602428

UNIPASS for AvSP? A Broader View*

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•This effort was supported by the NASA-ASEE Summer Faculty Fellowship and NACA NCC-1-336.

Outline

An overview of UNIPASS

Reliability in AvSP

Role of UNIPASS in AvSP

Examples

Concluding remarks

An Overview of UNIPASS

What is UNIPASS

- The way UNIPASS Technologies describes it

UNIPASS is a general-purpose probabilistic computer program consisting of three major modules, including preprocessor, solver and postprocessor. *UNIPASS* contains a user-friendly Graphical User Interface (GUI), numerous state-of-the-art probabilistic analysis techniques, a large library of statistical distributions and a function module with a large library of support functions that can easily define any complex limit-state function in a scripting FORTRAN-like syntax format. Its inverse probability analysis and sensitivities analysis capabilities make it a powerful design aid in any product cycle. Its precise numerical analysis engine is accurate enough to push the failure probabilities of a design to well below 10^{-50}. *UNIPASS* is equipped with advanced artificial intelligence that is designed to handle systems with an essentially unlimited number of random variables with ease and efficiency. Its modular arrangement allows you to tailor an analysis to the desired level of accuracy and efficiency. The depth and comprehensiveness of *UNIPASS* are built upon the decades of experience and expertise of industry leaders including Boeing Aircraft, NASA and the DoD. Its rich content also makes *UNIPASS* a valuable instructional tool for random processes and probabilistic mechanics.

An Overview of UNIPASS

Some definitions

- **Reliability R**

  The probability that a component or a system will perform a required function for a given period of time when used under stated operating conditions (static model versus dynamic model)

- **Failure probability P_f**

  $P_f = 1 - R$

- **Stress and strength**

  Stress is any load (electrical, chemical, thermal, mechanical) that may produce a failure, and strength is the highest stress value a component or a system can endure without failing

- **Cut set**

  Set of components whose failure will result in a system failure

- **Limit state function**

  Describes failure mechanisms of a component

An Overview of UNIPASS

What is UNIPASS (cont'd)

– A summary of its functions (and problems)

- ➢ A software tool that performs
  - ✓ Failure probability calculation of components and simple systems
    - » Given a limit state function g(x) that maps a multi-dimensional Euclidean space of RV's onto the real axis (uncertain g(.)?)
    - » Given a joint probability distribution of all random variables involved (unknown joint pdf f(x)?)
    - » Calculate $_{g(x)\ \text{threshold}}$ f(x) dx (accuracy problem for small f(x), sensitivity to threshold for large f(x))?)
    - » Methods: MBM, RSM, FORM, SORM, ISM, SM in the order of computational efficiency

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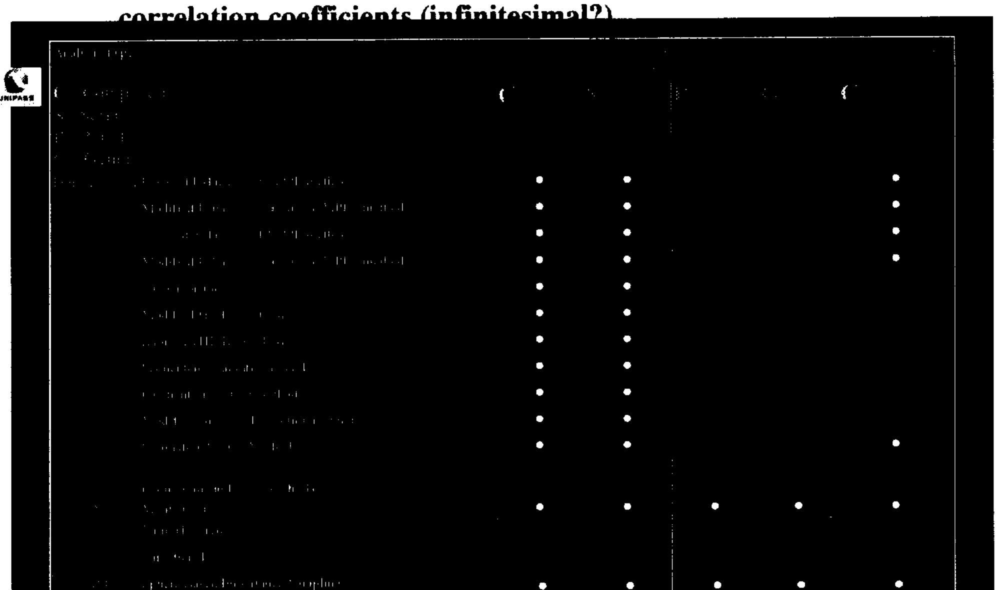
An Overview of UNIPASS

