

Structural Integrity of Ageing and Modern Airplane Structures – with Special Attention to Composites

COURSE OUTLINE

- **Cost of Fracture**
- **The Danger of Metal Fatigue**
 - Early transportation failures
 - Wright Flyer, Comet, F-111 crash
 - Structural Failure Modes
 - Environmentally induced and/or time-dependent failure modes
 - Creep, Fatigue, Corrosion, Wear, Fretting, Hydrogen Embrittlement
 - Synergistic processes
 - Corrosion fatigue, fretting fatigue, SCC, high temperature fatigue
 - Why High Strength materials are weak in fatigue!
 - Crack Initiation and Propagation
 - Design Strategies to combat Metal Fatigue
 - Safe Life
 - Safety Factor fantasies
 - Fail Safe
 - 1. Crack Arrest
 - 2. Multiple Load Path (Structural Redundancy)
 - Design for inspectability
- **Fractography**
 - What does a fatigue crack look like?
 - Striations and Beach Marks
 - Quantitative and qualitative use
 - Ratchet lines, Marker cycles
 - Guides on using Fractography
 - Scanning Electron Microscope
 - Use of fractography to perform failure analysis
- **Stress Concentration K_t , Finishes**
 - Stress Concentrations
 - Load Flow Lines (Streamlines): a useful analogy
 - Surface finish
 - Pitfalls in grinding
 - Chrome-plating dangers, zinc and other platings
 - Size effects
 - Leonardo da Vinci
 - Scatter, Reliability

- High Temperature Effects
- **Fatigue Life Prediction**
 - Cycle parameters
 - Range, amplitude, mean stress, R ratio
 - S-N Curves
 - Low cycle fatigue
 - Neuber's Notch strain analysis
 - Miner's Myth
 - Extremely limited applicability and lack of defensibility
 - It is not a RULE
 - Fracture Mechanics
 - Griffith Criterion
 - George Irwin, Naval Research Lab: Father of Fracture Mechanics
 - Stress intensity factor SIF K_I
 - Beta factors
 - Residual strength
 - Fracture toughness
 - Effect of thickness, orientation, impact, temperature
 - Dynamic fracture toughness and crashworthiness
 - Crack propagation
 - Thresholds
 - Inspection intervals
 - NDE, detectable crack sizes
 - Visual, eddy current, radiographic, ultrasonic, penetrant, magnetic particle
 - Applicability, comparison
 - POD (Probability of Detection)
 - Reliability of Inspections
 - Case Study: MD-88 uncontained engine failure
 - Short cracks
 - Can be deadly
 - Classroom tutorials in Fracture Mechanics
 - Rigorous, parametric evaluations of various interconnected variables: fracture toughness, initial flaw size, inspection interval, fastener holes, corrosion effects, coldworking, shot-peening, da/dN , material properties C , m , ...
 - Damage Tolerance
 - MIL-A-83444 -> MIL-A-87221 -> JSSG2006
 - 1. Fail-safe structure
 - Arrest of a rapidly running crack
 - Safe partial failure of a load path
 - Skin-stringer partnership
 - Titanium crack stoppers
 - 2. Slow crack growth structure
 - Degree of inspectability
 - Initial flaw assumptions

- Retardation Models
- Continuing damage
- ASIP, IATP
- **Environmentally Assisted Cracking**
 - Corrosion Fatigue
 - Effect of frequency, waveform, hold-time, ...
 - Stress Corrosion
 - K_{Isc}
 - SCC ratings for aircraft alloys
 - Case study: SCC of a High Strength Steel Frame in a USNavy Fighter
 - Fretting Fatigue
 - How surface finish, similar materials in contact, slip amplitude, temperature, and environment affect Fretting Fatigue
 - Contact fatigue
 - Gear failures
 - Aging aircraft issues
 - Durability vs Damage Tolerance
 - Multi-Site Damage, Widespread Fatigue Damage
 - The Aloha accident
 - Continued airworthiness
 - Supplemental inspection programs
- **Testing for Substantiation and Data accumulation**
 - Cycle Counting methods
 - Rain flow method
 - In-flight loads monitoring
 - Testing
 - Coupons, specimen, component and Full-Scale
 - Standardized Testing
 - Coupon preparation, precracking guidelines
 - E-399 K_{Ic}
 - E-647 da/dN
 - Service duplication Testing
 - Environmental chambers
 - Time compression issues in corrosion fatigue testing
 - Load Spectrum Generation
 - Canned Spectra
 - TWIST, MINITWIST, TURBISTAN, HELIX, FELIX, ...
 - Sequence effects
 - Truncation, clipping
 - Scatter, Reliability, Risk management
 - Weibull Paper
 - Fretting Fatigue
- **Do's and TABOOS**
 - Methods to improve fatigue resistance
 - Clever use of favorable residual stresses
 - Cold-working of holes

