FORCE BALANCE DETERMINATION OF A FILM RIDING SEAL USING CFD

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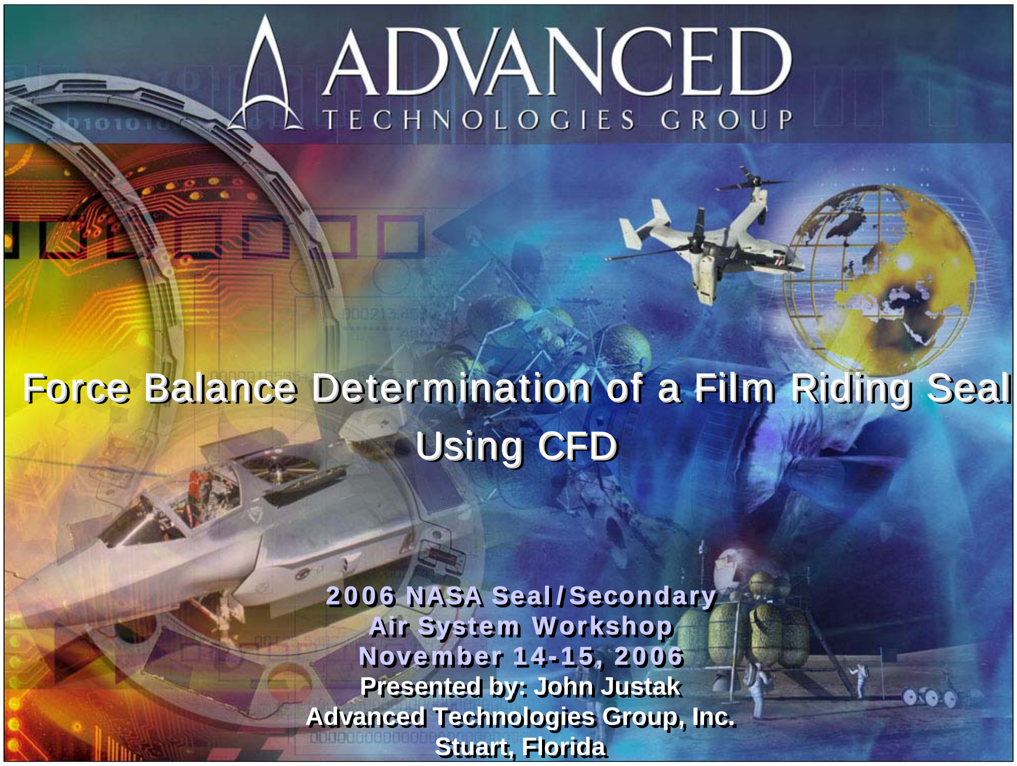
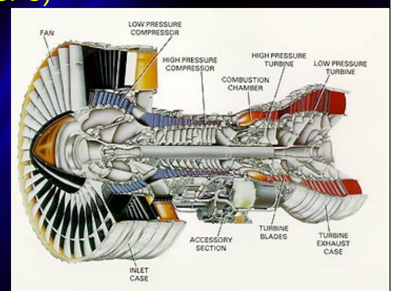


Advanced Seals

Advanced seals have been identified as critical in meeting engine goals for specific fuel consumption, thrust-to-weight, emissions, durability and operating costs.

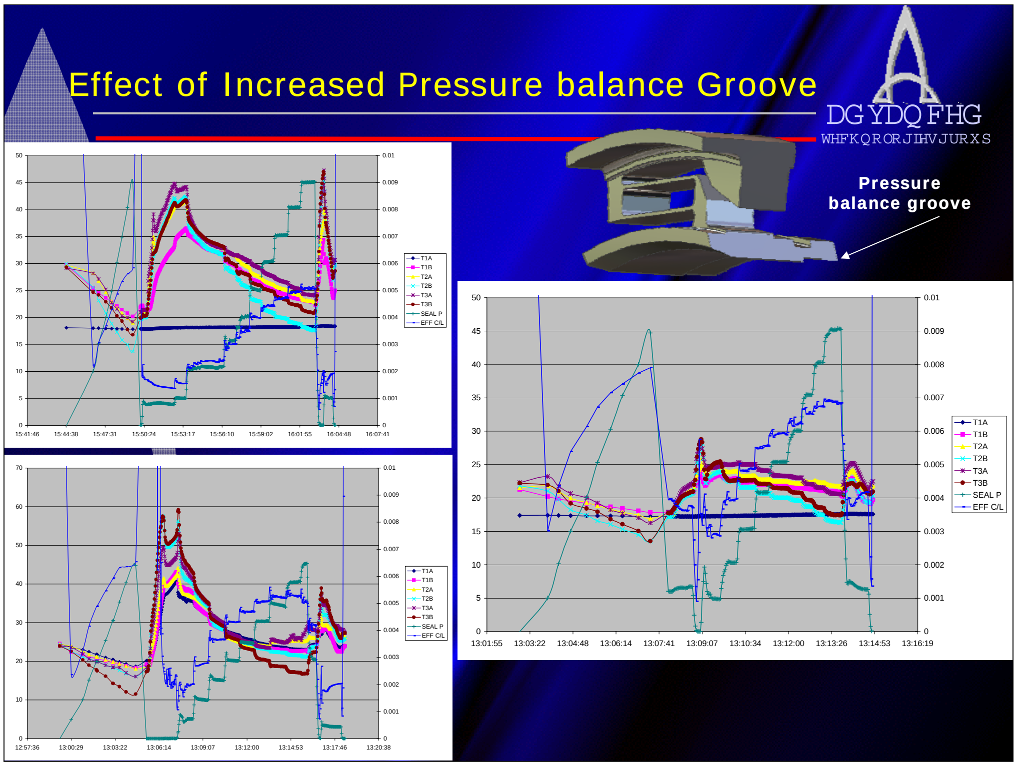
- Low leakage film-riding seals can cut in half the estimated 4% cycle air currently used to purge the high pressure turbine cavities.
- Cycle air reduction can be used to:
  - Reduce engine specific fuel consumption (SFC)
  - Thrust can be increased
  - Alternatively, RIT could be lowered, resulting in an increase in turbine blade life



