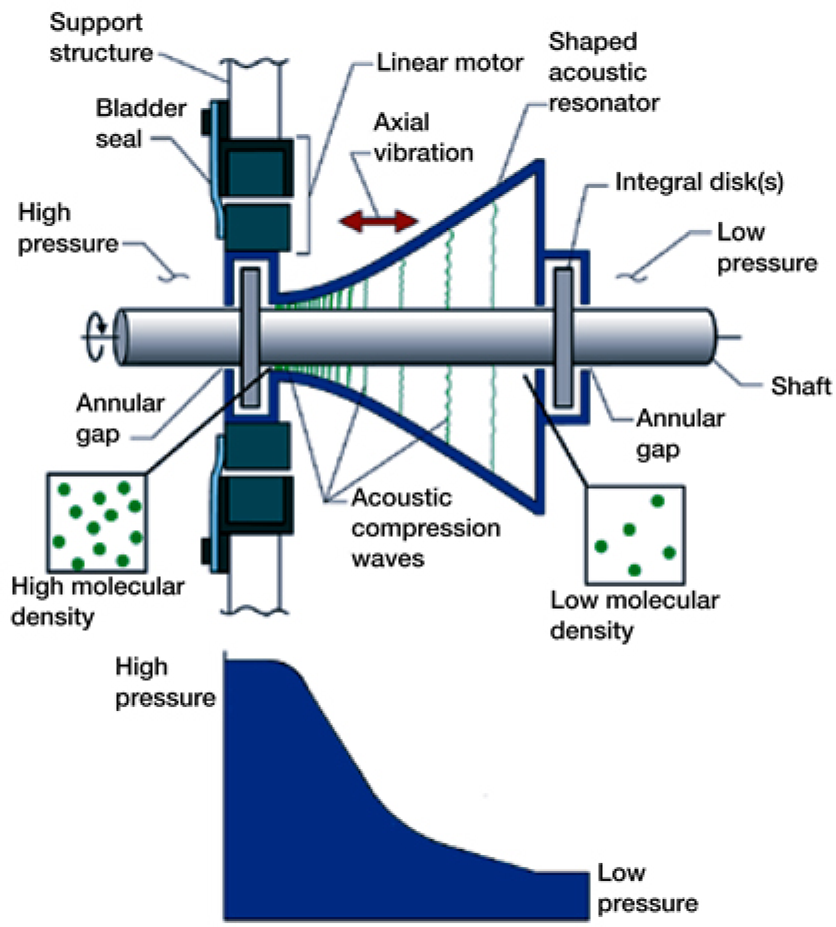
Nonlinear Acoustics Used To Reduce Leakage Flow

Leakage and wear are two fundamental problems in all traditional turbine seals that contribute to an engine's inefficiency. The solutions to seal leakage and wear conflict in the conventional design space. Reducing the clearance between the seal and rotating shaft reduces leakage but increases wear because of increased contact incidents. Increasing the clearance to reduce the contact between parts reduces wear but increases parasitic leakage. The goal of this effort is to develop a seal that restricts leakage flow using acoustic pressure while operating in a noncontacting manner, thereby increasing life.

In 1996, Dr. Timothy Lucas announced his discovery of a method to produce shock-free high-amplitude pressure waves. For the first time, the formation of large acoustic pressures was possible using dissonant resonators. A pre-prototype acoustic seal developed at the NASA Glenn Research Center exploits this fundamental acoustic discovery: a specially shaped cavity oscillated at the contained fluid's resonant frequency produces high-amplitude acoustic pressure waves of a magnitude approaching those required of today's seals.

