

A COMPLIANT CASING FOR TRANSONIC AXIAL COMPRESSORS

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**A COMPLIANT CASING FOR  
TRANSONIC AXIAL  
COMPRESSORS**

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Introduce Self

Acknowledge the contributions of my co-author, Chunill Hah



## Outline



- **Introduction and motivation**
- **Concept for compliant casing**
- **Rig and facility details**
- **Experimental results**
- **Numerical results**
- **Conclusions**

Introduction and motivation

Concept for compliant casing

Rig and facility details

Experimental results

Numerical results

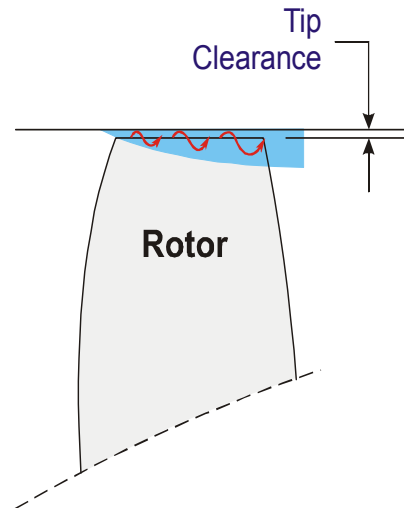
Conclusions



## Tip-Region Phenomena



- **Tip-leakage vortex flow**
  - Total pressure losses & mass flow blockage
  - Performance penalty scales with tip clearance
  - Minimize clearance for best aerodynamic performance
- **Some clearance is required to avoid tip rubs**
  - Short-duration events such as stalls, hard landings, etc.
  - Abradable coatings commonly used “just in case”
- **Rub events permanently degrade performance**



In aircraft engines, some clearance exists between rotor & casing

Pressure difference drives flow through the clearance gap (shown in red)

mostly  $V_q$  relative to the rotor

relatively low  $V_x$

produces a large blockage of the main flow (shown in blue)

this is a region of large entropy generation

results in reduced mass flow, pressure rise, and efficiency (Big 3)

Performance penalty scales with tip clearance (larger is bad)

You want to minimize the tip clearance for best aerodynamic performance, but from a practical standpoint, some clearance is required to avoid tip rubs

Short-duration events such as stalls, hard landings, etc.

Abradable coatings are commonly used “just in case”

The important thing to remember is that rub events remove material from casing and/or rotor

increases tip clearance

permanently reduces performance until the engine is removed from service and overhauled (*EXPENSIVE*)

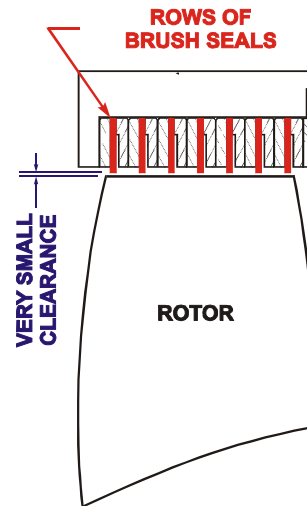


## Brush Seals Provide Compliant Casing



- **Approach**

- Utilize brush seals as a compliant casing for short-duration rub events
- Reduce effective tip clearance
- Eliminate permanent clearance increase due to casing rubs



This cartoon shows the use of brush seals to provide a compliant casing for short-duration rub events ... describe brushes (brush seals typical of those used for control of secondary flowpath leakage)

Make tip clearance smaller than you would dare with a solid case

In the event of a rub, the brushes will deflect and return...

This eliminates the permanent performance hit that currently results from a rub event

This is not a typical brush seal application like secondary flowpath control:

Brushes will not normally contact the rotor (only in short-duration rub event)

Some small amount of tip-leakage flow will still pass between the rotor and the brushes

At any given instant in time, most of the circumference of the brush is adjacent to the empty space between the blades

several brush packs are placed next to each other to obtain significant coverage in the axial direction

Due to the manufacturing limitations of the original brush seals, this provided a casing that is similar to circumferential-groove casing treatment, but with very shallow grooves



## Compliant Casing Installation



- **Installed in SMI rig**
- **7 rows of brushes**
  - **5 mil clearance between rotor tip & brush ID**
  - **25 mil clearance between rotor tip & backing plate**
  - **(Smooth casing had 13 mil clearance)**
- **Measurement uncertainties**
  - **Mass flow  $\pm 0.08$  lbm/s**
  - **Pressure ratio  $\pm 0.004$**
  - **Efficiency  $\pm 0.20$  percent**



### Discuss SMI rig

single stage machine typical of 1st stage of modern core compressor

19"OD, 1120 ft/s tip speed

tip chord = 3.5"

tip relative Mach number = 1.19

mass flow = 34.5 lbm/s

pressure ratio = 1.81

peak efficiency = 87%

### Discuss brush dimensional issues

5 mil minimum clearance

25 mil clearance to brush backing plates

No abradable coating installed here, so gap increased for safety

13 mil clearance to smooth casing (for comparison)

