DISCUSSION

L. Matsch[3]

This paper presents new and imaginative concepts in noncontacting face seal designs for jet engines that offer the combined potential advantages of long life and very low leakage rates. The authors indicate the manner by which such seals may be designed to meet the requirements of high performance and reliability through the utilization of current gas lubrication technology.

In establishing specific seal configurations for the SST jet engine, the authors have sought to satisfy explicit basic requirements through a step-by-step design procedure. It is with regard to the satisfaction of these basic requirements in the final configuration designs that the following questions and comments are directed.

Thermally induced axial deflections of the flexible seal and runner ensuing from the Fig. 8 temperatures are concluded by the authors to be insignificant. However, considering as the authors have that a 2 deg F axial temperature gradient exists across the seal, and assuming the seal to be totally free of constraint, differential axial deflection of this member is computed to be of the order 1.4×10^{-3} in. from the following expression:

$$W = \frac{\beta \Delta T(r_0^2 - r_i^2)}{2t}$$

The corresponding seal tilt angle, α, would thus be -1.07×10^{-3} radian with the sign convention that of Fig. 6. Beyond this, thermal distortion is that of the runner. For the same assumed 10 deg F axial temperature gradient, the differential axial deflection of this part within the seal region is 2.9×10^{-3} in. Distortion of the two parts are additive, and yield an effective seal tilt angle, α, of about -3.3×10^{-3} radian. The foregoing thermal distortions would necessitate a re-evaluation of the seal performance integrity during cruise operating conditions. It would also appear essential to perform thermal analyses of the seal at conditions corresponding to engine idle and takeoff, and to synthesize their results with the other performance criteria. In particular, the minimum film thickness of the seal during takeoff conditions would appear to be of possibly serious concern due to thermal distortions, which in this case would be additive to those induced by pressure unbalances.

In evaluating the dynamic performance of the flexible seal, the authors have superimposed results obtained separately for each of the three modes considered to obtain the total compromise in operating minimum film thickness. Such a direct superposition is considered by this discusser not necessarily to be in general conservative, particularly when the degradation in minimum film thickness associated with any one of the three modes becomes appreciable. A safer approach would be to simultaneously consider all three modes of distortion in the analysis.

[3] AiResearch Manufacturing Co., Phoenix, Ariz. Assoc. Mem. ASME.

Authors' Closure

The authors wish to thank the reviewer for his constructive comments in particular with regard to the thermoelastic deformation calculations performed to determine the extent of flexible seal and runner deformations. The formula presented on p. 7 was derived on the basis of a flat strip model and would indeed produce results which are less conservative than the ring distortion formula suggested by the reviewer.

Assuming now that one is to accept the reviewer's calculated seal tilt angle α of 0.0033 radians as the one actually in existence at the given steady state conditions of operation, then it can be shown that perfectly satisfactory performance can be achieved even under those conditions, the reason being simply the high flexibility of the stationary seal face in relation to the air film angular film stiffness. The flexibility of the seal ring in tilt can be calculated from

$$K_r = \frac{EI}{R^2}$$

where K_r is the seal ring tilt stiffness in $\frac{\text{in-lb}}{\text{radian}}$ per in. of circumference. Substituting the values given in the report,

$$K_r = 27 \ \frac{\text{in-lb}}{\text{radian}} \text{ per in.}$$

In comparison with the ring stiffness which represents in this case, the internal seal ring resistance to tilt, the angular film stiffness at cruise is of the order of $10^3 \ \frac{\text{in-lb}}{\text{radian}}$ per in. of circumference. As seen from Fig. 2, the magnitude of gas film restoring movement is thus more than sufficient to overcome the internal ring resistance to tilt and bring about a close to parallel film thickness condition in the presence of runner distortions. In further reference to the methods of thermal deformation calculations discussed so far, it should be pointed out that to obtain results which more closely approach actual distortions, it becomes imperative that final calculations include effects of variation in ring and seal cross sections as well as restraining effects of spring attachments and pressure deformations.

With regard to the suggestion of the discusser that all three modes of seal distortion be simultaneously considered in the dynamic seal response analysis, this approach, although undoubtedly ideal, could not be undertaken within the scope of this program.