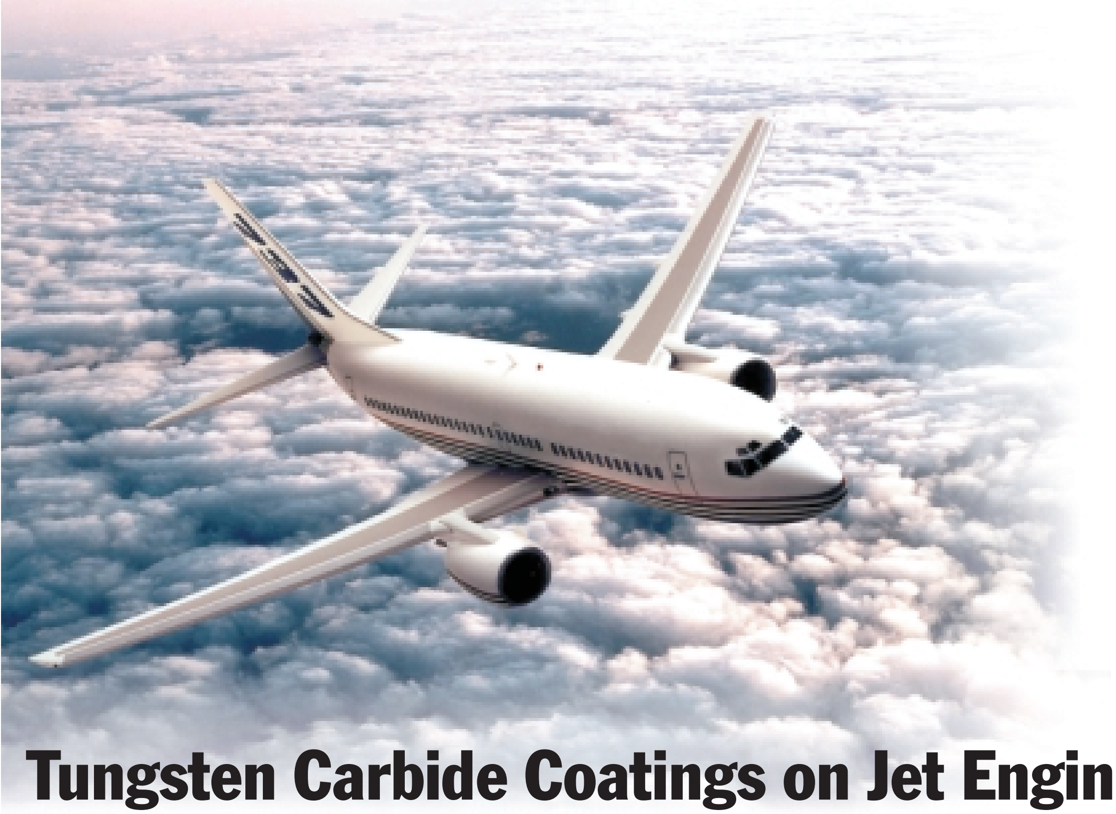

1■ *To enhance jet engine operational reliability, Volvo Aero Corporation applies tungsten carbide coatings to mid-span dampers of fan blades. This will increase the service life of these dampers.*

Tungsten Carbide Coatings on Jet Engine Components:

Safe Aviation

JAN WIGREN
LARS PEJRYD
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Tungsten carbide thermal spray coatings are used in the aerospace industry to mitigate mid-span damper wear on jet engine blades. In some cases, however, the fatigue life of the blade may actually be reduced if a coating is applied, or the coating may fail. The Volvo Aero Corporation in Trollhättan (Sweden) has comprehensively investigated various coating systems in collaboration with the University of Tulsa, Oklahoma (USA); the Sulzer Metco process was found to be the best one. On the following pages, we publish a short version of Jan Wigren's report on the investigation.

The vibration of fan blades in jet engines (Fig. 1■) can be controlled by the use of mid-span dampers (Fig. 2■) as a point of contact between the blades. Tungsten carbide (WC) thermal spray coatings are often applied to the contact surfaces of the dampers to reduce wear and, while the technique has proved successful in this respect, coating failures have been observed due to cracking and spalling caused by cyclic fatigue and impact. This can result in impaired coating performance or continuous crack propagation through the damper, culminating in complete engine failure. Based on existing studies, residual stresses had to be suspected of being the most decisive cause of these failures. Therefore, different factors contributing to this phenomenon have been studied in depth.

