ADVANCED SEALS AND SECONDARY AIRFLOW SYSTEMS FOR ALLISON AST

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The author will present results obtained to date of a secondary flow study currently being conducted. The purpose of the study is to investigate and report all the ramifications of intorducing advanced sealing technology into gas turbine engine secondary flow systems. In addition to detailed cost / benefit results we will also derive seal operational requirements which can be fed into a subsequent advanced seal development program.

Using the current Allison AE3007 engine as a model / baseline we have examined 6 different advanced seal variations. We have settled on a design with 2 advanced seals which results in a savings of 2% in chargeable cooling. The introduction of these advanced seals has resulted in substantial changes to surrounding engine components which will be reported.

SEALS & SECONDARY FLOW WORKSHOP

BACKGROUND

- Completed NASA study, Innovative Seal Technology for Next Generation Subsonic Aircraft - 1994
- Studied current and advanced versions of both T800 and AE3007
- Large gains in both T/W and simultaneous decrease in SFC possible with development and use of advanced seals
- Study provided sealing technology development roadmap
- Study indicated that advanced low leakage seals cannot be readily adapted into existing secondary airflow systems - greater gains were probably possible with a new approach
- Other issues: flight safety, cost, etc., needed to be addressed
- Systems level preliminary design study is currently underway as part of NASA/Allison AST initiative

Background

Allison completed a prior Task Ordered study for NASA Lewis Research Center wherein the potential beneficial effects of incorporating advanced sealing technology into advanced engines was investigated. The LHTEC T801 engine and the Allison AE3007 engines were used as the base line for the study the T801 is a small 1400HP class turboshaft engine, while the AE3007 is a 7000 pound thrust class turbofan. The study was conducted using existing secondary airflow models which were altered slightly to incorporate advanced seals into specific locations which were identified as high leakage areas. Turbine rim blade to vane locations, compressor discharge, etc. were identified as high value areas for advanced seals. Leakage data obtained from rig testing of advanced film riding seals was substituted for existing seals at the selected locations. We found that even the use of as few as 2 advanced seals greatly upset the existing flow systems. A great deal of "tweaking" was required to bring the flow system back into balance, and eliminate excess leakage at other locations so that a comparison could be made between configurations with current and advanced seals. The performance gains that resulted from the use of as few as 4 advanced seals were substantial.

In some cases the adjusted seal clearances could not be achieved in practice. An obvious conclusion was that it would have been better to start the flow system design assuming that the advanced seals would be available for use. The study focused on highlighting the potential benefits of advanced seals and presented a development road map.

The present work underway under the NASA Advanced Subsonic Transport (AST) initiative takes this earlier study one step forward, and will attempt to address other issues such as flight safety in the event of a single or multiple seals failures, cost, weight, and other collateral effects on the engine. The engine cycle being used for the study corresponds to an advanced version of the Allison AE3007.

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SECONDARY AIRFLOW PD STUDY

- Addresses most issues raised in previous NASA study
- Directed at Allison AE3007/301X - medium size turbofan
- PD study focuses on GG, particularly HP turbine
- **Rules of Engagement**: No change to flow path, blade cooling or LP circuit
- Study goals:
  - Determine operating requirements for advanced seals: pressure, temp., speed deflections/distortion of sealing faces
  - Analytically demonstrate safety of advanced system
  - Identify other potential benefits/concerns which may also accrue as a result of advanced seals/flow system - weight, cost, component life, blade tip clearance etc.

Secondary Airflow Study

The first task of Allison's AST seals task is to expand the scope of the previous study and do a preliminary design of an advanced flow system for the AE3007 engine which incorporates advanced seals. This study will include physical and mechanical constraints. One of the purposes of doing the study is to determine operating requirements i.e. pressures, temperatures, speeds, axial and radial motions, etc., which must be incorporated into the design of the advanced seals.

The engine being used for the study is an advanced version of the present Allison AE3007, a medium size turbofan. For the purposes of this study no changes are planned to the flow path aerodynamics. Blade cooling flows will be assumed to be adequate as currently planned, and will remain unchanged for this study. This study is also being confined to the gasifier section of the engine since the earlier study showed that most of the payoffs were in the HP turbine. Our intent is to leave the LP cooling circuit unchanged.

Another purpose of the study is to reveal the effects that use of the advanced seals might have on the rest of the engine HP rotor. We intend to report on cost and weight differences between the present system and the advanced. Flight safety will be addressed as well as the response of the HP rotor to transient operating conditions. What is planned is a systems level study which is as realistic as possible of the planned advanced flow system versus the current.

