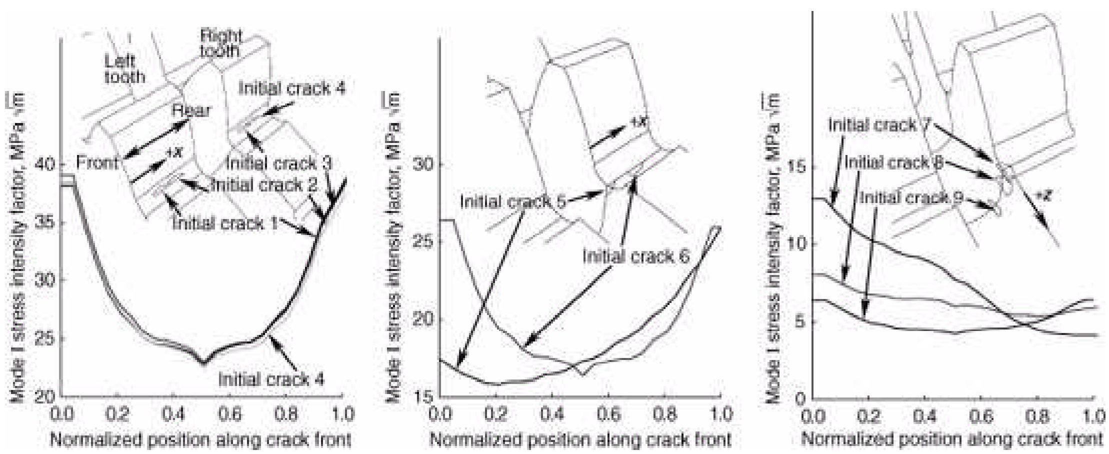
Three-Dimensional Gear Crack Propagation Studied

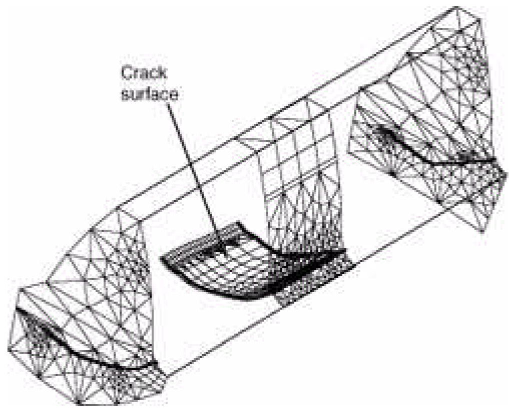
Gears used in current helicopters and turboprops are designed for light weight, high margins of safety, and high reliability. However, unexpected gear failures may occur even with adequate tooth design. To design an extremely safe system, the designer must ask and address the question, "What happens when a failure occurs?" With gear-tooth bending fatigue, tooth or rim fractures may occur. A crack that propagates through a rim will be catastrophic, leading to disengagement of the rotor or propeller, loss of an aircraft, and possible fatalities. This failure mode should be avoided. A crack that propagates through a tooth may or may not be catastrophic, depending on the design and operating conditions. Also, early warning of this failure mode may be possible because of advances in modern diagnostic systems.

One concept proposed to address bending fatigue fracture from a safety aspect is a split-tooth gear design (ref. 1). The prime objective of this design would be to control crack propagation in a desired direction such that at least half of the tooth would remain operational should a bending failure occur. A study at the NASA Lewis Research Center analytically validated the crack-propagation failsafe characteristics of a split-tooth gear (ref. 2). It used a specially developed three-dimensional crack analysis program that was based on boundary element modeling and principles of linear elastic fracture mechanics. Crack shapes as well as the crack-propagation life were predicted on the basis of the calculated stress intensity factors, mixed-mode crack-propagation trajectory theories, and fatigue crack-growth theories.



Effect of initial crack location on mode I stress intensity factors. Left: Tooth fillet locations. Center: Tooth foot locations. Right: Tooth groove locations.

The preceding figures show the effect of the location of initial cracks on crack propagation. Initial cracks in the fillet of the teeth produced stress intensity factors of greater magnitude (and thus, greater crack growth rates) than those in the root or groove areas of the teeth. Crack growth was simulated in a case study to evaluate crack-propagation paths (see the following figure). Tooth fracture was predicted from the crack-growth simulation for an initial crack in the tooth fillet region. This was the desired failure mode for an ultrasafe design. Lastly, tooth loads on the uncracked mesh of the split-tooth design were up to five times greater than those on the cracked mesh if equal deflections of the cracked and uncracked teeth were considered. This effect needs to be considered in the design of a split-tooth configuration.



Exploded gear tooth view of predicted crack growth after 15 steps.

This work was done in-house at Lewis in support of the National Rotorcraft Technology Center project, Ultra-Safe Gear Design, with the Boeing Defense and Space Group. The crack-propagation package was developed by the Cornell Fracture Group at Cornell University. The reported results, which are the initial findings of Lewis' gear-crack-propagation research for the Rotorcraft Base Program, will be further investigated to develop generalized gear design guidelines.

References

1. Drago, R.J.; Sane, A.D.; and Brown, F.W.: UltraSafe Gear Systems for Critical Applications--Initial Development. AGMA TP-97FTM10, 1997.

2. Lewicki, D.G., et al.: Three-Dimensional Gear Crack Propagation Studies. NASA TM-1999-208827, 1999.

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