SEVEN PROCESSES, THREE COATING MATERIALS

This article concentrates on the residual stress, bending crack resistance and low-cycle fatigue test results, since the characteristics of which they are representative accord with in-service observations and engine performance evaluations. The coating materials selected for study were tungsten carbide thermal spray coatings with cobalt (1), nickel (2), or cobalt/chromium (3) binders. Seven HVOF (High Velocity Oxy Fuel) processes (A to G) and one plasma spray process (H) have been used to apply the coatings, including a system by Sulzer Metco. As an

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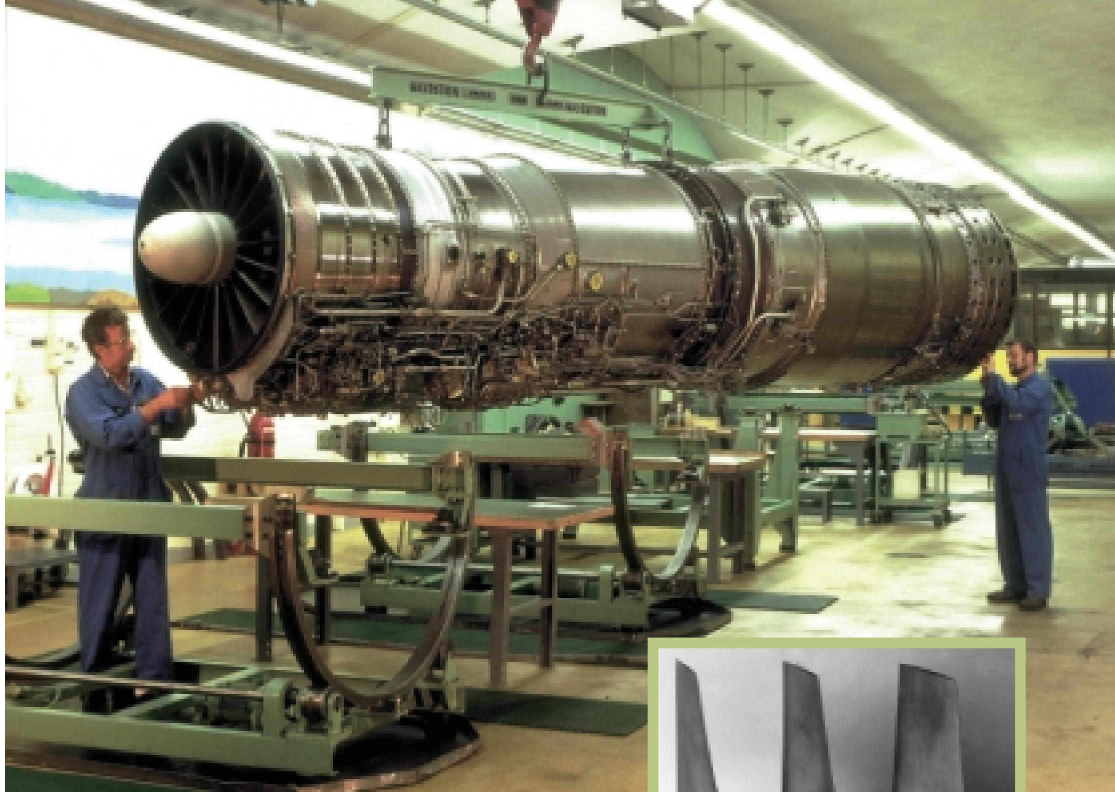
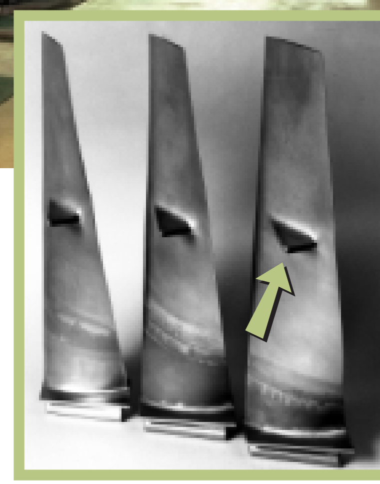
example, the coating system designation A-1 indicates a WC-Co coating applied by the HVOF process 'A'. The substrate was Ti-6Al-4V in all cases.