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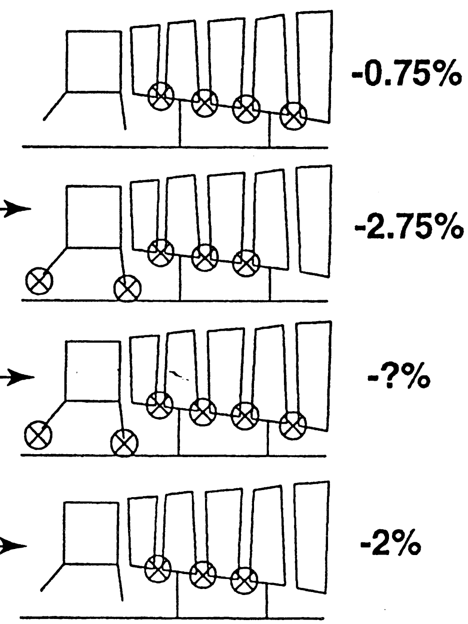
SECONDARY FLOW SYSTEM DESIGN

- Have completed 3 1/2 major iterations with several minor iterations within each to accommodate input from hot section design, flow systems, seal technology, heat transfer, lb. stress
- First pass - air everywhere at first! → 1
- Second iteration
  - Reduced leakage - bad for compressor → 2
- Third proposal
  - Total separation between HP & LP cooling circuits → 3
  - Too many seals for now…maybe later
- Final configuration → 4
  - Really just two advanced seals
  - Reasonable benefit for reasonable risk



Secondary Flow System Design

After several iterations through the proposed advanced secondary flow system we've selected a final design which balances complexity and risk against the benefits of reduced leakage. We are in the final stages of finishing up a detailed assessment of this final design configuration.

Four turbine rim seals were planned initially. These were placed into the secondary flow model with no other adjustments made to the flow system relative to the existing AE3007. This resulted in a net leakage reduction of 0.75%. It was clear we could do better. Much higher pressures were present in the rotor cavities. This caused large air leakage in places which in some cases had ingress from the gas path. In addition a large amount of high pressure air was leaking into the low pressure cooling circuit. Adjustments were made to reduce airflow into the HP turbine cooling circuit, as well as changes from segmented to solid cover plates.

A second major iteration removed the 2B-3V rim seal, and added 2 film riding face seals. This was an effort to prevent leakage of the HP air into the LP cooling circuit. This produced an overall leakage reduction of approximately 2.75% and did totally separate the HP and LP cooling circuits. Unfortunately the amount of air required through the compressor ID rotor bleed to feed the LP circuit was excessive.

A third proposal shown in the figure would have conceivably solved the compressor problem. Although this probably would have resulted in even greater leakage reduction the proposal was not evaluated due to flight safety concerns, and the sheer complexity and risk trying to introduce so many advanced seals at one time into the engine.

The result was the forth configuration which balances risk and benefits. Allison has concentrated on developing this final configuration.

