Summary

The Symposium on Case Histories Involving Fatigue and Fracture Mechanics showcased the most recent applications of fatigue and fracture mechanics analyses. In order to assemble this showcase, papers were solicited which described (1) how fatigue and fracture mechanics concepts were employed to design new structures and (2) how these concepts were used either to evaluate the integrity of structures containing defects or to determine why structures failed. The symposium was successful in attracting 24 papers which described the latest fatigue and fracture mechanics applications. This publication contains twenty-two of these papers. A brief summary of each follows.

Rahka described the cracking of a hydrogenerating pressure vessel. This cracking resulted from hydrogen attack of improperly-alloyed weld metal in the vessel. A detailed fracture mechanics analysis showed the existing cracks did not threaten the structural integrity of the vessel. Consequently, it was allowed to remain in service until a scheduled shutdown.

Smith explained that radial cracks frequently develop in the nozzle corners of nuclear pressure vessels. Generally, these cracks are initiated by thermal shock, and then propagated by subsequent pressure cycles. Small-scale pressure vessels have been fabricated and tested to study the initiation and growth of these flaws. Smith employed frozen-stress photoelastic methods to determine the validity of applying the results of tests on small-scale vessels to full-size vessels. The frozen-stress method showed the flaw shapes for the small- and full-scale vessels were basically similar. However, the stress-intensity factor distributions were as much as two times higher in the small-scale vessels than in the full-scale ones. Thus test results generated on small-scale vessels were conservative when applied to the full-scale vessels.

Kaplan, Willis, and Barnett analyzed the failure of a hatch cover on a pressurized cement barge. The hatch failed when it was partially unlocked to bleed air from the barge. The remaining locks on the hatch were unable to carry the pressure load, and the hatch failed. Detailed testing and analysis indicated the hatch design, hatch material, and barge design all contributed to the hatch failure.

Pearson and Dooman studied the explosion of a truck-mounted propane tank. An initial investigation located a crack in the tank. This crack was believed to be the cause of failure. However, fracture mechanics analysis showed the tank should not have failed at normal operating pressure even with the crack present. Further investigation showed (1) the relief valve on the tank was corroded shut; (2) the truck driver had overfilled the tank with liquid propane (a properly filled tank contains no more than 82.4% liquid); and (3) heat from the motor exhaust and the sun could raise the tank pressure to the bursting point. Factors (1) through (3), plus the crack in the tank, all combined to fail the tank.

Chow and Simpson described the sudden failure of a Zircaloy-2 pressure tube in a nuclear reactor. This tube was encased in a concentric Zircaloy-2 tube to insulate it from the reactor coolant. During construction, one of the spacers which maintain the concentricity of the tubes was displaced. Thus the two tubes contacted each other. The resultant heat sink led to the development of zirconium hydrides in the pressure tube. These hydrides led to cracking of the tube, and a reduction in the fracture toughness of the material. The crack subsequently propagated to a critical size and failed the tube. Fracture mechanics analyses and tests were conducted to confirm the sequence of events leading to the failure.

Reid and Baikie described the material selection process for the design of high pressure penstocks. Two steels were considered for these penstocks. A series of stress, fracture mechanics, and cost analyses were performed to establish which of these two steels would be most satisfactory. In addition, these analyses were used to establish defect acceptance standards and inspection intervals for the penstocks. This paper presents the specific procedures used in evaluating the two steels.

Christensen and Hill studied the impact of longitudinal weld-toe cracks on the structural integrity of pipeline steel. Their study indicated that the depths of these cracks were only one-third of the critical flaw depth. They confirmed their analysis with a full-scale pressure test on a cracked pipe section. A subsequent fatigue-crack-growth analysis showed 20 full-pressure cycles per day were required to propagate the existing toe cracks to failure in a 30 year period. Finally, tests confirmed that cathodic charging had no detrimental effects on the pipeline material.

Reemsnyder explained that fatigue cracks frequently developed at pin holes in the legs of off-shore oil drilling rigs. These cracks developed while the rigs were enroute from their fabrication sites to their installation sites. Studies showed the cracks resulted from a combination of high cyclic stresses and tensile residual stresses at the pin holes. To alleviate this cracking (1) the cyclic stresses were reduced by modifying the intransit configuration of the rigs thereby reducing vortex shedding, and (2) the residual stresses were reduced by thermal stress-relief following pin hole fabrication. No cracking has occurred at the pin holes since the vortex shedding and stress-relief steps were taken.

Nelson and Hampton investigated the failure of a large wind tunnel compressor blade. They found that a crack had initiated at a scratch in the shank of the blade and subsequently propagated to failure. Analysis indicated that crack propagation was aggravated by operation of the compressor at or near its resonant frequencies. Operation at these frequencies introduced high stresses in the blade. In order to prevent a recurrence of such a failure, (1) special procedures were developed for blade installation in order to reduce the risk of scratching the blades; (2) the compressor was required to pass through resonant frequencies as quickly as possible in order to reduce the number of high-stress cycles and (3) a regular inspection interval was established to detect cracks before they approached a critical length.

Cipolla, Grover, and Richman performed both one- and two-dimensional stress analyses of a burst compressor disk. These analyses showed a defect-free disk should not have burst in the short time the disk was in service. Further study showed the disk was subjected to nonroutine processing during fabrication. Normally, such disks are heated and quenched prior to final machining. Such processing frequently introduced quench cracks which were subsequently removed during final machining. However, investigation showed the burst disk was heat treated and quenched after final machining. Thus, quench cracks could have been present when the disk was initially put into service. The authors proposed that the growth of these quench cracks led to premature failure of the disk.

