AEROSPACE SYSTEMS SURVIVABILITY HANDBOOK SERIES

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FOREWORD

This Aerospace Systems Survivability Handbook Series is designed to provide its users with insight into the key activities performed by survivability personnel in support of aerospace systems acquisition. The series is not a specification or standard but rather a "how-to" guide for all survivability managers, engineers, and analysts associated with survivability activities likely to be needed on any program, government or commercial.

Some of the material used in the handbook series has been adapted from various sections of the Department of Defense (DoD) Deskbook, Internet links, and survivability documents produced by the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS), under the sponsorship of the Joint Aeronautical Commanders' Group (JACG). The Service laboratories and centers also produced source documents. This handbook series emphasizes the requirement for integrated teamwork of survivability management, engineering, test and evaluation, and systems analysis in order to accomplish a successful systems acquisition.

The handbook series (JTCG/AS Project A-8-01, Acquisition Deskbook Survivability Section Rewrite) was prepared for the JTCG/AS under the sponsorship of the Principal Members Steering Group (PMSG) and directed by LTC Charles R. Schwarz, Director, JTCG/AS. The handbooks were drafted by Hubert (Hugh) Drake, SRS Technologies, under contract to the Naval Air Warfare Center Weapons Division, China Lake, CA. As the Contract Technical Monitor, Dave Hall provided guidance and initial review. The following working group members provided oversight:

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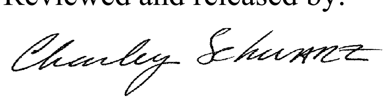

Lieutenant Colonel Charles R. Schwarz
Director, JTCG/AS

CONTENTS

ACRONYMS AND ABBREVIATIONS

ACAT	Acquisition Category
APU	Auxiliary Propulsion Unit
ATD	Advanced Technology Demonstration
CAIV	Cost as an Independent Variable
CFE	Contractor-Furnished Equipment
CM	Configuration Management
CM	Countermeasures
CDRL	Contract Data Requirements List
DAD	Defense Acquisition Deskbook
DAE	Defense Acquisition Executive
DoD	Department of Defense
DSMC	Defense Systems Management College
DT	Development Test
DT&E	Developmental Test and Evaluation
ECP	Engineering Change Proposal
EO	Electro-optical
EW	Electronic Warfare
GFE	Government-Furnished Equipment
HAZMAT	Hazardous Materials
HITL	Hardware-in-the-Loop
HW/SWIL	Hardware/Software-in-the-Loop
INCOSE	International Council on Systems Engineering
IOT&E	Initial Operational Test and Evaluation
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
IR	Infrared
IRCM	Infrared Countermeasures
ISTF	Installed Systems Test Facility
J/S	Jamming-to-Signal
JACG	Joint Aeronautical Commanders' Group
KSD	Kinematic Special Decor
LFT&E	Live Fire Test and Evaluation
LO	Low Observables
M&S	Modeling and Simulation
MDA	Milestone Decision Authority
MF	Measurement Facility
MNS	Mission Need Statement

MOE	Measure of Effectiveness
MOP	Measure of Performance
OAR	Open-Air Range
OIPT	Overarching Integrated Product Team
ORD	Operational Requirements Document
OT&E	Operational Test and Evaluation
PIPT	Program Integrated Product Team
PM	Program Manager
RCS	Radar Cross Section
RF	Radio Frequency
RFI	Request for Information
RFP	Request for Proposal
SE	Systems Engineering, Systems Engineer
SEIPT	Systems Engineering Integrated Product Team
SEMP	Systems Engineering Management Plan
SIL	System Integration Laboratory
SIPT	Survivability Integrated Product Team
SURVIAC	Susceptibility/Vulnerability Information Analysis Center
TEMP	Test and Evaluation Master Plan
T&E	Test and Evaluation
V/STOL	Vertical/Short Take-off and Landing
VV&A	Verification, Validation, and Accreditation
WBS	Work Breakdown Structure
WIPT	Working-Level Integrated Product Team

EXECUTIVE SUMMARY

This volume outlines the role of survivability as it evolves over the system life cycle as an integral part of the systems engineering process. The topic is especially pertinent today because emerging technologies are revealing unprecedented opportunities for bringing new and improved systems and products into being that will be more competitive in the private and public sectors worldwide. These technologies are expanding physically realizable design options and enhancing cost-effective capabilities. The purpose of design and analysis engineering activities is to determine how physical factors may be altered to create the most utility for the least cost.