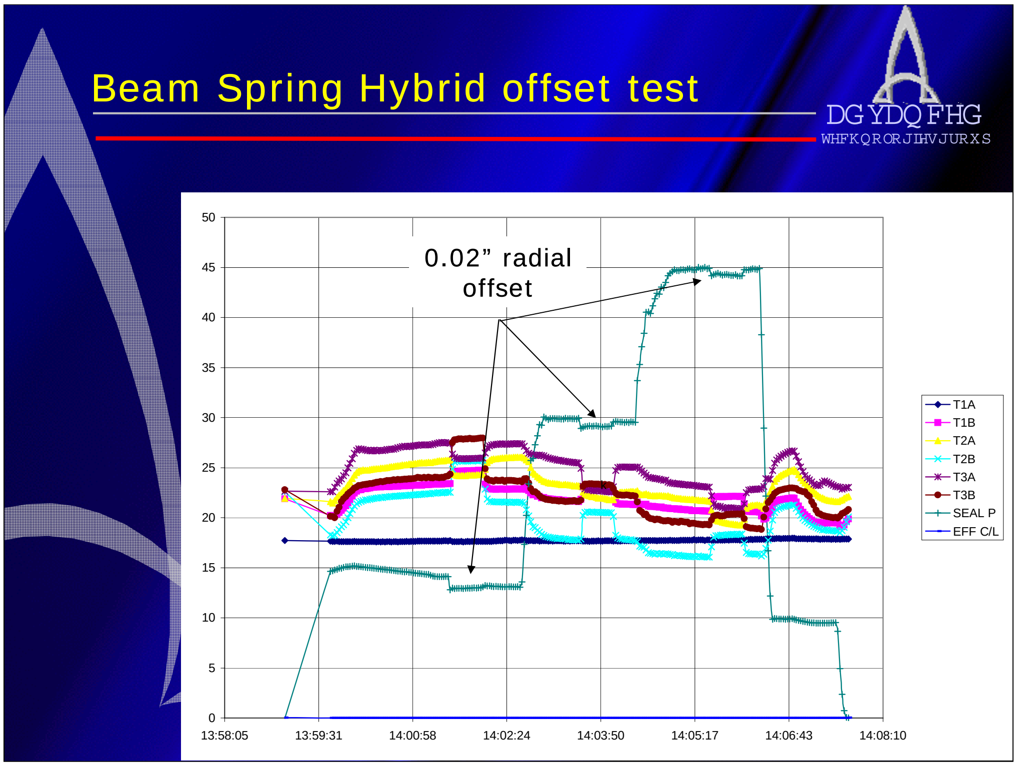
Because of their high performance payoff and their relatively low development costs, seals have repeatedly shown high performance-to-cost benefit ratios

The benefits of Advanced seals can be utilized in every compartment on the engine. IN addition, industrial gas turbines and steam turbines will benefit as well as cryogenic turbomachinery. Advanced Gas turbine seals continue to be one of the key components in the development of future engines.

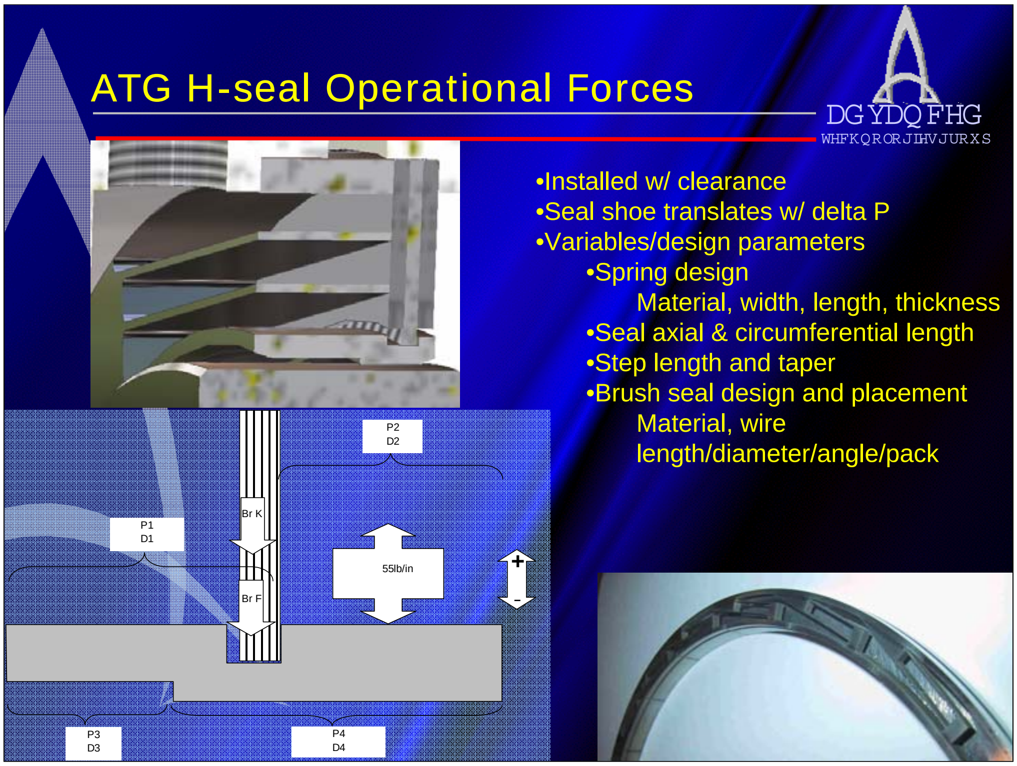
The ATG H-seal utilizes hydrostatic pressures to provide a compliant seal surface. The seal surface is supported by a spring housing that is “soft” radially and stiff axially. The seal utilizes a brush seal as a secondary seal which also provides damping for the hydrostatic bearing surface. The seal components can be modified to handle large radial and axial excursions as well as high temperature and pressure.