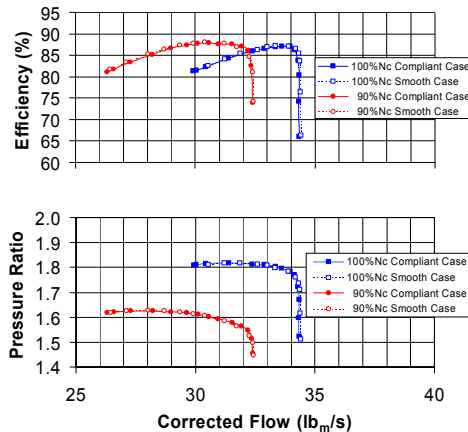
The SMI rig was tested in the CARL facility, and aerodynamic performance was determined by mass-averaging an array of 80 PT probes and 80 TT probes located 2.1 stator axial chords downstream of stator TE.

mass flow uncertainty is 0.08 lbm/s, PR uncertainty is 0.004, efficiency uncertainty is 0.2%

So we ran the test, and this is what we learned...



## Compliant Casing Performance



- PR and  $\eta$  were identical to solid casing values (within measurement uncertainty)
  - Stall margin showed moderate **IMPROVEMENT**
- Demonstrated compliant nature of casing
  - Stalled rotor 10 times
  - Clear evidence of rubbing was observed
  - No damage to either brushes or rotor
  - **Post-rub performance was identical to pre-rub**

Orient the reader to the maps:

constant speed lines are same color; red=90%Nc, blue=100%Nc

solid symbols are for compliant casing; hollow symbols are for smooth casing

Pressure rise and efficiency are identical for smooth and compliant casings (within measurement uncertainty). The measurement uncertainties are approximately the size of the symbols shown here

Stall margin showed moderate **IMPROVEMENT** (14% increase in flow range at design speed)

The compliant nature of the casing was demonstrated


Stalled rotor 10 times

Clear evidence of rubbing was observed


prior to testing, the rotor tips were painted with a black Sharpie marker; post-test inspection revealed shiny lines where rubbing with brush seals had occurred; brush tips were shiny in some (corresponding) places

No damage to either brushes or rotor was observed

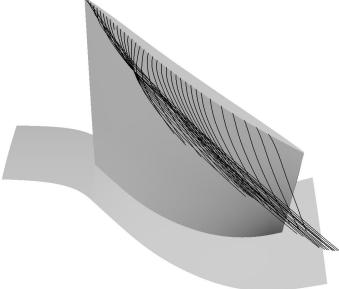
Data points repeated after stalling the rotor showed identical performance to pre-stall values (within measurement uncertainty). This is important: we beat on this rotor pretty hard. Some of the stall events lasted for several seconds before the rig recovered, but there was no post-rub performance penalty.



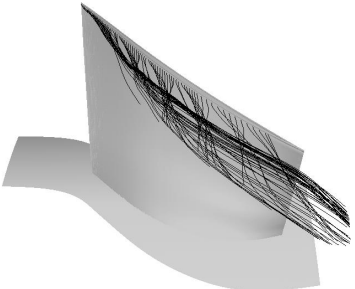
## Tip-Leakage Flow Field



**smooth casing**



**compliant casing**



- **Smooth casing produces typical tip-leakage flow field**
- **Small-gap regions of compliant casing disrupts tip-leakage vortex**
- **Decreasing gap between rotor tip and brush backing plate may improve pressure rise and efficiency characteristics**

A brief discussion of the tip-region flow field is in order here, but I believe tip-leakage flows are fairly well understood, in general, and this paper doesn't break new ground in this area.

Orient reader to figures:

Smooth casing (left) produces typical tip-leakage flow field

Single contiguous vortex starts at the leading edge and entrains the flow leaking over the entire axial length of the blade

Small-gap regions of compliant casing (right) disrupts tip-leakage vortex

This segmenting of the tip-leakage vortex into a series of mini-vortices reduces the overall blockage of the low-momentum clearance fluid

This confirms what is widely-known about tip-leakage flows, namely that the magnitude of the leakage vortex scales with the size of the tip gap.

The contribution made in this paper is that we have developed a rub-tolerant casing that allows us to close down the tip gap to values that the aerodynamicists like without suffering a permanent degradation of performance when rub events occur.

This also suggests that anything we can do to minimize the gap between the rotor tip and the brush backing plates (e.g., add an abrasable coating to the brush backing plates or reducing the axial gap between adjacent rows of bristles) may actually result in an improvement in pressure rise and efficiency relative to the smooth casing



## Conclusions



- **Compliant casing has been demonstrated**
  - **Stalled rotor 10 times**
  - **Clear evidence of rub events**
  - **No damage to either brushes or rotor**
  - **Post rub performance identical to pre-rub values**
- **Compliant casing improves stall margin**
- **Pressure rise and efficiency characteristics are identical to conventional casing**
- **Suggestions made to improve aerodynamic performance**

The things we've learned from this investigation are:

Compliant nature of the casing has been demonstrated

- Stalled rotor 10 times
- Clear evidence of rub events
- No damage to either brushes or rotor
- Post rub performance identical to pre-rub values

Compliant casing increased mass flow range between choke and stall by 14% at design speed

Pressure rise and efficiency characteristics are identical to conventional casing, so we haven't had to trade aerodynamic performance for damage tolerance

Suggestions have been made to improve this technology in ways that may lead to improvements in aero performance while maintaining rub tolerance.