


**BENEFITS OF IMPROVED HP TURBINE ACTIVE CLEARANCE CONTROL**

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*GE Aircraft Engines*


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***Benefits of Improve HP Turbine  
Active Clearance Control***

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## **Q** *NASA Propulsion 21 HP Turbine Clearance Control Study*

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### **Program Objective**

Develop a high-pressure turbine (HPT) active clearance control system (ACC) to increase HPT efficiency throughout the engine operation range thereby reducing emissions.

### **Technical Challenges**

- Minimize blade tip clearances through the entire engine operation
- Light blade tip to stator contact
- Reliable system

### **System Benefits**

- Reduce emissions
- Reduce exhaust gas temperature during take off conditions

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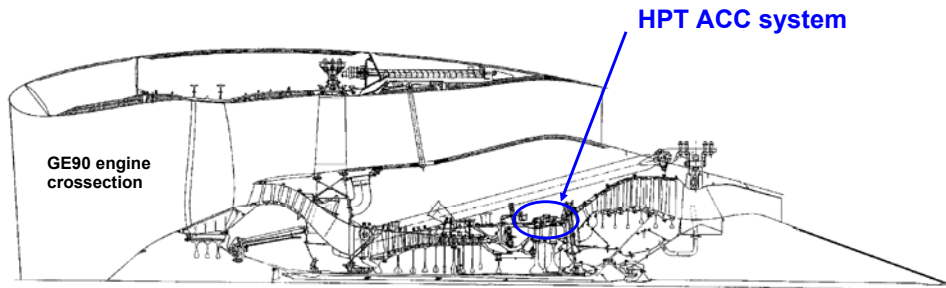
As part of the NASA Propulsion 21 program, GE Aircraft Engines was contracted to develop an improved high pressure turbine(HPT) active clearance control (ACC) system. The system is envisioned to minimize blade tip clearances to improve HPT efficiency throughout the engine operation range simultaneously reducing fuel consumption and emissions.

## **Q HP Turbine Active Clearance Control**

### **Background**

- NASA HPT Propulsion 21 ACC program was worked ~ Phase I and II
  - Studied existing and potential ACC concepts
  - Benched marked systems
  - Started scoring existing system against existing systems
  - Focused study on fast acting systems
    - Thermal actuated
    - Mechanically actuated
- This presentation deals with mechanical and thermal systems

## Q Potential System Benefits for a Long Haul Aircraft



### Average HPT Benefits

|                            |             |
|----------------------------|-------------|
| Efficiency                 | Up to 0.9%  |
| Fuel Burn Reduction        | Up to 0.95% |
| Emissions Reduction for 1% |             |
| NOx                        | 10%         |
| CO                         | 16%         |

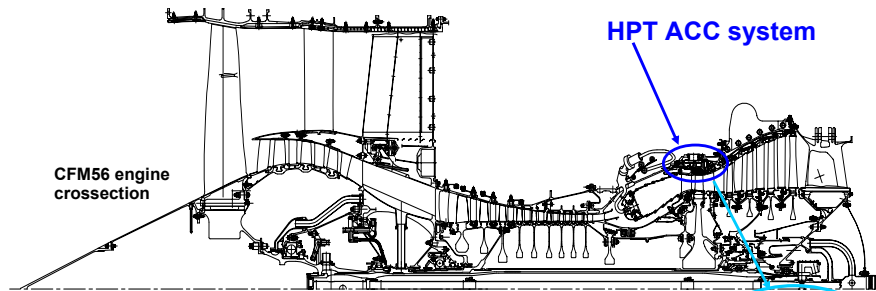
**High pressure turbine clearance/efficiency has significant impact on emissions**

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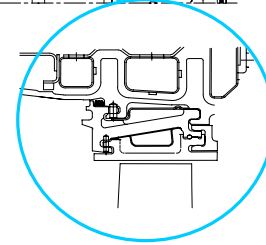
This slide summarizes the potential benefits of improving the HPT ACC system on long haul aircraft engine. The HPT ACC system have the potential of increasing HPT efficiency up to 1%, depending if the engine is new or deteriorated. This efficiency gain will result in reduction of engine fuel burn and consequently emissions.