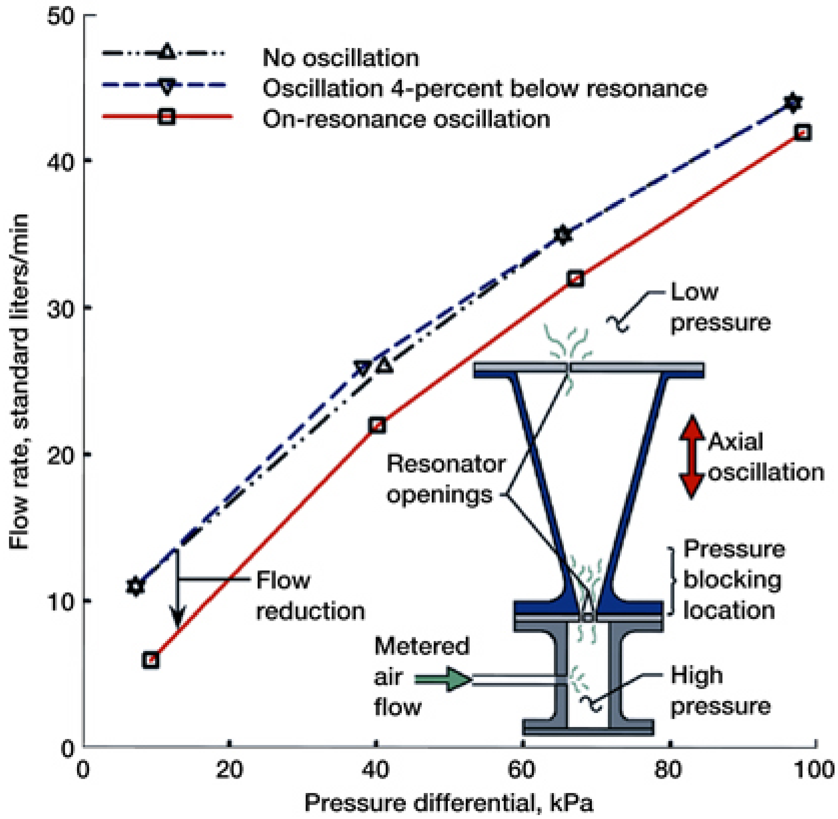
While the original researchers are continuing their development of acoustic pumps, refrigeration compressors, and electronic thermal management systems using this technology, the goal of researchers at Glenn is to apply these acoustic principles to a revolutionary sealing device. When the acoustic resonator shape is optimized for the sealing device, the flow from a high-pressure cavity to a low-pressure cavity will be restricted by a series of high-amplitude standing pressure waves of higher pressure than the pressure to be sealed (see the following figure). Since the sealing resonator cavity will not touch the adjacent sealing structures, seal wear will be eliminated, improving system life.



Top: Conceptual diagram of the acoustic seal. Bottom: Acoustically driven pressures are used to restrict flow through the seal.

Long description. The shaped acoustic resonator is oscillated axially between high-pressure and low-pressure cavities. The assembly is fixed to the stationary support structure by means of a bladder seal and is oscillated using a linear motor. A rotating shaft passes through the axis of the resonator with a meaningful clearance between the shaft and resonator. From the wide to narrow end of the resonator, a rise in pressure blocks the flow of air from the high-pressure to the low-pressure cavity

Under a cooperative agreement between Glenn and the Ohio Aerospace Institute (OAI), an acoustic-based pre-prototype seal was demonstrated for the first time. A pressurized cavity was attached to one end of the resonator while the other end remained open to ambient pressure (see the final figure). Measurements were taken at several values of applied pressure with the assembly stationary, oscillated at an off-resonance frequency, and then oscillated on-resonance. The three cases show that the flow through the conical resonator can be reduced by oscillating the resonator at the resonance frequency of the air contained within the cavity. The results are currently being compared with results obtained from a commercial computational fluid dynamics code. The objective is to improve the design through numerical simulation before fabricating a next-generation prototype sealing device. Future work is aimed at implementing acoustic seal design improvements to further reduce the leakage flow rate through the device and at reducing the device's overall size.



Experimental results showing flow reduction over the entire pressure range tested. Inset: Experimental pre-prototype acoustic seal used to assess leakage blocking capability.

Long description. The apparatus and results are detailed. The apparatus consists of a metered air supply flowing into a cavity, denoted as high pressure. The cavity has openings into the narrow end of the cone-shaped acoustic resonator through which air flows. The gas exits the wide end of the cone-shaped acoustic resonator to laboratory conditions, denoted as low pressure. The entire assembly is shown to oscillate axially. The flow rate of air is plotted against the pressure differential between the high-pressure cavity and the ambient pressure atmosphere. The baseline results, with no oscillation, show that flow rate increases with increasing pressure change. The flow rate recorded during oscillation at a frequency 4-percent lower than the resonance frequency is shown to differ little from the baseline case. Oscillation at the resonant frequency is shown to significantly reduce the flow rate of the air flowing through the cavity over the entire pressure range tested.

Find out more about this research at http://www.grc.nasa.gov/WWW/TurbineSeal/

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