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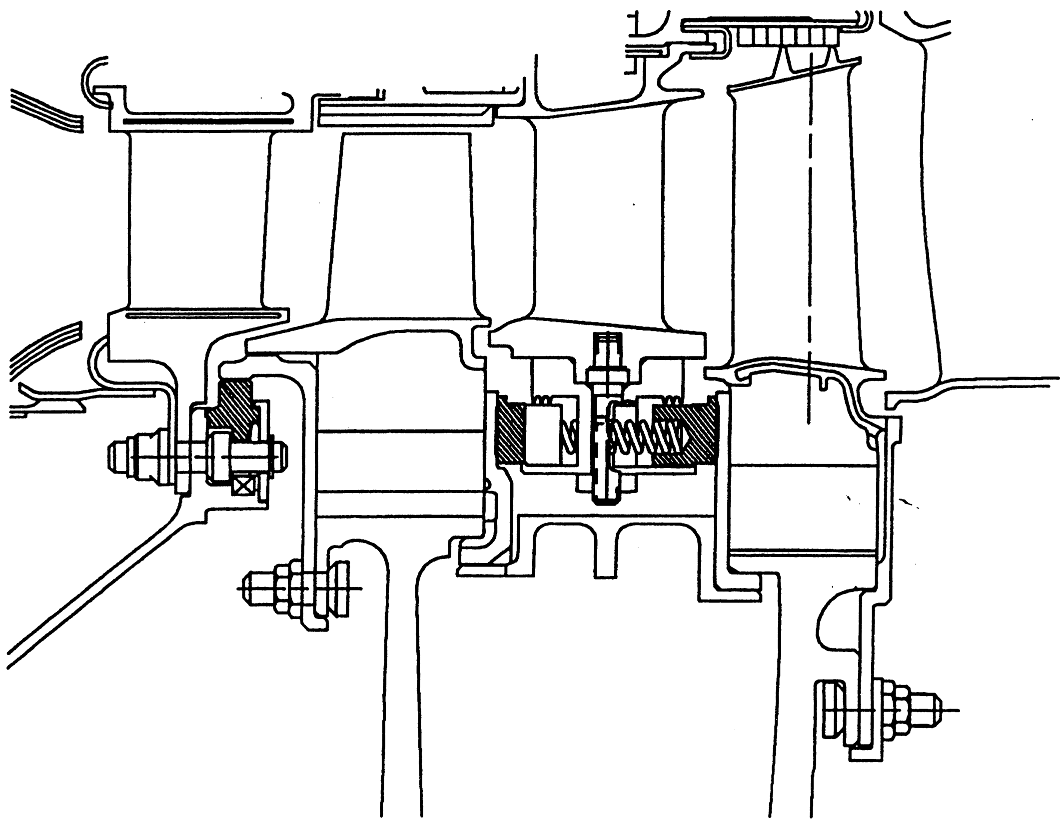
MECHANICAL CONFIGURATION



Mechanical Design

While the secondary airflow iterations were being accomplished, mechanical design / layout work was done in parallel to assure that the proposed seals could in fact be incorporated into the planned locations. All the advanced seals considered for this engine were various forms of film riding seals. Shown in the figure are both face and circumferential type film riding seals. Also shown in the figure, but not so obvious are other adaptations which had to be made to accommodate the seals, and maintain the low leakage capability of the advanced seals. The use of solid cover plates, instead of segmented is one of the major adaptations required. These are used both to reduce airflow between the blades, and in some cases to provide a contiguous mating surface as well for the seals.

This is also a good place to also note that the current configuration also satisfies the initial requirement that the airfoils be unchanged. Blades and vanes get their cooling air separately from the interstage cavity purge air. The new flow system has been designed so that a single or multiple seal failure will not effect airfoil cooling thus satisfying at least in part the requirement for flight safety.

Allison has estimated that if blade cooling flows are excluded that it presently takes approximately 4% of cycle air to keep the HP turbine cavities purged. The arrangement shown in the figure saves approximately 50% of this flow.

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RIM SEAL REQUIREMENTS

Turbine rim seals:

	1V - 1B	1B - 2V ~~1V - 1B~~	2V - 2B ~~1V - 1B~~
Temp. ˚F (max source)	1048	1108	1108
ΔP (max. psid)	25.9	28.8	115.8
ΔP (min. psid)	0.02	0.57	6.28
Radial excursion (in)	.04 - .09	.08 - .13	.02 - .08
Axial excursion (in)	-.04 - +.20	-.03 - +.13	-.04 - +.19
Max speed (ft/sec)	1150	1050	1050

- Table shows total excursions due to thermal, mechanical, tolerance, etc.
- Less radial excursion than axial, but axial and/or radial must be accommodated in mechanical design
- Need to define acceptable leakage

Seal Requirements

As the study proceeds, we expect to derive in some detail requirements for the advanced seals which can then be used to guide subsequent development activities. At present we have been able to determine some gross operating parameters for the seals based on the expected pressures and temperatures for the mechanical configuration previously indicated.

The figures given in the table are derived from the secondary flow model, heat transfer results, and AE3007 engine limit stack analysis and are therefore believed to be very representative of an engine with advanced seals installed. Not yet defined are more detailed results of potential distortions of the initially flat, rotating, seal mating rings. We expect that due to thermal gradients, rotation, loading from blades, etc. the initially flat seal mating rings will not remain that way. The result will certainly be some amount of coning, and circumferential out of flatness which the seals will have to accommodate. We plan on obtaining these results from a structural finite element analysis of these parts. This work is presently underway.

It is clear from the differential pressure values presented in the table that a purely hydrostatic seal will not be practical for these proposed applications. While adequate differential pressure is available at the maximum power point, it is essentially zero at idle. An aircraft, particularly a regional airliner would be expected to spend about 30% of its time in what is essentially an idle mode, e.g. ground idle, taxiing, flight idle for descent, etc. The conclusion is that a hydrodynamic seal capable of dealing with relatively large distortions is required to be successful in the proposed applications.

