AIR FORCE BRUSH SEAL PROGRAMS

Capt Connie Dowler
Aero Propulsion & Power Directorate
Wright Laboratory
Wright-Patterson Air Force Base Ohio

Aggressive pursuit of increased performance in gas turbine engines is driving the thermodynamic cycle to higher pressure ratios, bypass ratios, and turbine inlet temperatures. As these parameters increase, internal air system and resultant thermodynamic cycle losses increase. This conflict of reducing internal airflows while increasing thermodynamic efficiency and performance is putting more emphasis on improvements to the internal flow system. One improvement that has been and continues to be pursued by the Air Force for both man-rated and expendable turbine engine applications is the brush seal. This presentation briefly describes both past and current brush seal research and development programs and gives a summary of demonstrator and developmental engine testing of brush seals.

OUTLINE

- PAST R&D PROGRAMS
- CURRENT R&D PROGRAMS
- DEMONSTRATOR ENGINE BRUSH SEALS
- F119 BRUSH SEALS
- SUMMARY

PAST AF BRUSH SEAL R&D PROGRAMS

- ALLISON: HIGH TEMPERATURE BRUSH SEALS
  - Inconel X-750 bristles wear better than Haynes 25 in hot dynamic contact with chrome-carbide journal
  - Initial build-up interference effects static leakage
  - Brush seal with hot running clearance has less leakage than 4-knife lab seal at same pressure ratio
  - Report #: WL-TR-91-2005
- TELEDYNE: BRUSH SEAL DESIGN
  - Brush seals provide a factor of 3 or more reduction in leakage flow over conventional lab seals
  - Brush seals retain a significantly reduced leakage over lab seals for time periods of limited-life engines
  - Brush seals can survive shaft excursions of over 0.025 inches without any performance loss
  - Report #: WRDC-TR-90-2123

PAST AF BRUSH SEAL R&D PROGRAMS (cont.)

- TEXAS A&M: BRUSH SEAL ROTORDYNAMICS
  - Last stage of seal group develops higher pressure drop than previous stages
  - Increasing inlet tangential velocity increases leakage slightly
  - Cross-coupled stiffness coefficient very low and generally negative (stabilizing)
  - Whirl frequency ratio indicates brush seal is extremely stable
  - Rotordynamic coefficients independent of seal spacing and inlet tangential velocity
  - Comparison with 8-cavity lab seal indicate brush seal will generally improve rotordynamic characteristics
  - Report #: WL-TR-91-2013 (original)
    corrected report in progress

CURRENT BRUSH SEAL R&D PROGRAMS

- EG&G SEALOL
  - Brush Seal Development Program
  - Advanced Brush Seal Development Program (New Start)
- PRATT & WHITNEY
  - High Speed Brush Seal Development Program (New Start)
- IN-HOUSE
  - Brush Seal Leakage Flow Modeling
  - Brush Seal Compressor Shroud Test

BRUSH SEAL DEVELOPMENT PROGRAM
EG&G SEALOL

OBJECTIVE:

Develop a comprehensive design methodology for application of brush seals to man-rated engines

APPROACH:

Conduct parametric testing of design variables for brush seals to define performance, fatigue, oxidation, and wear characteristics

ACCOMPLISHMENTS:

- Examined effect of bristle angle, bristle length, stiffness, staging, and packwidth on hysteresis, ΔP capability, leakage, wear
- Significant hysteresis with speed, but not pressure
- Increased Packwidth gave higher ΔP capability, lower leakage
- Multiple Stage Brush Seal Performance
  - Leakage reduction
  - Unequal pressure distribution
    - May be controlled by using mixed stiffness designs
    - Staging with higher packwidth seals most effective
- Tribopair Test and Evaluation
- Evaluating Advanced Designs to Reduce Hysteresis
- Designing Full-Scale Seal for Demonstrator Engine Test

PROJECT ENGINEER: Capt Connie Dowler, 513-255-8210

ADVANCED BRUSH SEAL DEVELOPMENT PROGRAM
EG&G SEALOL

OBJECTIVE:

Develop a comprehensive design methodology for application of advanced, high performance brush seals in man-rated engines

APPROACH:

Conduct experimental characterization of seal design and materials pairs and CFD modeling to maximize single- and multi-stage brush seal Δ P capability and axial and radial excursion accommodation. Investigate feasibility of non-contacting brush seal.