– A summary of its functions (cont'd)

- ➢ A software tool that performs
  - ✓ Sensitivity analysis of failure probability or reliability index of a component with respect to RVs, means, standard deviations, and correlation coefficients (infinitesimal?)



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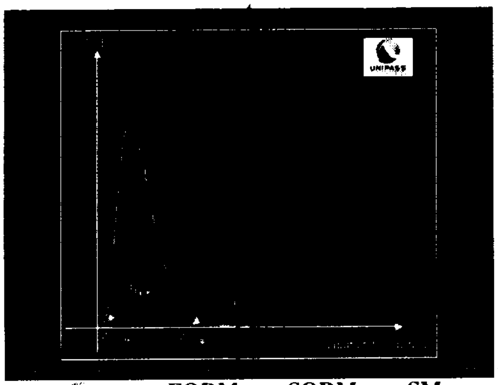
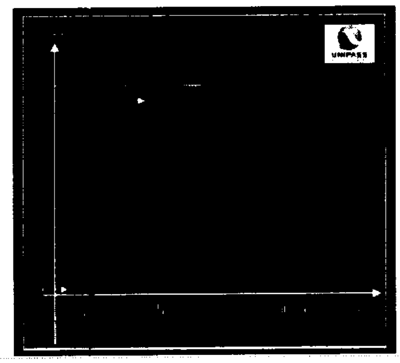
An Overview of UNIPASS

– A summary of its functions (cont'd)

➢ A software tool that performs

✓ Inverse probability and PDF/CDF calculation of the limit state function of





UNIPASS	FORM	SORM	SM	ISM	RSM	MVBM
Inverse	C		C	C		
PDF/CDF	C	C	C	C	C	C

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Reliability in AvSP

Role of reliability analysis in AvSP

- Identify and quantify the needs for aviation safety enhancement
- Specify the safety goals and measures
- Set an all encompassing criterion and guidelines for integrated system designs
- Provide tools for validation and verification of modified and new designs aimed at reliability enhancement

Reliability in AvSP

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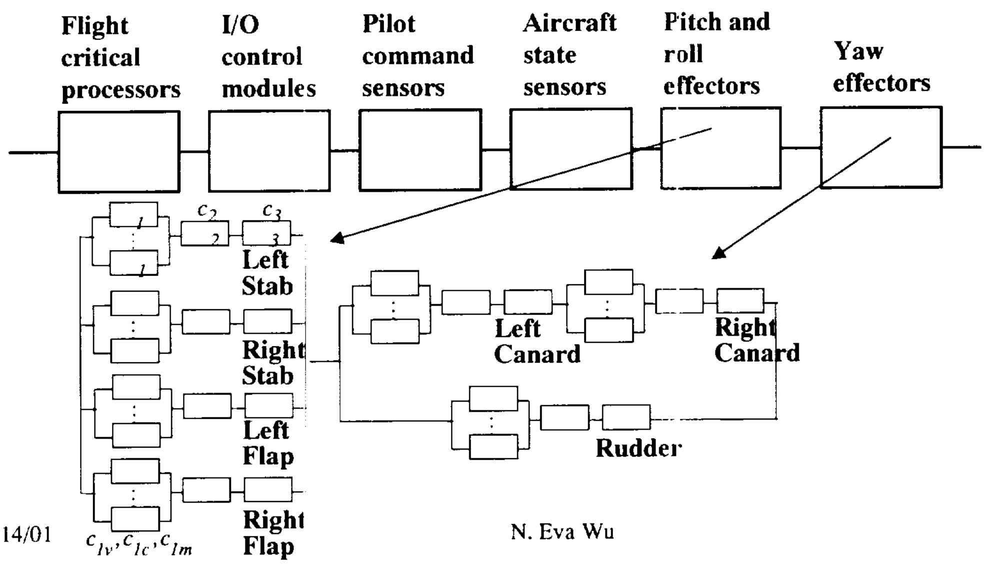
An example