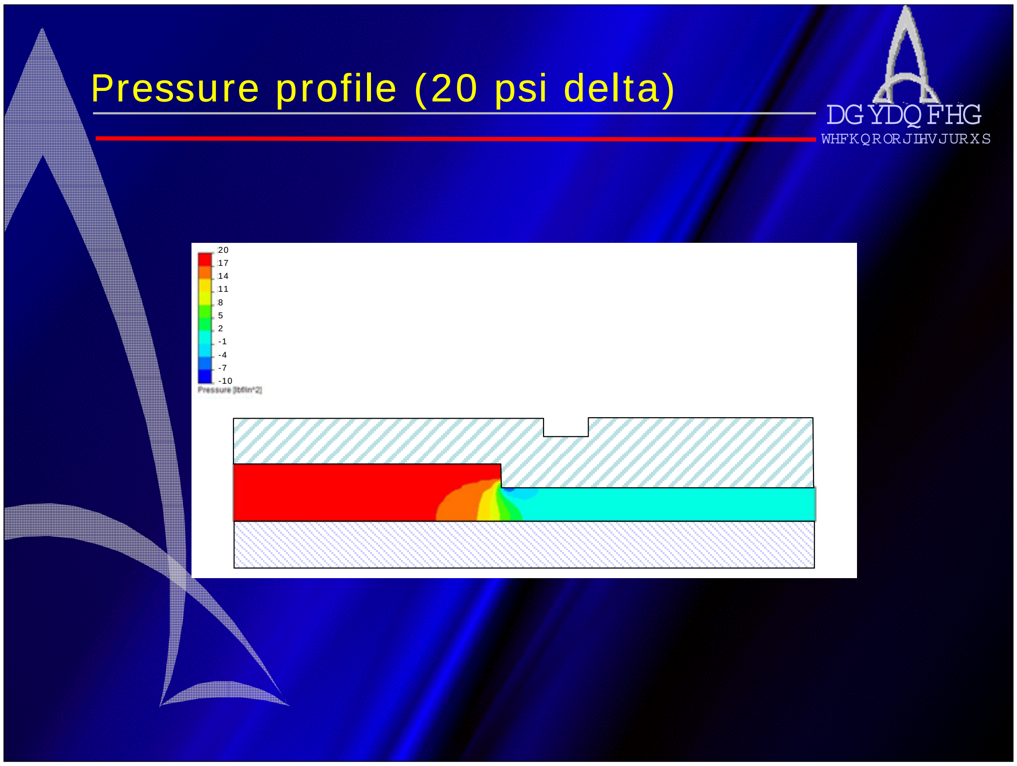
Earlier testing with the seal (installed as a hydrodynamic film riding seal) indicated that pressure balancing of the surfaces was required. During rig testing the pressure groove which shown in the upper right image, was increased in axial length. The predicted and experimental results are shown the three excel plots. Starting in the lower left corner and working clockwise, as the groove length is increased so does the effective clearance. This indicates that we can set the clearance between the seal shoe and rotor.



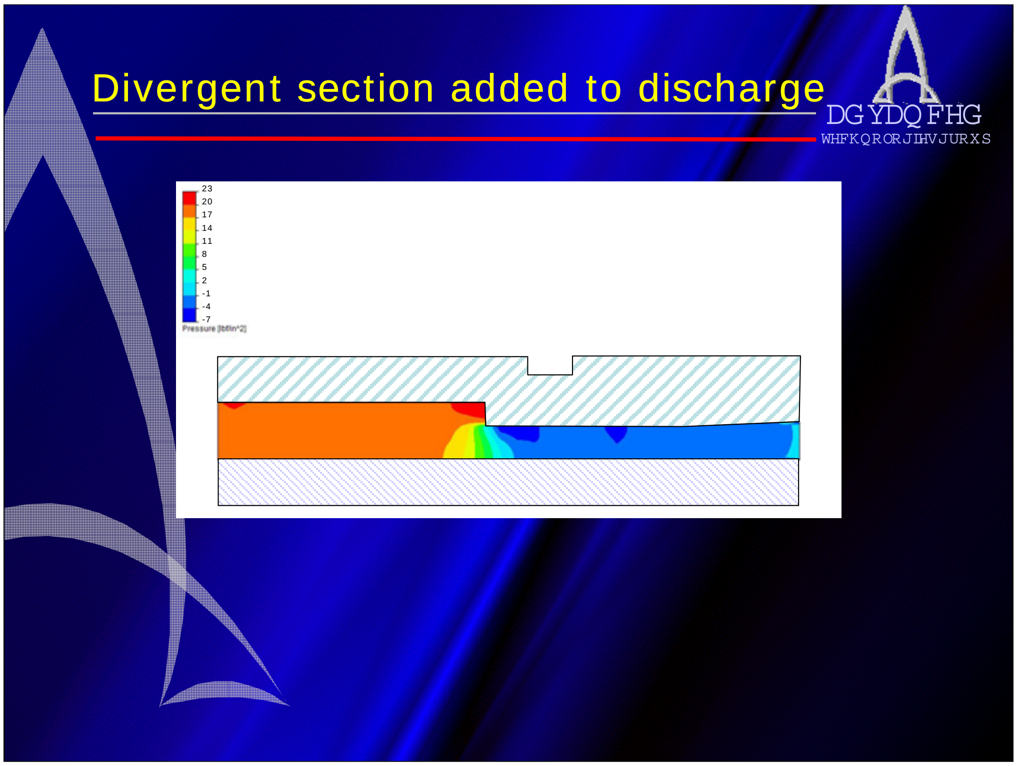
It was during offset tests (0.02” radial offset during 15,000rpm rotation) that we realized the hydrostatic forces at work. During this test the seal was moved 0.02” inches radially into the 15000rpm rotor at three seal pressures of 15, 30 and 45 psi. The ATG H-seal shoes little effect from the offset. There does not appear to be any rotor contact despite an effective clearance of 0.005”. All temperatures and pressures remain relatively constant during the offset and there appears to be no hysterisis.