ACCOMPLISHMENTS:

New Start

PROJECT ENGINEER: Lt Carolyn Sunderland, 513-255-8210

HIGH SPEED BRUSH SEAL DEVELOPMENT PROGRAM
Pratt & Whitney

OBJECTIVE:

Provide verification of advanced brush seal technology needed to enable continued application of brush seals in IHPTET Phase II demonstrator engines.

APPROACH:

Conduct an application study using IHPTET Phase II engine design and mission flight cycle to determine surface speed and temperature requirements for brush seals. Design and fabricate brush seals for rig testing to verify their capability to operate at IHPTET Phase II conditions (~ 1400fps, 1400 F).

ACCOMPLISHMENTS:

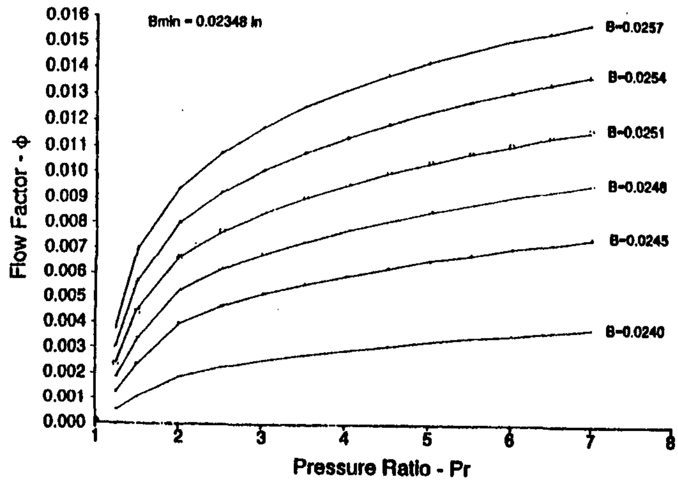
New Start

PROJECT ENGINEER: Lt Carolyn Sunderland, 513-255-8210

BRUSH SEAL LEAKAGE FLOW MODEL
FLOW MODEL APPROACH

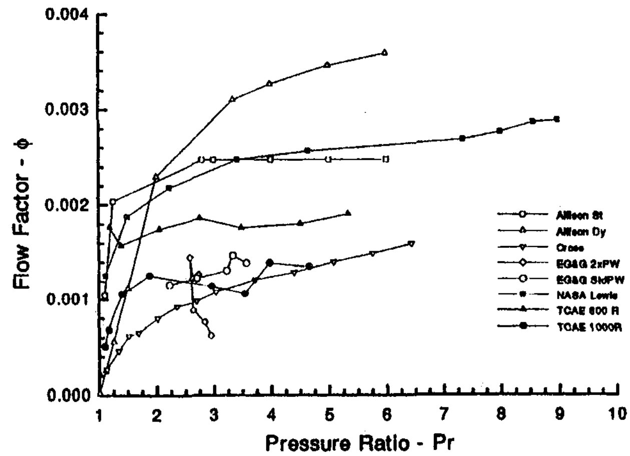
- 1-D MODEL, WITH RADIAL AND AXIAL FLOW CONSIDERED
- FLOW CORRELATIONS FROM KNUDSEN AND KATZ
  - Laminar Flow
  - Turbulent Flow
  - Transition Flow
- SINGLE CORRELATING PARAMETER: EFFECTIVE THICKNESS
- MODEL 1
  - Linear
  - Square Array Bristle Bed
- MODEL 2
  - Linear
  - Hexagonal Pack Bristle Bed
- MODEL 3
  - Modification of Model 2 to Account for Curvature Effects
  - Effective Thickness Constant Between Journal and Mean Diameter
  - Bristle Bed Configuration Varies
    - Increased Transverse Bristle Spacing
    - Increased Leakage Flow Area at Mean Diameter
    - Hexagonal Pack Bristle Bed

TYPICAL MODEL PERFORMANCE CHARACTERISTICS



- SHAPE OF Ø VERSUS P_r IS EXPECTED CHARACTERISTIC CURVE
- FLOW INCREASES WITH B AS THE BRISTLE PACK OPENS UP
- TRANSITION FROM LAMINAR TO TURBULENT FLOW NEAR $P_r = 2$