The objective is to design the system to minimize losses when it operates in a manmade hostile environment. Designing to meet survivability requirements means considering an optimum mix of susceptibility and vulnerability designs for low susceptibility and low vulnerability. The goal is to develop and demonstrate protection technologies required to ensure survivable operation of warfighting assets in both the natural space environment and the hostile warfighting environment. Specifically, the survivability program evaluates through high-fidelity subsystem and system models the effects of the threats on U.S. and allied systems, and then develops and demonstrates the efficacy of multithreat protection techniques against those threats.

The initial focus of survivability engineering and analyses is to develop and define survivability-related design factors based on a firsthand understanding of user needs and of survivability technical challenges. This activity consists of the selective application of survivability engineering and analyses planned for the program. The contractor should propose an appropriate survivability process that will properly manage risk in the program and that encompasses interface with the Integrated Product and Process Development (IPPD) process as an integral member of the Integrated Product Team (IPT).

The volume also describes a planned series of survivability analyses necessary to support survivability engineering. Steps are outlined to ensure that all primary system functions and elements of a proposed system concept or design are examined to determine the survivability that is required to protect the system over its life cycle. The iterative application of survivability analyses described herein will balance survivability requirements to ensure the development of the most cost-effective system over its life cycle.

The technical approach includes:

- Definition of the threat (hostile and natural, including space debris for space operations).
- Development with users of program survivability requirements.
- Performance of susceptibility and vulnerability experiments at various levels of integration.

- Selection or development where necessary of models or analytic techniques for extrapolating data to higher levels of system interaction.
- Performance of trades for survivability enhancement options.
- Development of survivability enhancement techniques based on those performance trades.
- Demonstration of those techniques on appropriate subsystems.

Survivability enhancement as it is discussed herein focuses on the design of survivable aerospace vehicles, enumerating the steps that must be taken to ensure that survivability considerations are taken into account during systems engineering of all aspects of aerospace vehicles. The developer can optimize survivability only by applying vulnerability and susceptibility analyses in the application of survivability reduction concepts.

Survivability enhancement begins during research and technology development efforts that provide scientific and technological innovations in the following areas:

- Lethality
- Design for low vulnerability
- Design for low susceptibility
- Survivability assessment
- Sensor design
- Signatures and signal processing
- Power resources
- Materials and structures
- Battlefield environmental effects
- Human factors
- Advanced computing
- Advanced electronics

1.0 INTRODUCTION

When survivability is designed into a combat system, the benefits are many. The system's combat capability will be improved, the lifecycle cost will be lower, and there will be less loss of life. As with other "- abilities," the best designs result when survivability is addressed from the beginning of the development cycle. The earlier problems and the need for trade studies are discovered, the more time there is to think of solutions, and the less work must be undone.

A survivability program must be established and maintained throughout the system life cycle to attain overall program objectives. The program should stress early investment in survivability enhancement efforts that improve system operational readiness and mission effectiveness by:

- Providing threat avoidance capabilities (low susceptibility).
- Incorporating vulnerability reduction (damage tolerance) in system design (low vulnerability).
- Maximizing wartime availability and sortie rates via operationally compatible threat damage tolerance and rapid repairability features.
- Minimizing the impact of the survivability program on the overall program cost and schedule.

Engineering Design Elements in the Acquisition Process

An understanding of the acquisition process discussed in Volume 2 is fundamental to both the application of survivability engineering and the practice of systems engineering. The acquisition process begins with the identification of need and extends through planning, research, design, production or construction, evaluation, utilization, maintenance and support, and ultimate retirement (disposal).

The engineering design approach for bringing products into being considers the system's entire life cycle. The objective behind engineering for the life cycle is to ensure that the entire life of the system is considered from inception. Engineering design elements are depicted in Figure 1. Consideration of these elements not only should transform a need into to a definitive product configuration for customer use, but also ensure the design's compatibility with related physical and functional requirements.

