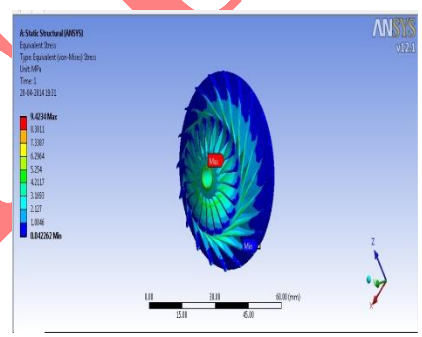

Figure 18

Compressor Stress Analysis

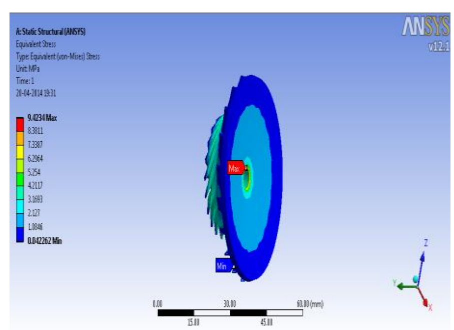

Figure 19

Compressor Stress Analysis

Material Data: Titanium Alloy

TABLE 15
Titanium Alloy > Constants

Density	4.62e-006 kg mm^-3
Coefficient of Thermal Expansion	9.4e-006 C^-1
Specific Heat	5.22e+005 mJ kg^-1 C^-1
Thermal Conductivity	2.19e-002 W mm^-1 C^-1
Resistivity	1.7e-003 ohm mm

TABLE 16
Titanium Alloy > Compressive Yield Strength

Compressive Yield Strength MPa
930

TABLE 17
Titanium Alloy > Tensile Yield Strength

Tensile Yield Strength MPa
930

TABLE 18
Titanium Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
1070

TABLE 19
Titanium Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

7 CONCLUSIONS

The work presented in the report is an attempt at designing a micro turbine of a required power. Extensive literature review was carried out to study the various aspects and applications of micro turbines.

A suitable design procedure was chosen from the available methods to design different parts of micro turbine. Unigraphics is used extensively for making parts with diff types of operations. Then all the parts are assembled for making a complete turbine in unigraphics Assembly section. Micro turbines are relatively new in the market and are attracting wide attention due to their varied applications. Development of a sophisticated engineering product like micro turbine is a continuous process. A lot of work is yet to be done on the design aspects before the micro turbine can be readied for market consumption. The design procedure has to take into various other parameters to make it suitable for practical applications. Also, manufacturing of such complex shapes of minute size is another ongoing research work. Further research into the design and manufacture process would result in production of even better micro turbines.
CFD analysis can be performed on the micro turbine developed using one dimensional mean line flow analysis, in order to optimize the design. The efficiency of the system for power generation can be increased by using a recuperator.

10 FUTURE SCOPES

From the design experience detailed in this report, conclusions and ideas for possible future work were made.
A main goal of any future project should be to increase power output of the micro-turbine. Possible methods to accomplish this include using modern airfoil shapes instead of flat flats for turbine blades and adding a fixed stator stage (pre-swirler) upstream of rotating turbine to direct inlet flow into turbine stage. Use different motors as generators might also change the power outputs.Development of composite materials having higher tensile strengths is a promising technology for the development of these components.The machining of the complicated micro components can be accomplished using MEMS technology. Since there is a significant development in MEMS technology, the production of these components using MEMS technology is quite possible.Combustion chambers can be developed to bear higher temperatures which leads to increase in power output.Engines will be developed to have lower specific fuel consumption by improving the fuel inlet nozzles.Burning fuel more cleanly with fewer emissions which will run more quietly is also possible. More air borne and ground engine-conditioning-

monitoring equipment will be used such as vibration and oil analysers and radiometer sensors to measure turbine blade temperature while the engine is operating.

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