## Q Potential System Benefits for a Short Haul Aircraft



### Average HPT Benefits

|                            |            |
|----------------------------|------------|
| Efficiency                 | Up to 0.8% |
| Fuel Burn Reduction        | Up to 0.7% |
| Emissions Reduction for 1% |            |
| NOx                        | 10%        |
| CO                         | 16%        |



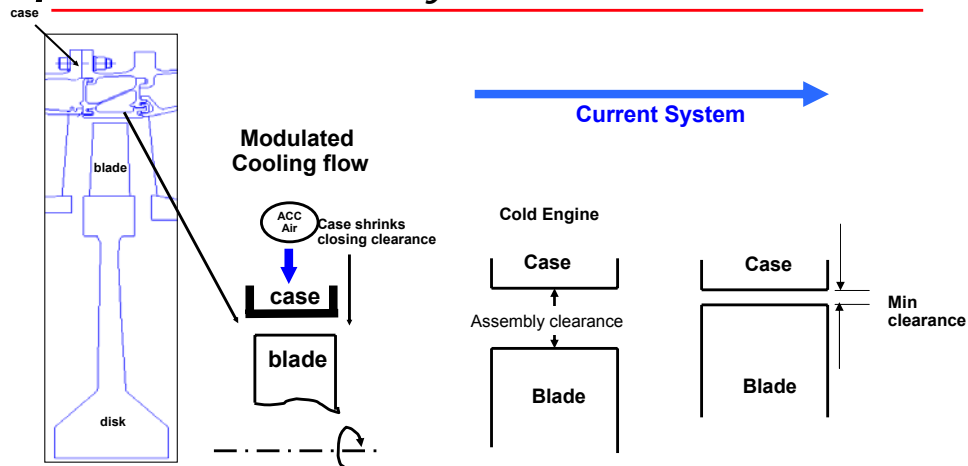
**High pressure turbine clearance/efficiency has significant impact on emissions**

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This slide summarizes the potential benefits of improving the HPT ACC system on long haul aircraft engine. The HPT ACC system have the potential of increasing HPT efficiency up to 1%, depending if the engine is new or deteriorated. This efficiency gain will result in reduction of engine fuel burn and consequently emissions.

## Current HPT ACC System Clearance



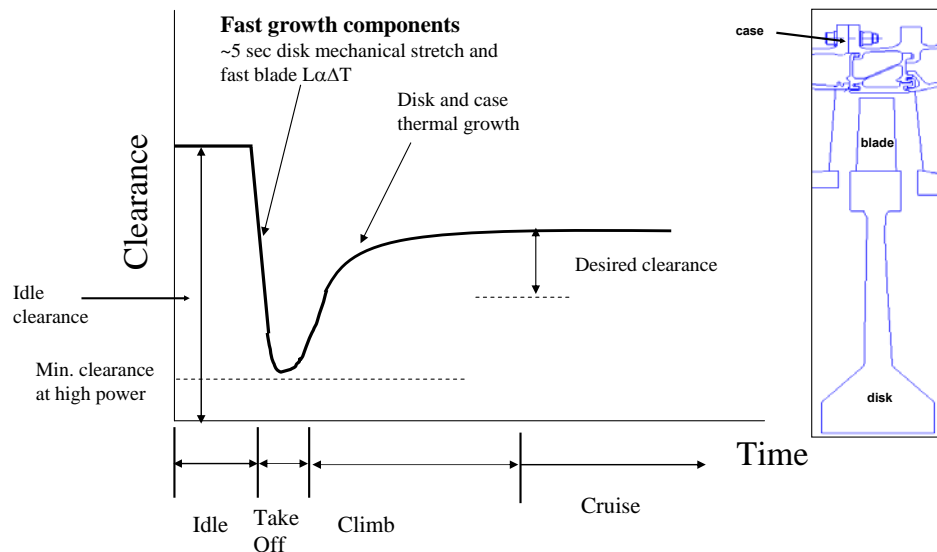
- **Min clearance set to minimize rotor to stator contact**
  - **Include margin for increase engine power (step climb)**
  - **Contact shortens blades and result in more open clearance at other conditions => rub avoidance is key**

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On today's engines, during engine operation, the HPT clearances are controlled by cooling the case using modulated cooling air flow. The cooling air, coming from engine bleed sources, will shrink the case, closing the clearances between rotor and case (some times called stator). The HPT modules are build with certain assembly clearances which it's magnitude depends on anticipated thermal and mechanical radial deflections of the rotor and stator during engine operation and the desired minimum clearance to protect against rubs during instantaneous increase in engine power.