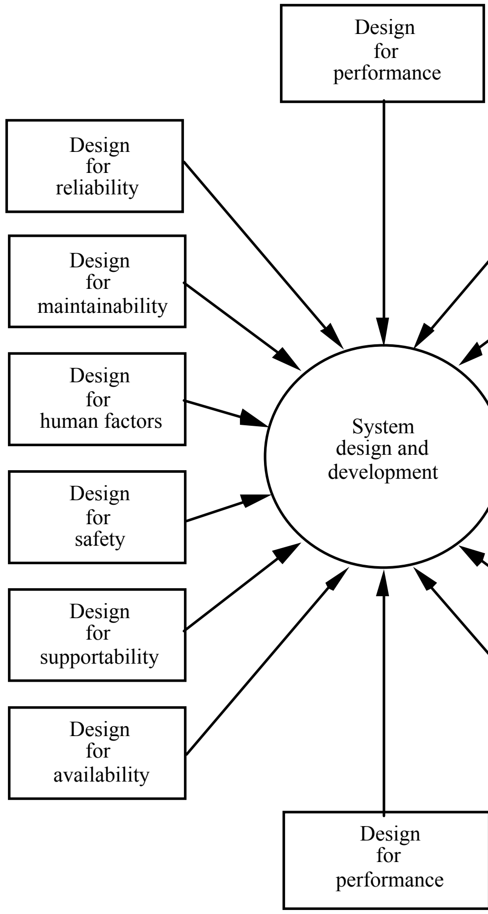

Figure 1. Engineering Design Elements

The elements should take into account life-cycle outcomes as measured by performance, effectiveness, producibility, reliability, maintainability, and cost. Because of the numbers and types of engineers representing the different engineering disciplines associated with systems acquisition, the systems engineer (SE) has the responsibility to provide the necessary input to the design process. The SE needs to use specifications, the appropriate checks and balances throughout the design process, selected design reviews, and an effective integrated test and evaluation (T&E) effort, ensuring throughout this process that the necessary feedback for corrective action is provided as required.

Many large systems require the combined input of specialists representing a wide variety of engineering disciplines. For example, an aircraft system will require participation of the following specialists:

- Aeronautical engineers
- Electrical engineers
- Electronic engineers

- Mechanical engineers
- Metallurgists
- Survivability engineers
- Logistics engineers
- Reliability and maintainability engineers
- Human factors engineers
- Systems engineers
- Producibility engineers
- Quality engineers
- Value/Cost engineers
- Industrial engineers
- Test engineers
- Engineers in other specialties

The foregoing list might not be all-inclusive, but it does show that many different engineering disciplines, including that of survivability, are directly involved. These engineers, forming parts of a larger organization, not only must be able to communicate with each other but also must be conversant with such supplemental activities as purchasing, accounting, manufacturing, and legal issues. The project environment for a system's design and development is typically highly dynamic. Many individuals with different specialties and backgrounds rotate into and out of a program at varying times. Good communication is essential, as well as a good understanding of the numerous interfaces existing in any given program. Use of the systems engineer in conjunction with the Integrated Product and Process Development /Integrated Product Teams (IPPD/IPT) concept and process (see Volume 2) ensures coordination throughout the life cycle.

According to the Defense Acquisition Deskbook (DAD): "The Program Manager shall ensure that a systems engineering process is used to translate operational needs and/or requirements into a system solution that includes the design, manufacturing, T&E, and support processes and products. The systems engineering process shall establish a proper balance between performance, risk, cost, and schedule, employing a top-down iterative process of requirements analysis, functional analysis and allocation, design synthesis and verification, and system analysis and control."

Integrated Product and Process Development/Integrated Product Teams

DoD defines IPPD as "A management process that integrates all activities from product concept through production/field support, using a multifunctional team, to simultaneously optimize the product and its manufacturing and sustainment processes to meet cost and performance objectives." IPPD evolved from concurrent engineering, and is sometimes called integrated product development (IPD). It is a systems engineering process integrated with sound business practices and common sense decision making. Organizations may undergo profound changes in culture and processes to successfully implement IPPD.

