System Would Detect Foreign-Object Damage in Turbofan Engine

Vibration-sensor and gas-path-analysis data would be fused.

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A proposed data-fusion system, to be implemented mostly in software, would further process the digitized and preprocessed outputs of sensors in a turbofan engine to detect foreign-object damage (FOD) [more precisely, damage caused by impingement of such foreign objects as birds, pieces of ice, and runway debris]. The proposed system could help a flight crew to decide what, if any, response is necessary to complete a flight safely, and could aid mechanics in deciding what post-flight maintenance action might be needed.

The sensory information to be utilized by the proposed system would consist of (1) the output of an accelerometer in an engine-vibration-monitoring subsystem and (2) features extracted from a gas path analysis. ["Gas path analysis" (GPA) is a term of art that denotes comprehensive analysis of engine performance derived from readings of fuel-flow meters, shaft-speed sensors, temperature sensors, and the like.]

- The acceleration signal would first be processed by a wavelet-transform-based algorithm, using a wavelet created for the specific purpose of finding abrupt FOD-induced changes in noisy accelerometer signals. Two additional features extracted would be the amplitude of vibration (determined via a single-frequency Fourier transform calculated at the rotational speed of the engine), and the rate of change in amplitude due to an FOD-induced rotor imbalance.
- This system would utilize two GPA features: the fan efficiency and the rate of change of fan efficiency with time.

The selected GPA and vibrational features would be assessed by two fuzzy-logic inference engines, denoted the "Gas Path Expert" and the "Vibration Expert," respectively (see Figure 1). Each of these inference engines would generate a "possibility" distribution for occurrence of an FOD event: Each inference engine would assign, to its input information, degrees of membership, which would subsequently be transformed into basic probability assignments for the gas-path and vibration components. The outputs of the inference engines would be fused by use of Dempster's combination algorithm (more precisely, an algorithm, based on the Dempster-Shafer-Yager theory of evidence, for fusing uncertain or imprecise information) to provide a reduced body of information to a human or computer decision maker. Figure 2 depicts some outputs generated in response to simulated accelerometer and GPA signals.

This work was done by James A. Torso of QSS Group, Inc. and Jonathan S. Litt of the U. S. Army Research Laboratory for **Glenn Research Center**. *Further information is contained in a TSP (see page 1).*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17843-1

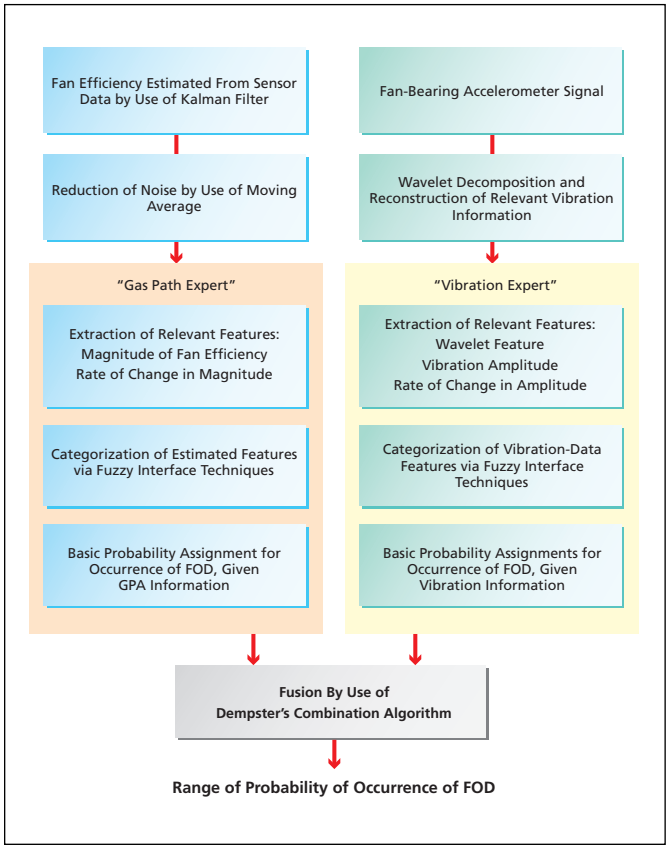

Figure 1. **Outputs of Two "Experts"** (fuzzy-logic inference engines) would be fused at the feature level by means of Dempster's combination algorithm.

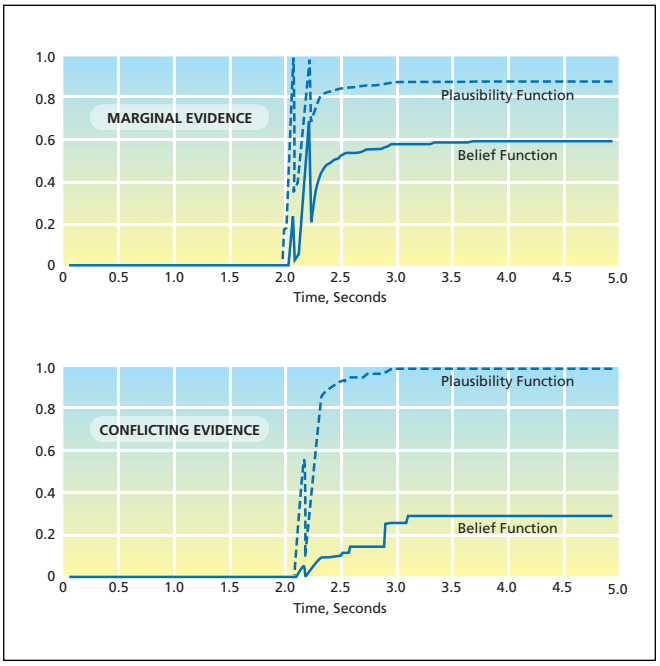

Figure 2. These **Example Outputs** of the proposed system were generated in response to simulated vibrational and GPA inputs characteristic of marginal and conflicting evidence, respectively, of occurrence of an FOD event near the 2-second time mark.