## Operational Tip Clearances Variation



- Current thermal ACC systems only address disk and case thermal growth.
- A fast acting system is required to match fast growth components.

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This slide shows how the HPT clearance varies overtime for idle, take off, climb and cruise conditions for a typical engine. The clearances are a function of the rotor and case thermal and mechanical radial growth.

Approximately, during the first five seconds into take off, the disk stretches mechanically and the blade expands thermally resulting in an instantaneous reduction in clearances. During this condition, the stator is not thermally fast enough to follow the rotor. Due to this reason, clearances are set more open during idle to avoid a rotor and stator contact during acceleration.

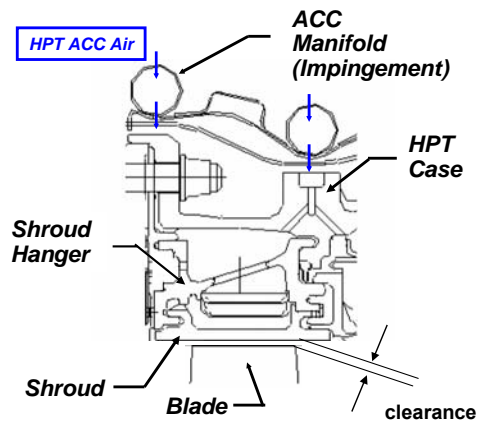
Following the initial acceleration, the stator and the disk grow thermally. At this point in time, the ACC system starts to modulate cooling air to match the case deflections with the rotor thermal deflections to minimize clearances during the thermal transient.

Once the engine reaches cruise condition, the stator and the rotor are nearly steady state and this is where the ACC air is fully used to close the clearances to maintain minimum clearances. Current HPT ACC systems are generally limited in clearance range capability.

A system that moves the stator as fast as the disk stretch and blade thermal growth is required for the HPT in order to operate near minimum clearances.

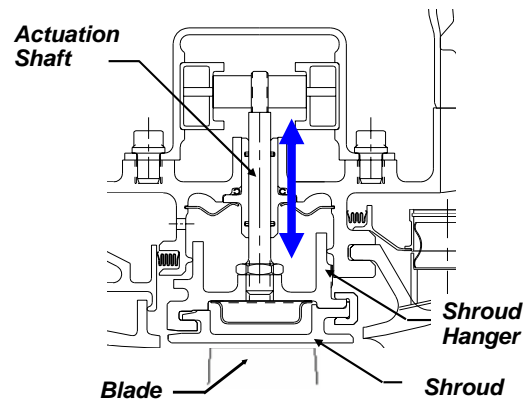
## Q Potential HPT ACC Systems

### Thermally Actuated, Conventional



Shroud radial position set by case temperature

### Mechanically Actuated



Shroud radial position set by actuator

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This slide gives a description of some of the ACC concepts studied, the thermal actuated and the mechanical actuated system.

Thermally actuated ACC systems are used on today's production engines. In this system, the shroud, a segmented member, radial position is set by cooling the case using modulated cooling air from engine bleed sources. As was shown on previous slide, this system does not address the fast components during take off conditions. The system response is characterized by the thermal time constants.

On the other hand, the mechanically actuated system is a new revolutionary system. The concept behind this system is to control the radial position of individual shrouds by means of mechanical actuators, thereby setting clearance. This system in combination with a clearance sensor has the potential of addressing the fast components allowing the HPT to operate at near minimum clearances. The system response will depend on the response rate of the actuators.