IPPD is a management technique that simultaneously integrates all essential acquisition activities through the use of multidisciplinary teams to optimize the design, manufacturing and supportability processes. IPPD facilitates meeting cost and performance objectives from product concept through production, including field support. One of the key IPPD tenets is multidisciplinary teamwork through IPTs. These teams enable making the right decisions at the right time.

The IPT is composed of representatives from all appropriate functional disciplines, including survivability, working together with a Team Leader to build successful and balanced programs, identify and resolve issues, and make sound and timely recommendations to facilitate decision-making. There are three types of IPTs: An Overarching IPT (OIPT) focuses on strategic guidance, program assessment, and issue resolution. A Working-Level IPT (WIPT) identifies and resolves program issues, determines program status, and seeks opportunities for acquisition reform. A Program IPT (PIPT) focuses on program execution and may include representatives from both government and (after contract award) industry.

An IPT has the following objectives:

- Produce a design solution that satisfies initially defined requirements.
- Communicate that design solution clearly, effectively, and in a timely manner.

Multi-functional integrated teams also have the following objectives:

- Place balanced emphasis on product and process development.
- Require early involvement of all disciplines appropriate to the team task.

Design-level IPT members are chosen to meet the team objectives and generally have distinctive competence in the following:

- Technical management (systems engineering)
- Life-cycle functional areas (eight primary functions)
- Technical specialty areas, such as safety, risk management, quality, etc.
- When appropriate, business areas such as finance, cost/budget analysis, and contracting

Survivability involvement is a function of the needs of the Program Manager (PM). The options include a dedicated Survivability IPT or survivability representation on the Systems Engineering team and the various associated IPTs.

The purpose of IPTs is to make team decisions based on timely input from the entire team (e.g., program management, engineering, manufacturing, test, logistics, financial management, contracting, contract administration), including customers and suppliers. IPTs are generally formed at the Program Manager level and may include members from both the Government and the system contractor. A typical IPT at the program level, for example, may be composed of the following functional descriptions: design engineering; manufacturing; systems engineering; T&E; subcontracting; considerations of safety and hazardous materials (HAZMAT); quality assurance; training; finance; reliability, maintainability, survivability and supportability; suppliers; and customers.

Survivability Considerations as Part of the IPPD/IPT Process

The best time to address survivability is early in the acquisition process. Survivability objectives are developed through trade studies, which are conducted before an acquisition approach is finalized. To facilitate that process, the OIPT for each ACAT I program (and ACAT IA program as required) should establish a Survivability IPT (SIPT) as an integral part of each WIPT. The user community should be represented on the SIPT. Industry representation, consistent with statute and at the appropriate time, should also be considered. Prior to each milestone decision, the PM reports the SIPT findings to the OIPT leader.

The successful application of survivability as a functional discipline within the IPT structure requires not only the close association of the PM and the SE but also employment of the concept of IPPD throughout the program design process to the maximum extent practicable. This use of the IPPD concept can best be accomplished by establishing a Systems Engineering IPT (SEIPT) and ensuring that the systems engineer has a key role in the Integrating IPT (IIPT).

The Systems Engineering Process

Systems engineering consists of two significant disciplines: (1) the technical knowledge domain in which the systems engineer operates and (2) systems engineering management. Systems engineering is defined as the technical and management efforts of planning, directing, and controlling a totally integrated engineering effort for a system or program. Systems engineering includes, but is not limited to, the engineering effort to transform an operational need or statement of deficiency into a description of system requirements and a preferred system configuration; and the technical planning and control effort for planning, monitoring, measuring, evaluating, directing, and replanning the management of the technical program. If a prime contract is in force, the design engineering and production engineering directly related to the products or services of a deliverable end item are the responsibility of the prime contractor.

The systems engineering process is a structured, disciplined, and documented technical effort through which systems products and processes are simultaneously defined and developed. The systems engineering team is responsible for the technical and management efforts of directing and controlling an integrated engineering effort on a system or program.

Systems engineering involves design and management of the entire system, including hardware and software as well as other system life-cycle elements. The most effective way to implement systems engineering is through multidisciplinary teamwork as part of an overall integrated product and process development effort. As a functional discipline, survivability plays a major role in systems engineering in support of engineering (design and development), analysis (systems as well as independent), T&E (DT&E, OT&E and LFT&E), M&S (development and VV&A), and associated program-level documents (MNS, ORD, SEMP, TEMP, etc.).