To determine the through-thickness residual stress distribution, the layer has been removed from the specimen, followed by measuring the change in strain of the substrate. Figure 3■ shows the typical through-thickness residual stress distribution in the longitudinal direction for the coating systems E-3 and F-1. The E-3 result indicates residual tensile stresses in the coating and residual compressive stresses in the substrate, close to the interface. In the F-1 case, it is noteworthy that the residual stress profiles of these two systems are opposite in sign, although the coating compositions and application processes are similar.

RESISTANCE TO CRACKING IN BENDING

Figure 4■ illustrates the three-point bending test used to determine the coating crack resistance under a bending load. The test was designed to simulate the bending-strain configuration on a mid-span damper subject to centrifugal forces. Every coating system has been evaluated by the extension of the cracked area and the crack length.



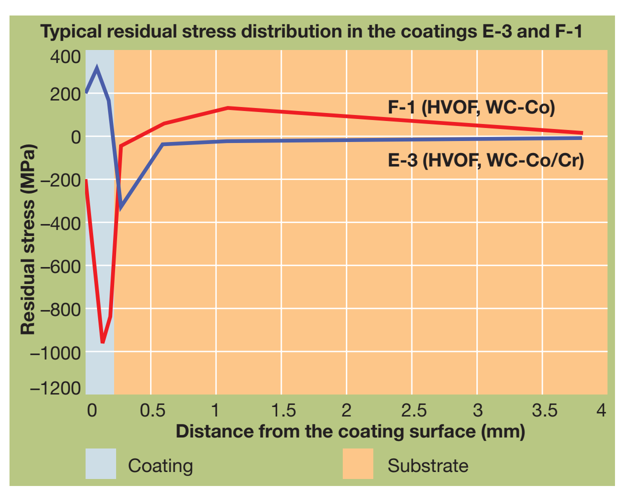


2■ *Mid-span dampers (arrow) are used as a point of contact between the fan blades to reduce vibration.*

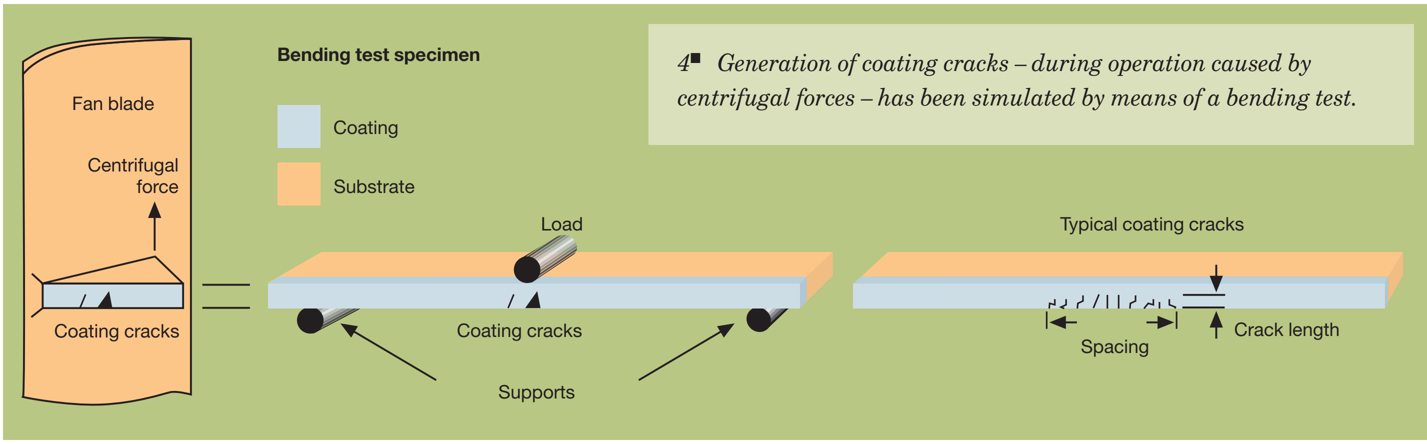
STRESS/PERFORMANCE CORRELATION

Certain observations can be made regarding the correlation between residual stress and the performance characteristics of a coating system. Those coatings in which the residual stresses were compressive exhibited the highest rankings, while those with tensile residual stresses displayed reduced crack resistance. These results suggest that compressive residual stresses will greatly enhance the resistance of the coating to cracking under a bending load.