## Q Potential HPT ACC Systems –Cont'd

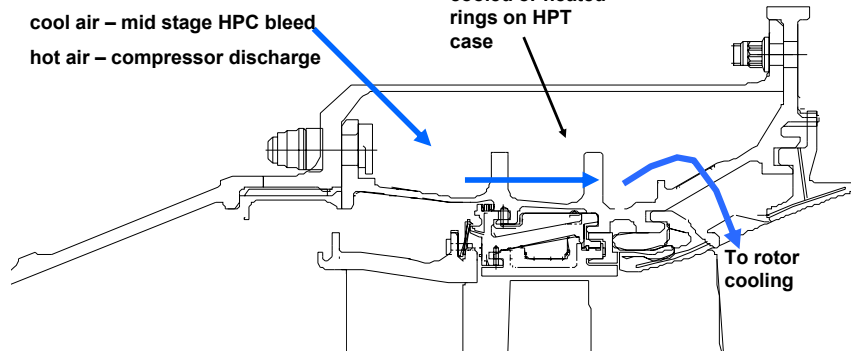
### Thermally actuated fast acting system

#### Compressor bleed

cool air – mid stage HPC bleed

hot air – compressor discharge

Transpiration  
cooled or heated  
rings on HPT  
case



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GE Aircraft Engines is working, under Prop 21, on a thermally actuated system which promises to provide fast response. This system uses hot and cool air as heat sinks for a convection cooled or heated case. In order to quickly change the temperature of the case, and thereby its diameter, a significant temperature difference as well as mass of air are needed. This flow is “borrowed” from rotor cooling for Active Clearance Control purposes.

## Q Increasing muscle – How it helps

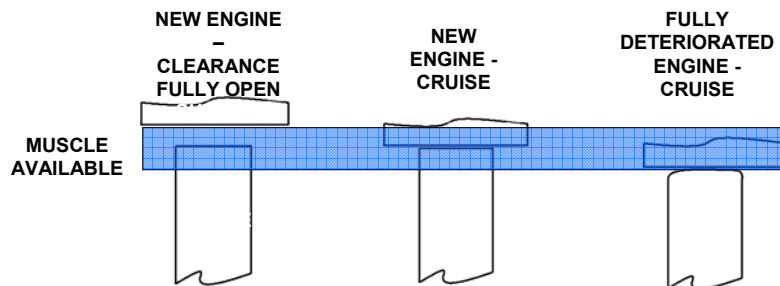
### SYSTEM RANGE

#### •HPT CASE “MUSCLE”

$$\delta_T = L\alpha\Delta T \text{ – deflection depends on temperature}$$

#### •DETERIORATED ENGINE SYSTEM PERFORMANCE

Maintain new engine HPT clearance throughout engine life



*Conventional ACC designs can use this to improve performance over time*

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The “Holy Grail” of clearances is a reliable system allowing for generous and nearly instantaneous control of HPT shroud diameter. Such a system would respond to blade tip position throughout an entire engine mission, as well as its entire life. The “muscle” of an HPT clearance control system is the difference between the smallest and largest shroud radius it can produce. A new engine may not need as much closure capability as a deteriorated one, but a good clearance control system should be able to compensate for the wear.

A thermally controlled system is contained within boundaries of the temperatures available for thermal control. In the case of the CFM56 this means the temperatures of the air at which compressor bleed is extracted.