Selz and Peterson described the rationale used to develop inspection intervals for high-pressure heater vessels. This rationale involved (1) location of the high-stress areas; (2) determination of the maximum flaw size which could escape detection during inspection; (3) calculation of the number of cycles required to propagate the flaw in (2) to a critical length; and (4) selection of a safety factor which permitted location of the flaw prior to its reaching a critical length. The authors describe in detail the procedures used in completing steps 1 through 4.

Chang explained that welded structures frequently contain crack-like flaws. He described a computer code for predicting the growth of these flaws. This code, named EFFGRO III, was used to predict the growth of embedded flaws in welded aircraft structures. The effects of residual stresses were included in these predictions. The prediction results were compared with test results and good correlations were found.

Rich, Pinckert, and Christian reported that cracks were found in fastener holes in the compression-loaded spar caps of F-15 aircraft. Analysis indicated that the local stresses around the holes exceeded the material's compressive yield strength. Upon unloading, residual tensile stresses were introduced at the holes. The authors developed an analytical model for predicting the role of these tensile stresses in initiating and propagating cracks in the spar caps. This model was used to predict crack initiation and propagation to a predetermined size. The U.S. Air Force used these predictions to set overhaul intervals for their F-15 aircraft.

Howard reviewed the inflight failure of an aircraft horizontal stabilizer. The failure resulted from a fatigue crack in the top chord of the stabilizer. This crack propagated through the chord and subsquently failed it. Once the chord failed, the stabilizer separated from the aircraft and it crashed. Inspection of the fracture surfaces indicated the crack propagated by fatigue intermixed with a series static crack jumps. Fracture mechanics analysis techniques were used to explain the growth sequence of the crack.

Saff and Ferman reported that fuel-structure interaction dynamics significantly increased stresses in wet-wing aircraft. These high stresses produced drastic reductions in fatigue life as compared to the life of dry-wing aircraft. Combinations of vibration loads and internal pressure were found to cause even further reductions in fatigue life. They presented procedures for predicting fatigue lives under dynamic conditions. Laboratory tests were strongly recommended to validate the predictions.

Denyer explained how fracture mechanics techniques were used to track fatigue damage accumulation in the wing structure of the T-39 aircraft. These techniques were used to compute the remaining structural life, and to establish inspection intervals for each aircraft. Tracking was accomplished by analyzing flight records and then using the analytical results to predict the growth of flaws. The paper described the crack-growth procedures used in making these predictions.

Rich and Orbison described the failures of two dies. One die was used to swage fittings onto wire ropes, the other to mold gears in a powder metallurgy process. Detailed analysis and inspection showed the swaging die failed as a result of a combination of high stresses, low material toughness, and small fabrication cracks. The powder metallurgy die failed as a result of the growth of a fatigue crack to a critical size.

Clarke investigated the failure of an arbor on a lumber mill trimming saw. Visual inspection indicated the crack initiated at an abrupt change in the diameter of the arbor. Initially, the stress concentration associated with this diameter change was thought to be responsible for the failure. However, a detailed fatigue analysis showed the operating stresses were too low to initiate a fatigue crack. Further study of the lumber mill operations showed a piece of steel had recently contacted the saw and knocked off several teeth on the blade. The imbalance loads associated with the loss of these teeth were adequate to initiate a fatigue crack. Once the damaged blade was replaced, the service loads were adequate to propagate the crack to a critical size.

Tubby and Wylde investigated the effects of six parameters on the fatigue resistance of welded joints. They found that (1) the material's ultimate tensile strength and fracture toughness, and (2) weld residual stresses had relatively little effect on fatigue resistance. They further found that contouring the weld joint was somewhat beneficial, but was probably not cost effective. Finally, they reported that stress concentrations and material thickness had significant impacts on fatigue resistance. Both high stress concentrations and thicker materials had lower fatigue resistances.

Mattheck, Kneifel, and Morawietz described the fracture of intramedullary nails which are used to repair fractures in large bones. Fatigue cracks initiated at slots and screw holes in the nails. The growth of these cracks was predicted using fracture mechanics techniques. The procedures for making these predictions, and for predicting crack arrest, were presented. A new design for the intramedullary nails was proposed. This design was expected to have considerably lower stress concentrations, and consequently longer fatigue lives.

Rimnac, Wright, Bartel, and Burstein investigated the failure of twenty-one hip implants. They found that fatigue cracks initiated on both the medial and lateral surfaces of the implants and then propagated to critical lengths. Crack development was attributed to the basic design of the implant, the high applied stresses and the properties of the AISI 316L stainless steel used for the implant.

Demaid and Lawley described the failure of an elevator brake rod. Inspection showed this failure resulted from the initiation and growth of fatigue cracks at the root of screw threads on the brake rod. Detailed stress analyses and stress measurements defined the stress distribution within this rod. These analyses and measurements were then used to approximate the life of the brake rod using fracture mechanics procedures. The inherent vulnerability of single-load-path structures was most clearly manifest in this case history.

C. M. Hudson
NASA-Langley Research Center, Hampton, VA 23665; cochairman and coeditor.

T. P. Rich
Bucknell University, Lewisburg, PA 17837; cochairman and coeditor.