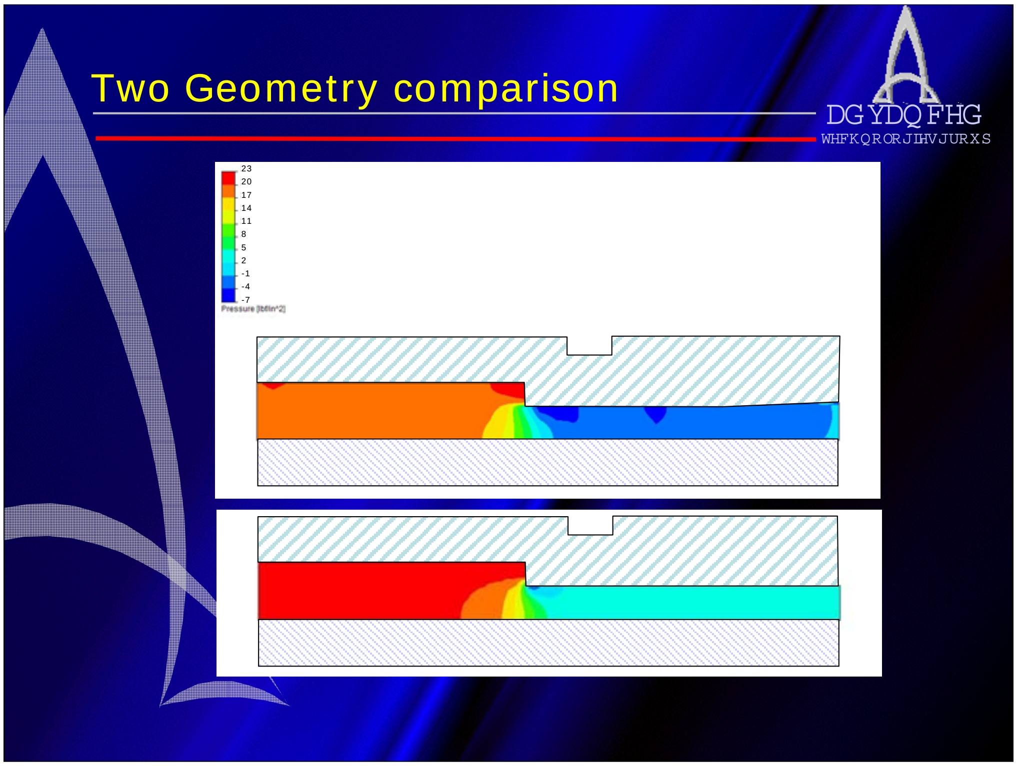
A free body diagram was developed to aid in the design and development of the H-seal. Static force can be applied. However, the seal is dynamic. As the seal moves toward or away from the rotor the pressures between them change.



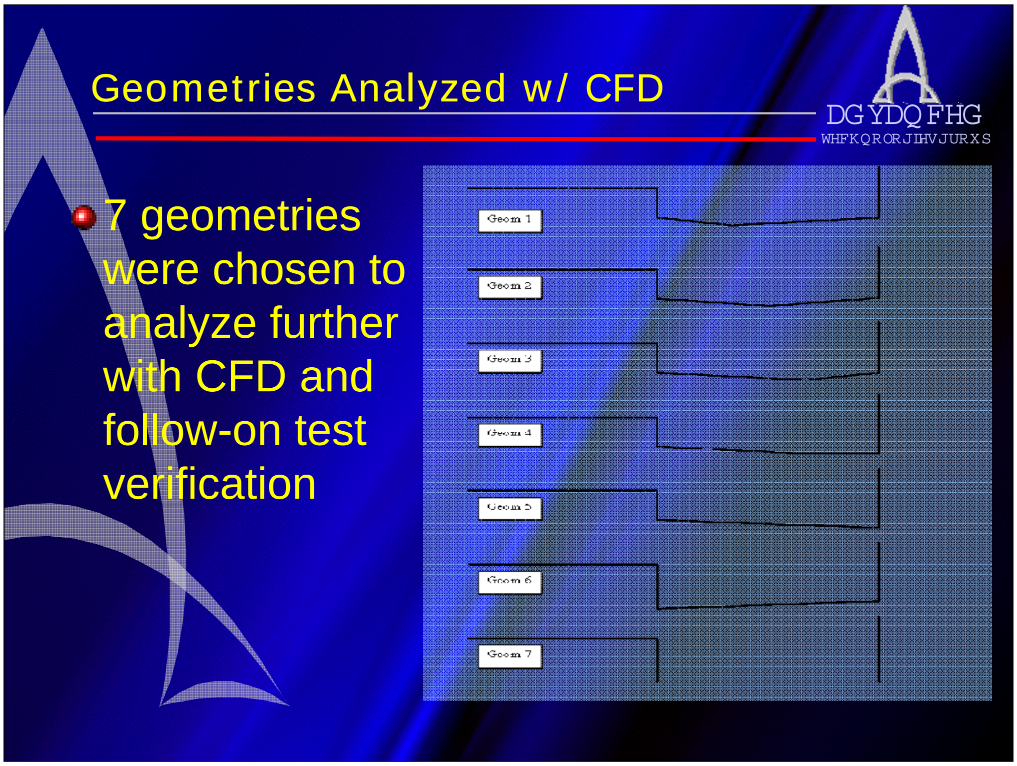
This seal has the narrow portion between the seal and rotor completely concentric. A small area at the entrance corner indicates a pressures below static discharge pressures. It is this low pressure that causes the seal to contract towards the rotor.