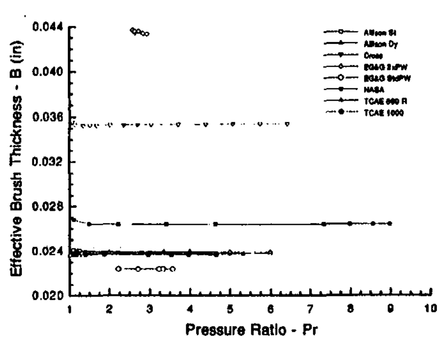
LEAKAGE PERFORMANCE DATA

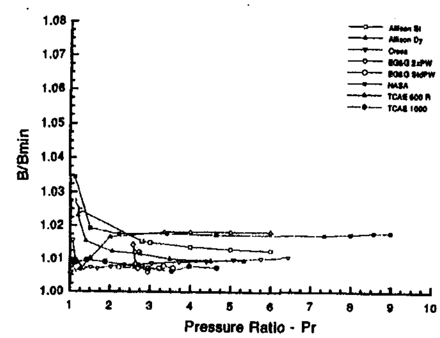


- HYSTERESIS EFFECT REMOVED
- ALLISON DATA ARE AVERAGED RESULTS FOR SEVERAL SEALS
- TELEDYNE CAE DATA ARE FOR A BASELINE BRUSH SEAL
- CROSS DATA PROVIDED CHECK ON EFFECT OF BRISTLE DENSITY
- NASA LEWIS DATA PROVIDED CHECK ON SEAL DIAMETER EFFECT

BRUSH SEAL LEAKAGE FLOW MODEL

MODEL RESULTS





- WIDE RANGE OF B INDICATIVE OF DIFFERENCE IN ACTUAL SEAL THICKNESS
- B/Bmin INDICATOR OF BRUSH SEAL LEAKAGE EFFECTIVENESS
- EG&G DOUBLE PACKWIDTH SEAL LESS EFFICIENT THAN STANDARD DENSITY SEAL
- CROSS SEAL VERY EFFICIENT
- NASA SEAL LESS EFFICIENT THAN LARGER DIAMETER SEALS

BRUSH SEAL COMPRESSOR SHROUD TEST

- PART OF ADLARF TEST PROGRAM IN COMPRESSOR RESEARCH FACILITY
- TENTATIVELY SCHEDULED TO TEST JAN 93
- INVESTIGATING CAPABILITY OF BRUSH SEAL SHROUD TO IMPROVE
  - BLADE VIBRATIONS (DAMPING)
  - STALL MARGIN
  - EFFICIENCY
- PROJECT ENGINEER: Lt Carolyn Sunderland, 513-255-8210

DEMONSTRATOR ENGINE BRUSH SEAL TESTING

- TESTING TO DATE:
  - PRIMARILY IN TURBINE SECTION
  - HAYNES 25 BRISTLES
  - CHROME CARBIDE OR ALUMINUM OXIDE COATING
  - 20 TO 80% REDUCTION IN LEAKAGE OVER LAB SEALS
  - REDUCED HEAT GENERATION
  - GENERALLY GOOD DURABILITY
  - MAX CONDITIONS: 1275 FPS, 1130 F, 55 PSI ΔP
- FUTURE TESTING:
  - PLANNED FOR ALL DEMO ENGINES (ATEGG, JTDE, JTAGG, ETEC)
  - COMPRESSOR AND IGV LOCATIONS
  - BRUSH SEAL SHROUD
  - HIGHER SURFACE SPEED AND TEMPERATURE (>1400 F, >1400 fps)

F119 BRUSH SEALS

- BILL OF MATERIALS
  - 3 STATIC SEALS
  - HPT & LPT SHROUD
- TECHNOLOGY TRANSITION PLANS
  - HPT (3 Locations)
  - LPT (2 Locations)
  - REPLACE LAB SEALS WITH BRUSH SEALS AT ALL COMPRESSOR INTERSTAGE LOCATIONS
  - 0.9% TFSC IMPROVEMENT (TOTAL)

SUMMARY

- AF COMMITTED TO DEVELOPING AND TRANSITIONING BRUSH SEAL TECHNOLOGY
- EMPHASIZING BRUSH SEAL RIG TESTING (CONTRACT AND IN-HOUSE)
- PUSHING FOR INCORPORATION OF BRUSH SEALS IN ALL DEMONSTRATOR ENGINES
- WORKING WITH PROGRAM OFFICES TO TRANSITION BRUSH SEAL TECHNOLOGY TO OPERATIONAL AND DEVELOPMENT ENGINES