– Functional dependency of a flight control system

- Problem: given subsystem failure rates and corresponding coverage values, estimate the overall system reliability



Reliability in AvSP

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An example (cont'd)

– Major difficulties

- Reliability models for subsystems
- Coverage models for subsystem failures
- Disparate rates in failure and recovery processes
- Large state space

Role of UNIPASS in AvSP

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What can UNIPASS do?

- **Failure probability analysis for components** (known LSF & JPDF)
  - ➢ Good prediction when component LSFs have small uncertainties
  - ➢ Help dynamic reliability modeling through covariate methods
  - ➢ Provide useful information for feedback control (Sean Kenny)
- **Identify needs and the potential for component reliability enhancement**
  - ➢ Sensitivity analysis
- **Difficulties**
  - ➢ Joint probability distribution model for components
  - ➢ Randomized limit state treatment

Examples

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Examples (exhaustive list from UNIPASS manual, results published 1975-1996)

- **Plane frame structure with 3 plastic failure mechanisms**
  - ➢ 2 failure modes (series system, static)
  - ➢ 6 random variables
  - ➢ Analysis: failure probability, sensitivity
- **A simply supported beam subject to dynamic load**
  - ➢ 1 failure mode (component, static)
  - ➢ 4 random variables
  - ➢ Analysis: failure probability, inverse probability, pdf
- **Local buckling stress for a flanged component under longitudinal load**
  - ➢ 1 failure mode (component, static)
  - ➢ 7 random variables
  - ➢ Analysis: failure probability

Examples

Examples (exhaustive list from UNIPASS manual, results published 1975-1996)

- Fatigue life prediction
  - 1 failure mode (component, dynamic)
  - 4 random variables (initial crack size, cyclic load, fracture toughness, a constant)
  - Analysis: inverse probability, pdf
- Maximal radial stress of a rotating disc
  - 1 failure mode (component, static)
  - 6 random variables
  - Analysis: failure probability, cdf
- Burst margin of a rotating disk
  - 1 failure mode (component, static)
  - 7 ransom variables
  - Analysis: failure probability

Examples

Examples (exhaustive list from UNIPASS manual, results published 1975-1996)

- Gear contact stress design
  - 1 failure mode (component, static)
  - 8 random variables
  - Analysis: failure probability, cdf, pdf
- Timing belt cumulative fatigue problem
  - 1 failure mode (component, dynamic)
  - 5 random variables (Miner's Rule constant, Arrhenius' Law constant, Material slope, Material intercept, Angular speed)
  - Analysis: LSF level identification, fatigue life analysis

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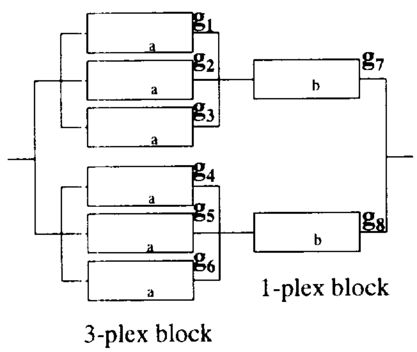
Examples

UNIPASS solution to the degradable 2-layer problem

– Problem

- Calculating $p_f(T)$



Reliability requirements:
1-out-of-3 for inner layer
1-out-of-2 for outer layer
Coverage of failures:
1st 3-plex failure: c_0^a
2nd 3-plex failure: c_1^a
3rd 3-plex failure: c_2^a
1st 1-plex failure: c_0^b