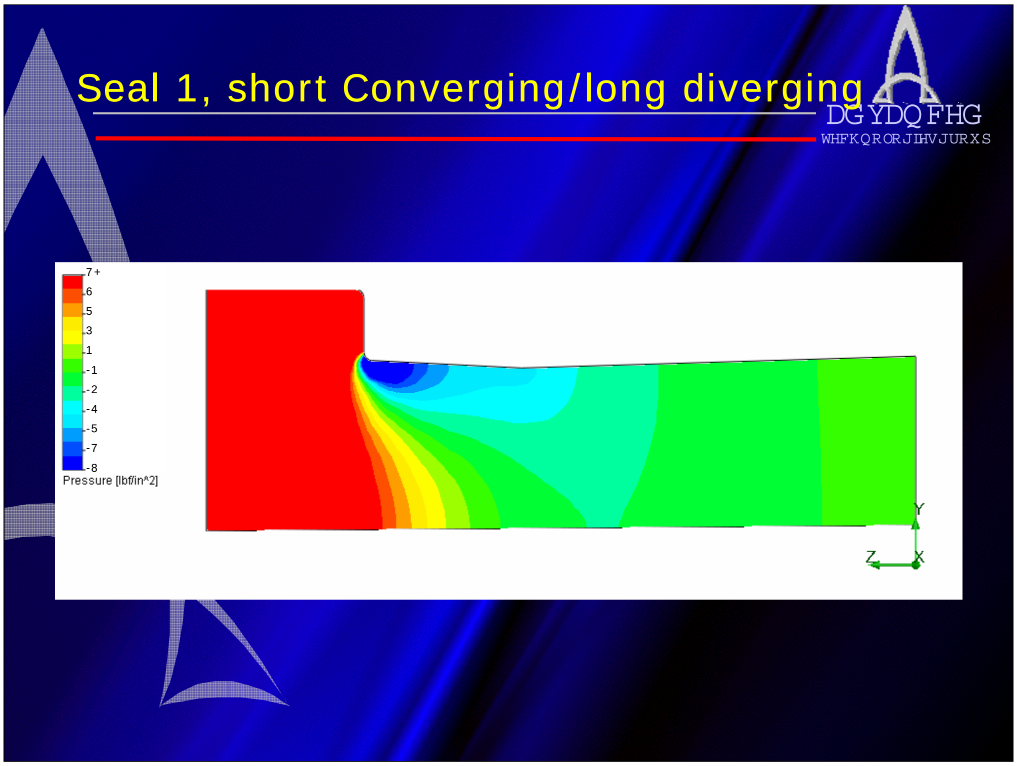
If a small divergent section is applied to the low pressure side of the seal seal pressures are reduces even further.