Regarding the substrate fatigue life, which has been extensively investigated as well, a substrate

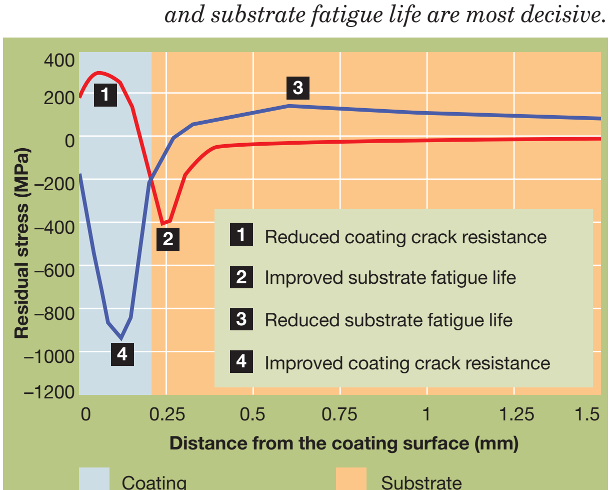


3■ *Remarkable results have been found on residual stress measurement. The through-thickness residual stress distribution is completely different for the coatings E-3 and F-1, although similar coating materials had been applied using similar HVOF coating systems.*



4■ Generation of coating cracks – during operation caused by centrifugal forces – has been simulated by means of a bending test.

5■ For selecting a suitable coating system, the relationships between residual stress, coating crack resistance and substrate fatigue life are most decisive.



with a compressive residual stress may be significantly superior to one in which the stress is tensile – an interesting result since, in a substrate of that type, the coating stress is likely to be tensile, reducing the crack resistance.

The findings relating to coating crack resistance in bending and substrate fatigue life suggest that a coating system may be specified on the basis of the residual stress in the coating and the component design criteria. For example, the fatigue life of the substrate in a system with a relatively high coating crack resistance (due to compressive residual stress) may be lowered by a tensile residual stress in the substrate itself. A system of this type would be specified if cracking of the coating was unacceptable and the reduction in substrate fatigue life could be compensated for by the design of the component. On the other hand, a system with a relatively low coating crack resistance (the result of tensile residual stress) might have a higher substrate fatigue life as a result of compressive residual stress in the latter. This type of system would be the choice if cracking of the coating was acceptable and substrate fatigue life was the most important design criterion. The relationships between residual stress, coating crack resistance and substrate fatigue life are plotted in Figure 5■.

TESTING UNDER SERVICE CONDITIONS

Three coatings have been selected as examples because of their different properties in this context. Systems A-1 and F-1 exhibit superior coating crack resistance, while H-1 possesses superior substrate fatigue life. All three systems were evaluated on fan blades with mid-span dampers in a jet engine, under test conditions designed to simulate actual service conditions. The engine performance evaluations were used to validate the final coating selection.

The engine test evaluation figures suggest that coating systems in which the residual stress in the coating is compressive are superior to such in which the stress is tensile. Figure 6■, however, shows a mid-span damper coated with the system F-1 – the one with the highest value of compressive coating residual stress – in which spalling failure of the coating occurred during the engine test. The reason for this failure may be that the high compressive residual stress in the coating is close to the ultimate compressive strength of the tungsten carbide material. This supports the contention that compressive residual stress in the coating is essential to satisfactory mid-span damper performance, provided that the sum of the in-service and residual stresses is below the level at which spalling occurs.

During the tests, the Sulzer Metco type Diamond Jet Hybrid system (Fig. 7■) was found to be the optimum coating system. It was selected for mid-span damper production on the basis of the bending and fatigue life test results, residual stress evaluations and performance test findings. The chosen system gives exactly the residual stress distribution which is ideal for the purpose: The compressive residual stress in the coating was shown to be sufficiently low to prevent spalling, while the coating exhibited the best performance under engine operating conditions. Till today, mid-span dampers coated with the selected system have sustained many operating hours without failure. Ω

6■ *Although a coating in which the residual stress is compressive is normally superior in performance to one in which the residual stress is tensile, the coating system with the highest compressive stress (F-1) failed during a test under service conditions due to spalling of the coating.*

INFO DIRECT

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7■ *After extensive investigation, the HVOF installation type Diamond Jet Hybrid by Sulzer Metco was found to be the optimum coating system. This result has been confirmed meanwhile by thousands of jet engine service hours without failure.*