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Examples

UNIPASS solution to the degradable 2-layer problem

– Procedure

- Define random variables: $x_1, \ldots, x_8$
- Define the time of interest: T
- Define limit state functions: $g_i = x_i - T$, $i = 1, 2, \ldots, 8$
- Define the cut sets: $(g_1, g_2, g_3, g_8), \ldots, (g_7, g_8)$
- Select MPP id method and LSF approximation method
- Create input file "twolayer.pas"
- Run UNIPASS solver
- Save output data (T, P_f)
- Redefine T

Examples

UNIPASS solution to the degradable 2-layer problem

- Major problems
  - Inability to incorporate coverage which is resulted from redundancy management and reconfiguration actions
  - Cumbersome input data entry
  - Provide only point output (inverse probability and pdf tools applicable to only components)
  - No accuracy guarantee
  - Nontrivial problem formulation for non-expert users
  - Problematic for small probability (refuses to calculate for T<2000 hrs even with sample points=10,000,000,000,000,000)
  - Despite the claim of 6 methods, only Monte Carlo method works

Examples

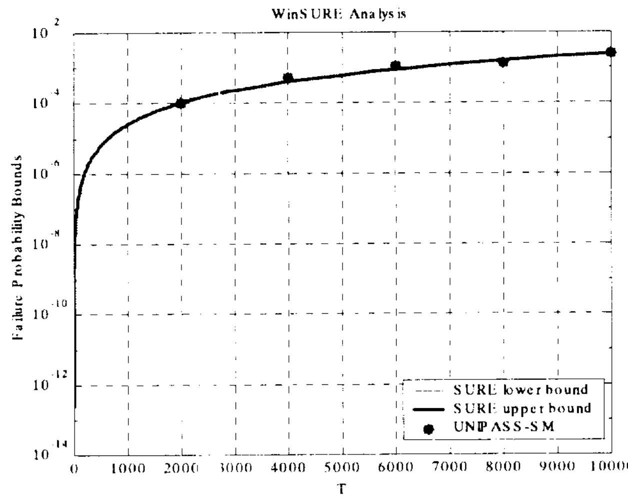
ASSIST/SURE solution to the degradable 2-layer problem

- SURE (Butler, et al., NASA Langley)
  - Semi-Markov Unreliability Range Evaluator
- ASSIST (Butler, et al., NASA Langley)
  - Abstract Semi-Markov Specification Interface to the SURE Tool

Examples

ASSIST/SURE solution to the degradable 2-layer problem

- Failure probability v.s. time
  - Nontrivial problem formulation for non-expert users
  - Handles coverage easily (not included in this example)



Concluding Remarks

UNIPASS v.s. SURE

- UNIPASS focuses on static and component level failure probability
  - Requires a joint PDF of physical variables
  - Requires a limit state function of for each component
  - Required information is obtained via "physics of failure" modeling
    - ✓ pdf describes variations in stresses and in operating conditions that components experience
    - ✓ but the limit state function (allowable-response) defines the boundary of the failure domain in a deterministic fashion (one of the three classical classes of static models: random stress and constant strength)
  - Possibly large number of RVs ($<10^8$) but simple system configuration
  - UNIPASS generally cannot handle typical problems dealt with by SURE

Concluding Remarks

UNIPASS v.s. SURE

- SURE focuses on dynamic (semi-Markov process) and system level probability
  - ➢ Requires PDF of time to failure for the i^{th} component that has a slow failure process $f_i(t) \quad {}_i(x)e^{\quad {}_i(x)t}, t \quad 0$
  - ➢ Requires the mean and the variance of time to reconfigure for a fast reconfiguration process
  - ➢ Required information is obtained via statistical means
    - ✓ Collection and analysis of failure data
    - ✓ Parameter estimation and goodness of fit tests
    - ✓ Interpretation of result: infer from failure data to the general population
  - ➢ Possibly large number of components, complex system configuration and reconfiguration strategies, but small number of RV's
  - ➢ SURE generally cannot handle typical problems dealt with by UNIPASS

Concluding Remarks