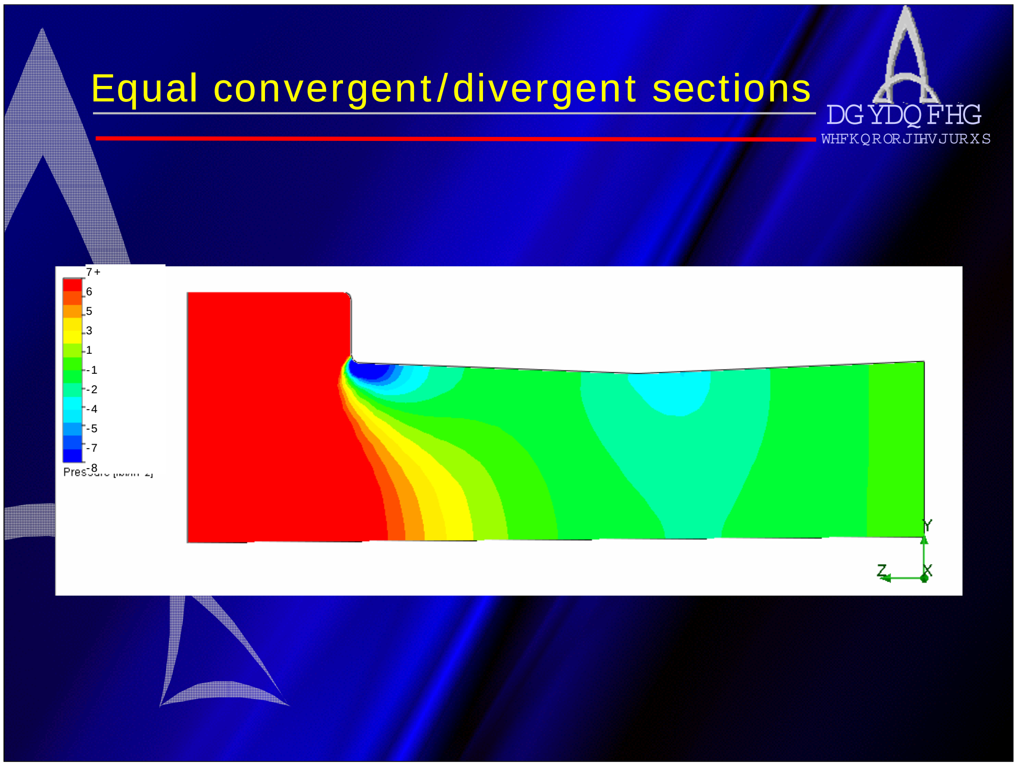


A graphic side by side comparison clearly shows what effect the small divergent section has on the static seal pressures.

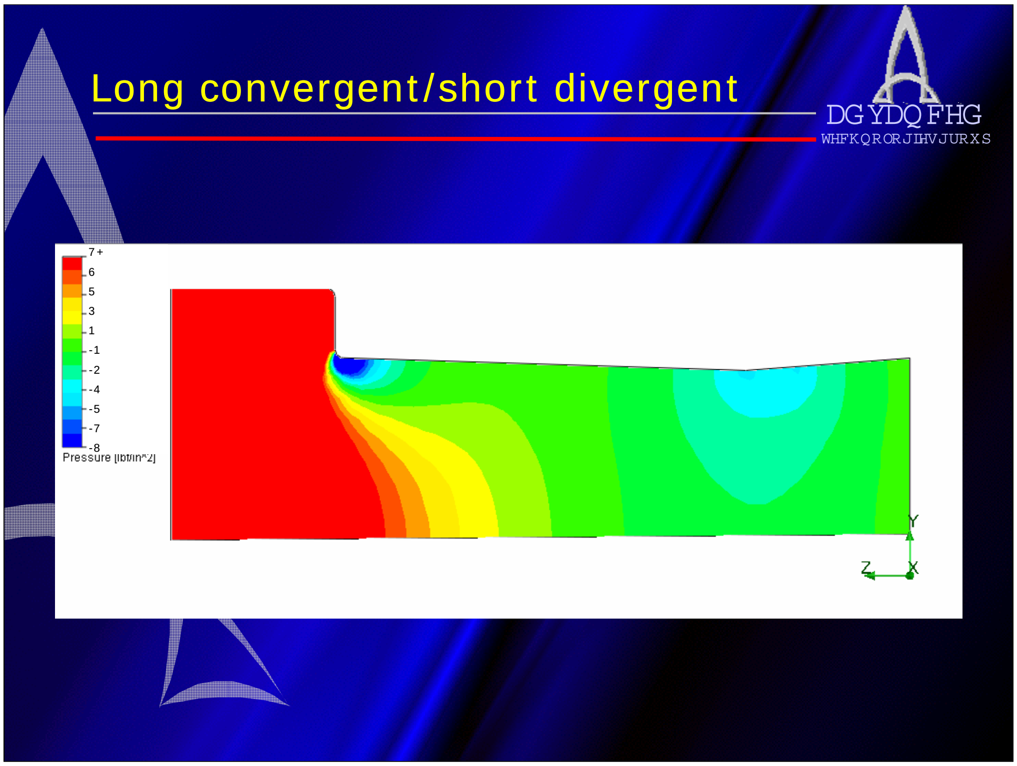


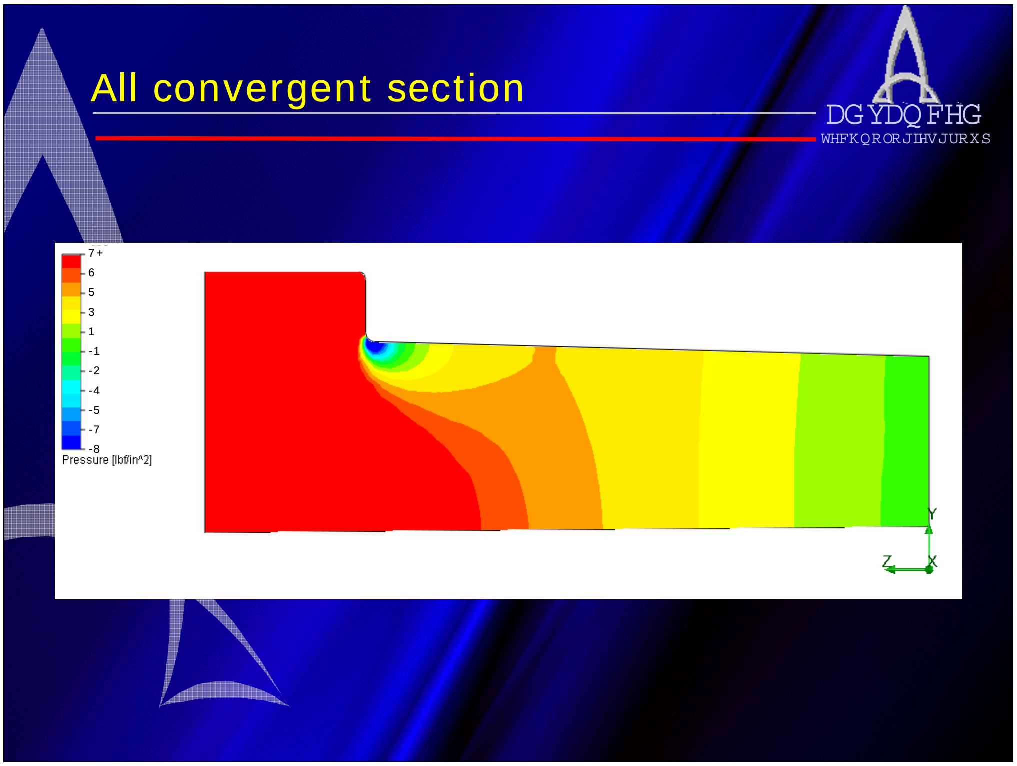
7 basic geometries were modeled to determine their effects on fluid static pressures.