$\delta_T$  – deflection of member

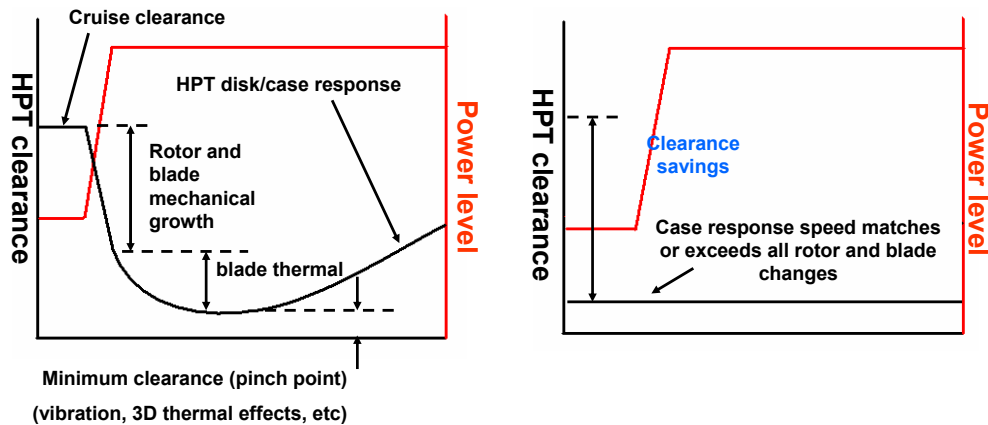
L - length of member

$\alpha$  – coefficient of thermal expansion

$\Delta T$  – temperature difference

## Q *Speed of Actuation – How it helps*

### •Deflection match throughout engine mission



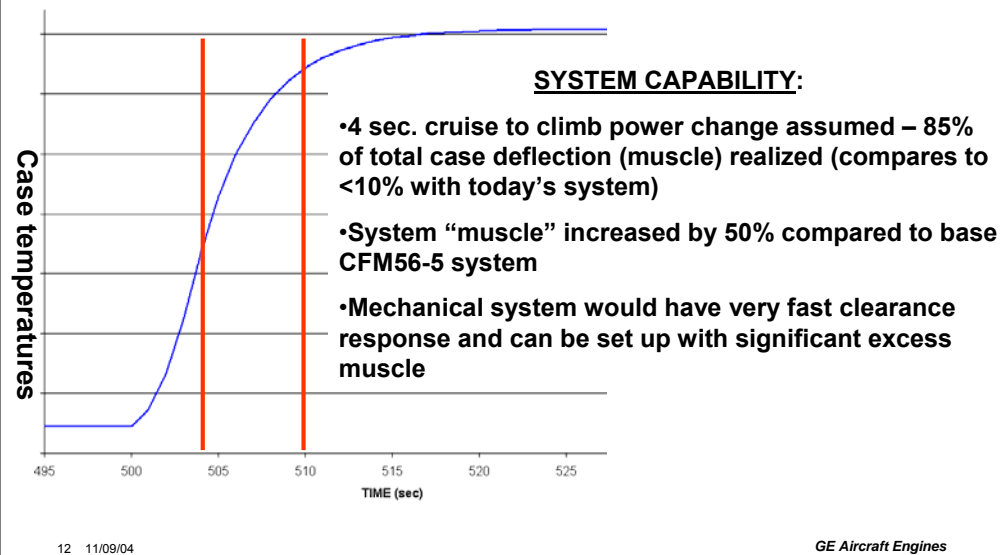
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For a system to be considered truly fast-acting the response of the shroud (or the case which carries it) needs to match or exceed that of the HPT blade tip. If this is achieved no extra clearance needs to be provided for the protection against rubs which would occur during engine acceleration.

This slide shows what happens to HPT clearance during a change in engine power level. An immediate effect is mechanical growth caused by increased rotational velocity. The second relatively fast effect is the thermal expansion of the blade due to increased flame temperature. Finally, change in pressures also causes instantaneous deflections on all parts – this is however, the smallest element of the change in clearance. All three of these cause closure of the HPT clearance. The much slower thermal growth of the rotor can easily be surpassed by the growth of the case, which is why clearances increase after the pinch point.