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HEAT TRANSFER STUDY

- Utilized existing AE3007 models for basis of study
- Modified model to simulate geometry and flows resulting from new seals
- Adjusted secondary flows until no ingress predicted anywhere
- Starting point for analysis
  - Effective seal leakage increased via bypass holes to provide required flows
  - Analysis shows large temperature reductions throughout rim cavity area - over cooled
- Tried parametric analysis
  - Ran analysis at design seal flow
  - Ran at mid point between first two points
- OK from heat transfer to run at leakage flows expected from seals. Some local hot spots created, but manageable within present design and materials

Heat Transfer Study

Existing AE3007 heat transfer models were used for thermal modeling of the HP turbine rotor areas effected by the new seals. Although it does not show in the geometry output files, these models have been modified to simulate the new advanced seal configuration.

The starting point for this work was again the secondary airflow model. Interstage cavity purge airflows were increased until the model no longer predicted ingress. This required bypass holes around the advanced seals, as they could not be made to provide the increased flow the model predicted would be required. The heat transfer model indicated that we could get by with a great deal less airflow. We were predicting temperature reductions of almost 200°F less than the current AE3007 in some locations.

We next ran a case with airflow reduced to an intermediate level halfway between the predicted no ingress airflows, and the airflows which would result with as predicted advanced seal leakages. This result also showed that we were in some cases still over cooling and wasting air. However it also pointed out that air was escaping through the second row of blades via the still segmented rear cover plate.

A final iteration was done using the as predicted seal leakages with no bypass holes. Secondary flow revised the airflow predictions based on a solid 2B rear cover plate. This final result was deemed acceptable. Leakage was reduced by approximately 2% versus the current AE3007. Temperatures throughout the HP rotor are essentially unchanged versus the current design with 2 exceptions.

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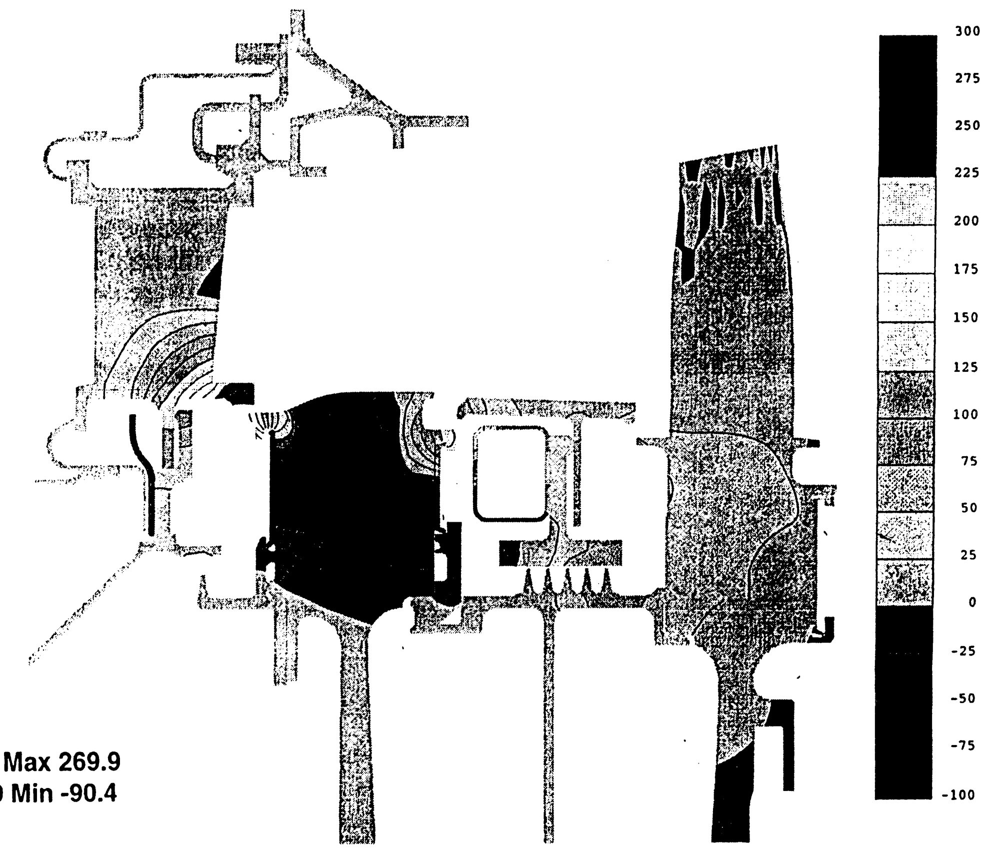
HEAT TRANSFER RESULTS