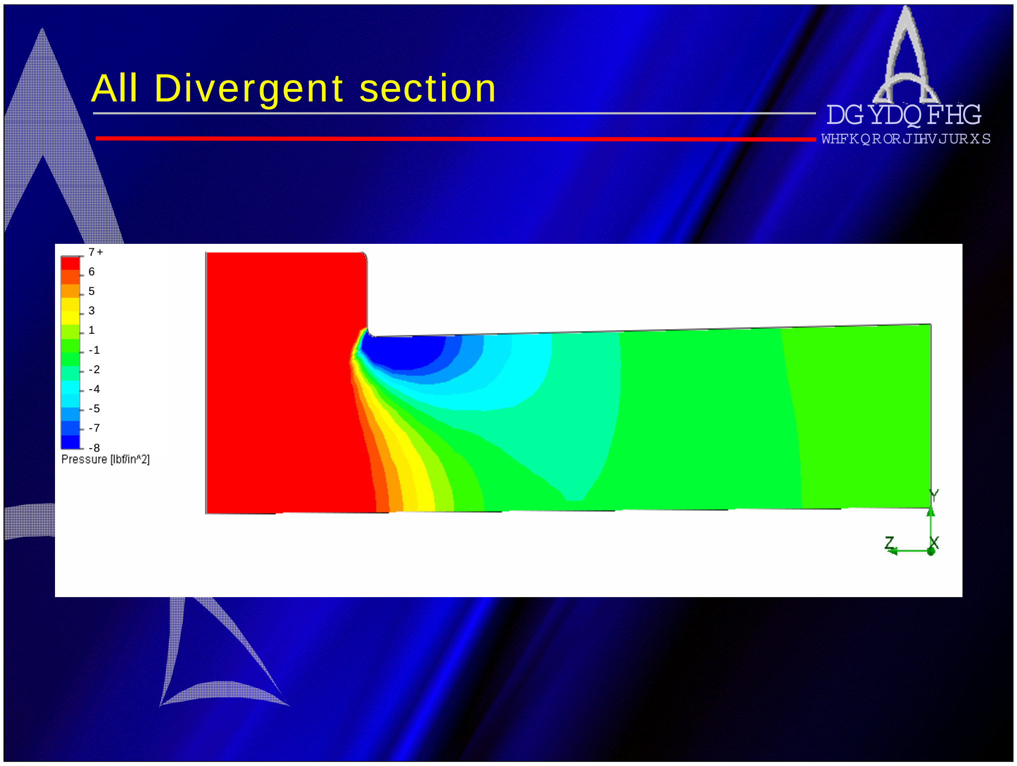

Seal 1, short Converging/long diverging
7+
6
5
3
1
-1
-2
-4
-5
-7
-8
Pressure [lbf/in^2]
Y
Z
X



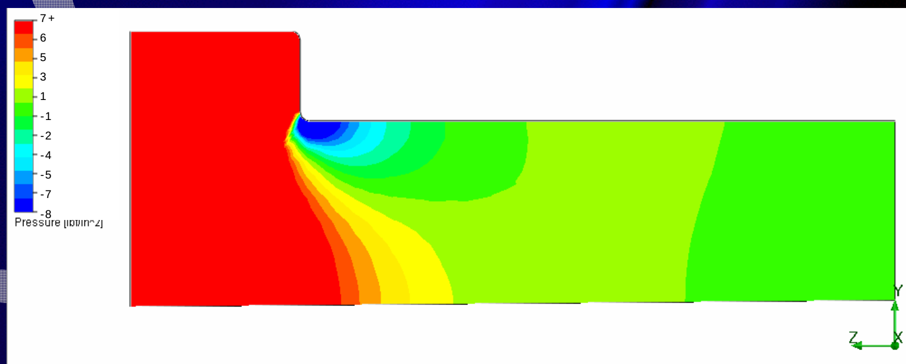
Equal convergent/divergent sections
7+
6
5
3
1
-1
-2
-4
-5
-7
-8
Y
Z
X