- Shot Peening
 - Residual Stress control measures
 - Bolts, Rivets, Springs, Bearings, Welds, ...
 - Failure Analysis: useful learning tool
 - Care and handling of fractures
 - Repair techniques
 - Japan Air Lines 747 crash
 - “stop”-drill?
 - Helpful treatments and processes
 - plating
 - Hi-Tigue and other fatigue rated fasteners
 - Guidelines based on experience
- **Integrity of Composite Structures**
 - the crucial role of Damage Tolerance
 - how to account for different damage conditions and damage states
 - role of NDI, emerging technology
 - Stiffness issues and residual strength considerations
 - Elastic instability
 - Safety and Durability of Composite Structures
 - FAR, JAR Regulations on Composite Structures
 - Validation and Certification of Original Structures and Repairs
 - The Boron-Epoxy Composite Patch
- **Environment Effects on Composite Structures**
 - Temperature Effects, Corrosion, Moisture Ingression, Thermal Spike, Hygrothermal Aging, Weathering, Erosion, Lightning, Stress Corrosion, Blistering
 - Case Studies: Westland Sea King & WG.30 Helicopters, Boeing 737 Spoiler, Lockheed L-1011 Fairing, Douglas DC-10 Rudder & Aft Pylon, C-130 Wing Box, CH-54 Fuselage, USAF F-15, A-7D, F-111, US Navy F-14 Horizontal Stabilizer, H-46 Rotor Blades
- **Composite Damage and Fracture**
 - Failure Criteria, Debonding, Fiber Pullout, Delamination, Matrix Cracking, Toughness Enhancement of Matrices, Damage-based Strength Model, Failure Mechanisms and Toughness Maps, Fatigue Damage Mechanics and Lifetime Prediction, Variable Amplitude Loading Effects
- **Concluding Remarks**

Instructor

Sam Kantimathi

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Sam Kantimathi is based in California. His specialties are metal fatigue, fracture mechanics, damage tolerance analysis. Prior to founding his company, Sam held senior engineering positions at AeroStructures, Inc. and Raytheon, where he completed fatigue and fracture mechanics substantiation of various transport structures. At AeroStructures as a consultant to NAVAIR and NAVSEA, his responsibilities included fatigue and fracture mechanics evaluations of helicopter and fixed wing US Naval aircraft structures. He developed and installed a fatigue crack initiation tracking program for the F-4S fleet in the US Navy. It was the first sequence-accountable scheme employed by the Naval Air Development Center for its quarterly "Structural Appraisal of Fatigue Effects" (SAFE) reports.

Recently Sam has conducted courses for Princeton University and numerous organizations including Boeing Company, Delta Airlines, FAA, Singapore Airlines and US Navy, as well as dozens of companies in five continents. For 4 recent years, he was the sole instructor in his workshop at George Washington University entitled "Minimising the Danger of Fatigue in Metals and Composites." He also prepares and executes a phenomenally successful course for the American Institute of Aeronautics and Astronautics (AIAA) called "Fracture Mechanics - Aerospace Applications" and also one on Advanced Fracture Mechanics. AIAA added his course entitled "Aerospace Structural Accidents" to its course offerings in 1995. He has taught graduate and undergraduate courses in design methods, fatigue, wear, fracture and materials. He has been an Associate Fellow of AIAA for the past twenty years and has served on committee E08 on fatigue and fracture of American Society for Testing and Materials, (ASTM). He belongs to ASM International. He is also affiliated with American Society for Training and Development, American Defense Preparedness Association and American Helicopter Society. Sam

Kantimathi earned a BS Degree in Mechanical Engineering from the prestigious Indian Institute of Technology and a MS Degree in Mechanical Engineering from Wichita State University. For the past 23 years Sam has owned Fatigue Concepts and has built it into a leader in worldwide provider of on-site structures training at various institutions and companies. Lockheed Martin, MOOG, LORD Corporation, The Lawrence Livermore Lab are among the companies that have utilized Sam and Fatigue Concepts for consulting. Sam has taught dozens of classes at Various Air Force Bases, CAA, FAA locations, Airlines, MROs, and Repair Stations.

For the past few years he has a contract with the US Department of Transportation to administer training for their Inspectors, Engineers and Managers.