AST HP Turbine Temperatures
Minus AE3007 HP Turbine Temperatures
Steady State MTO, SLS, 73F Day, 175KCAS



*** Max 269.9**
0 Min -90.4

Heat Transfer Results

The chart depicts predicted temperatures for the HP rotor relative to the existing AE3007 at a maximum power point. Large areas of the turbine are essentially unchanged with respect to temperatures with the exception of the 1B attachment, and the 1V platform. The current AE3007 experiences slight ingress at the 1B attachment area. Higher rotor air pressure resulting from use of the advanced seals completely reverses the situation from slight ingress to slight leakage. This in turn results in a decrease in temperature in this area of approximately 90°F.

On the other hand the low leakage provided by the 1V-1B rim seal results in increased ingress in this now tiny interstage cavity. This ingress results in a predicted increase of approximately 270°F of the trailing edge of the 1V platform. This was judged to be acceptable as the current vane is operating well within accepted material limits on the current AE3007.

Based on the results, heat transfer finds the current configuration, seal leakages, and air flows acceptable.

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REMAINING TASKS

- Determine rotating component lives due to new thermal distribution in parts
- Determine expected seal distortion to feed into future seal design work
- Run transient analysis to determine effect on blade tip clearance during engine transients
- Run failed seal condition
  - Present flow system designed around leakage characteristics of advanced seals
  - Recognizes that potential ingress due to failed seal is not immediately fatal - need to reliably detect failed seal condition
  - Flows to airfoils will be unaffected by single or multiple seal failures
- Compile results and report

Remaining Work

Most of the remaining work involves determination of stresses and deflections in the HP turbine rotor components. The estimated deflections of the seal mating surfaces can be used as design requirements for future advanced seal development activities. We also plan to run a 0-max-0 type transient to determine what effects the new seals / flow system design have on turbine blade tip clearances. There had been some concern that the new design would have a tendency to thermally isolate the turbine rotor and would aggravate the tip clearance control problem. Based on the results so far, however it does not appear that the bulk turbine rotor temperatures are much different than the current AE3007, so this may not be a problem.

Another remaining task is to run a multiple seal failure case. These analyses will enable us to determine the potential effects of a seal failure relative to flight safety concerns. The best outcome would be that the engine would simply experience an increase in leakage which would be detectable as a sudden increase in fuel consumption. The engine design group has allowed that any detectable failure which does not cause immediate catastrophic consequences, i.e. the engine could continue to operate at least to the end of the planned flight, is an acceptable failure mode. The present flow system design does insure the integrity of the airfoils in the event of seal failure.

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SUMMARY

- Have demonstrated mechanical feasibility
- Have demonstrated thermal feasibility
- Advanced seals had only minor effect on engine emissions
- Slightly higher NOx predicted, but lower CO and unburned hydrocarbons
  - Higher CDT and longer combustor residence time mostly responsible for effect on emissions
  - NOx increase almost offset by decrease in fuel flow due to less parasitic leakage

Summary of Results to Date

At this point we have demonstrated that it is feasible to place advanced film riding seals close to the HP turbine blade / vane overlap gaps and thus directly control leakage through these points. This is a fundamental change to the way ingress is prevented in all present gas turbine engines.

We have also completed a parametric thermal model of the proposed mechanical arrangement and determined that predicted temperatures are within acceptable limits for the current materials. We note that in some areas the advanced seals and new secondary airflow system have resulted in large (>25°F) changes in predicted metal temperatures. We plan to take this analysis one step further and determine what effect the changed temperature changes have if any on component life.

Finally we have tried to assess the effect on emissions due to introduction of the advanced seals into the engine. We adjusted the AE3007 engine cycle to reflect the predicted reduction in leakage due to the advanced seals at the 4 ICAO points. These points were then used in an emissions model and the results compared to the existing AE3007. We found that there was only a slight effect on emissions due to advanced seals. Higher CDT and longer combustor residence time increased NOx (0.72%), which was partly offset by a reduction in fuel flow. CDT and longer residence time resulted in reduced CO (3.47%) and unburned hydrocarbons (2.91%). The predicted SAE smoke number was not effected since it is already small, and prediction accuracy is only ±3%.