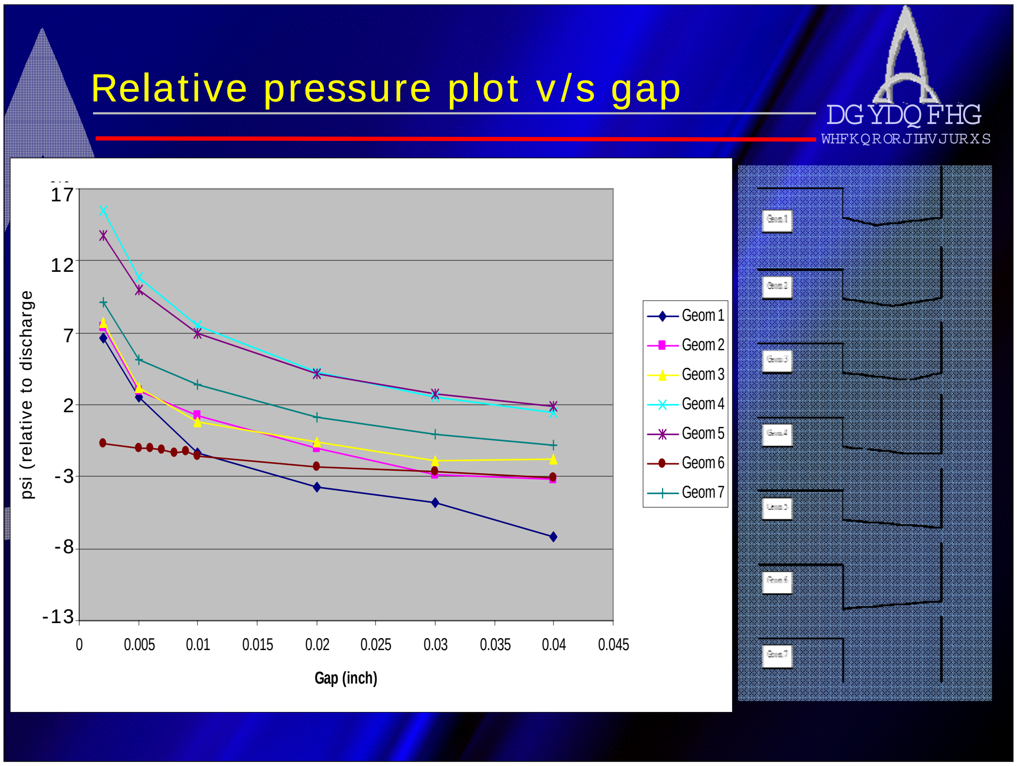

Long convergent/short divergent
7+
6
5
3
1
-1
-2
-4
-5
-7
-8
Pressure [lbf/in^2]
Y
Z
X


All convergent section
7+
6
5
3
1
-1
-2
-4
-5
-7
-8
Pressure [lbf/in^2]
Y
Z
X

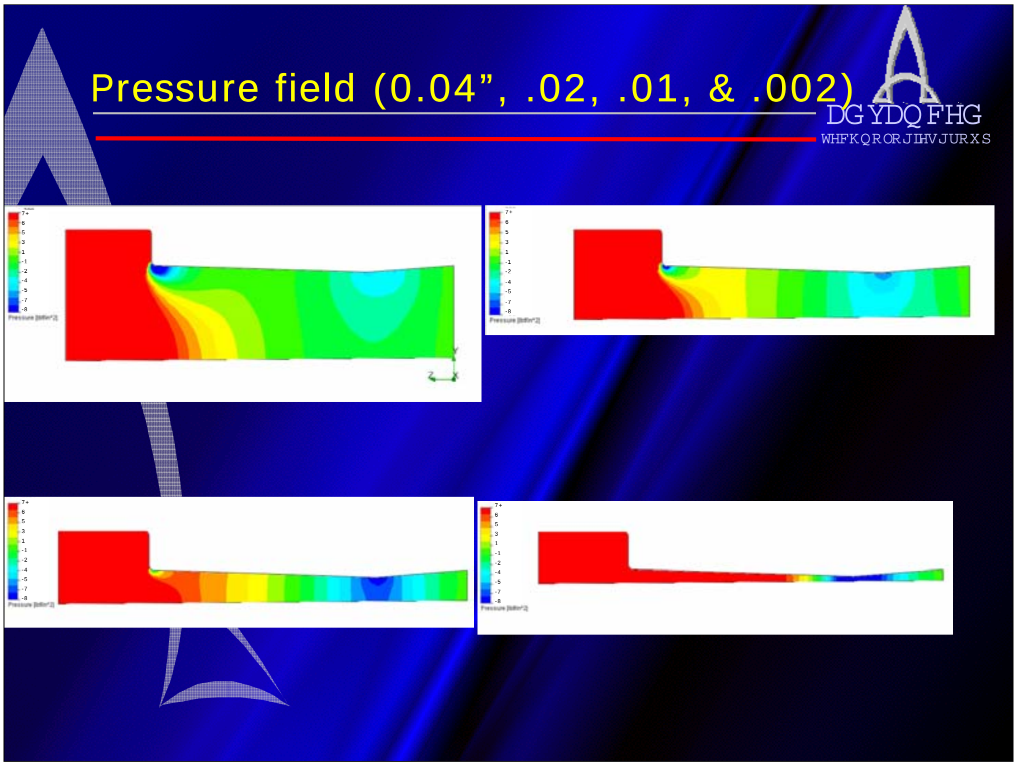

All Divergent section
7+
6
5
3
1
-1
-2
-4
-5
-7
-8
Pressure [lbf/in^2]
Y
Z
X

Straight seal section





The CFD static pressure results were then plotted over the seal surfaces to determine the overall force differences. Typically with all of the geometries as the seal gap closes, the pressure increases. Thus, the seal closes to a certain point and then the force balance is reached at different gaps based on the seal geometry. However, geometry 6 had static pressures which continued to always be negative, or lower than the discharge pressure. This could lead to seal contact and failure.



For geometry 3, the CFD plots for 4 different gap sizes.

Results/Conclusions

- CFD analysis provides a means of discerning H-seal functionality
- H-Seal geometry can be modified to provide smaller or larger operational gap
- H-Seal can be installed with large cold clearance and maintain a small operational effective clearance

CURRENT STATE OF DEVELOPMENT

- The technology is currently being applied to several engine applications
  - Design and test Higher delta P designs
  - Design and test High surface speed designs
  - Design and test seals over segmented rotor
- Extensive CFD analysis has been completed, more is being performed