## Q Speed of Actuation – Thermal system study results

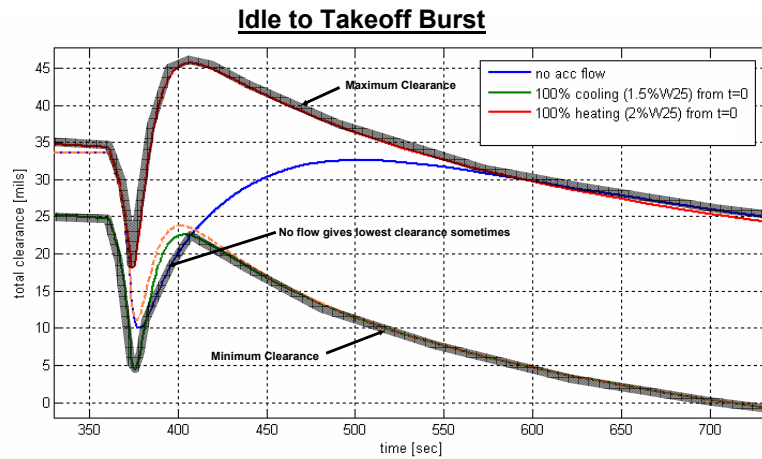


This is a result of analysis of a flight maneuver where speed was increased from cruise to climb. This type of change typically is executed to bring aircraft to a higher altitude. The reason for this change may be to make the flight more efficient as the aircraft burns off fuel, or to increase passenger comfort during excessive air turbulence.

It is assumed that this acceleration is linear over 4 sec. This is the time allowed for the system to react and respond to the clearance change associated with the acceleration. The system provided 44% of its entire thermal deflection range in this time. This allows for rub protection to be excluded from cruise clearance setting. Also, the amount of “muscle” provides for clearance changes associated with normal deterioration of an engine.

## Q Control – What is the optimum Valve Schedule?

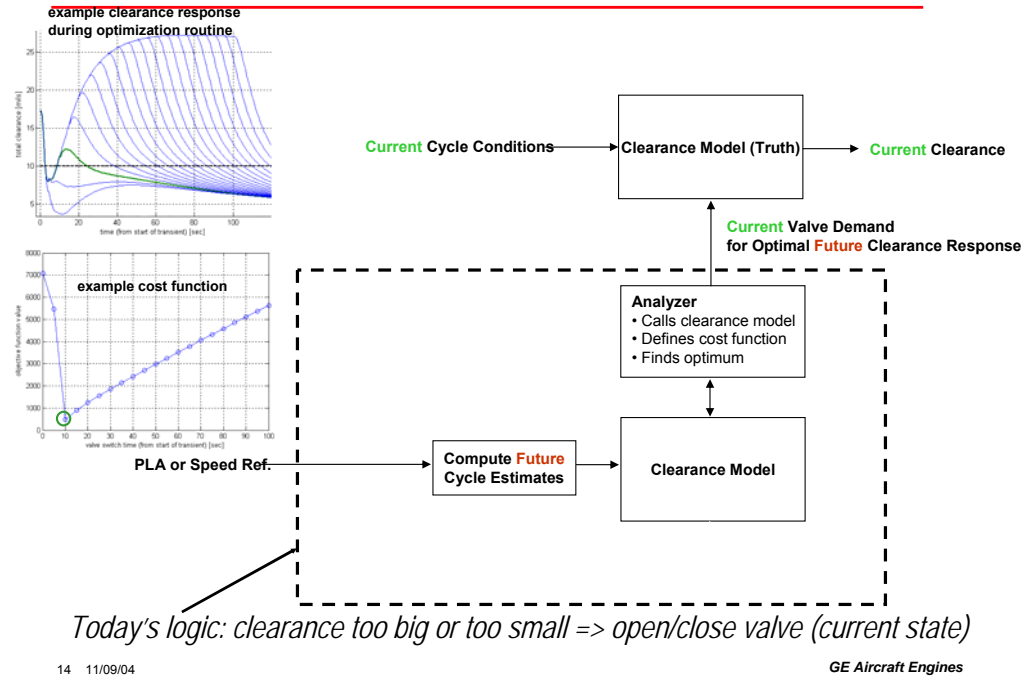
- Fast acting system great for clearing step climb rub but less forgiving of improper valve control



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# Control – Predictive scheme needed for best clearance



## Q *Summary*

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- HPT clearance can significantly reduce fuel burn & emissions
- Current HPT ACC systems have potential for improvement
  - Fast thermal has most potential as next evolutionary step for aircraft
  - Fast mechanical could be used on land-based applications (wt)
- Additional work required to develop optimum systems
  - Work details of design
  - Rig test to demonstrate the system capability
  - Develop clearance sensor to reduce analytical uncertainty
  - Develop the control logic for the system
  - Engine demo test