From a systems engineering standpoint, the survivability engineer (SIPT Lead) becomes a primary participant in design synthesis and verification for survivability. Design synthesis and verification activities translate survivability functional and performance requirements into design solutions that include people, product and process alternative concepts and solutions, and internal and external interfaces. These design solutions need to be in sufficient detail to verify that requirements have been met. The verification process addresses the design tools, products, and processes, with verification of the design including a cost-effective combination of design analysis, design modeling and simulation, and demonstration and testing.

Throughout the system design and development, many different alternatives (or concepts) require evaluation and trades. The process of investigating and evaluating these alternatives constitutes an ongoing analytical effort, which is inherent within the systems engineering process. To accomplish this activity in an effective manner, the engineer and/or analyst relies on the use of analytical techniques and tools to make early trade studies and to facilitate the quantitative system analysis process delineated below:

- Define the problem.
- Identify analysis requirements.
- Select evaluation criteria.
- Establish models and simulation requirements.
- Acquire necessary models and simulations.
- Generate input data.
- Perform analysis.

Systems Engineering References and Definitions

Since an industrial standard does not yet exist, it is pertinent to stay abreast of the organizations and activities that address the topic of systems engineering. Two organizations and their systems-engineering training materials, discussed below, are of special interest and should be used for reference.

The Defense Systems Management College (DSMC) Press published its supplementary text, *Systems Engineering Fundamentals*, in October 1999. This book provides a basic, conceptual-level description of engineering management disciplines that relate to the development and life cycle management of a system. For the nonengineer, the book provides an overview of how a system is developed. For the engineer and project manager, it provides a basic framework for planning and assessing system development.

Information in the book is from various sources, but a good portion is taken from lecture material developed for the two Systems Planning, Research, Development, and Engineering courses offered by Defense Acquisition University. This text supplements course material at DSMC and is the first guidance issued on the topic of systems engineering since the *Systems Engineering Management Guide* was published in 1990.

DSMC has also suggested the use of the International Council on Systems Engineering (INCOSE) SE "How-To" Handbook, which offers the following: **"**Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. This includes operations, performance, testing, manufacturing, cost & schedule, training and support, and disposal."

Three commonly used definitions of systems engineering are provided by the best-known technical standards that apply to this subject. These definitions have a common theme:

- "A logical sequence of activities and decisions transforming an operational need into a description of system performance parameters and a preferred system configuration." (MIL-STD-499A, *Engineering Management*, 1 May 1974. Now canceled.)

- "An interdisciplinary approach encompassing the entire technical effort, to evolve into and verify an integrated and life cycle balanced set of system people, products, and process solutions that satisfy customer needs." (EIA Standard IS-632, *Systems Engineering*, December 1994.)

- "An interdisciplinary, collaborative approach to derive, evolve, and verify a life cycle balanced system solution which satisfies customer expectations and meets public acceptability." (IEEE P1220, *Standard for Application and Management of the Systems Engineering Process*, [Final Draft], 26 September 1994.)

In summary, systems engineering is an interdisciplinary engineering management process to evolve and verify an integrated, life-cycle balanced set of system solutions that satisfy customer needs.

2.0 SYSTEM DESIGN AND DEVELOPMENT PROCESS

The survivability system design and development process follows from a set of stated survivability requirements for a system and evolves through (1) conceptual design (the establishment of performance parameters, operational requirements, and support policies), (2) preliminary systems design, and (3) detailed design. This process generally begins with a visualization of what is required and extends through the development, test, and evaluation of an engineering or prototype model of the system. The output constitutes a configuration that can be directly produced or constructed.

Design Considerations

Chief among the many considerations that influence system design are the following:

- Cost
- Manufacturing/production
- Quality
- Open systems design
- Survivability
- Logistics/supportability
- Reliability, maintainability
- Availability
- Environment and safety
- Human systems integration
- Interoperability

From the design engineer's perspective, the top-level work breakdown structure (WBS) for a system needs to take the following into consideration:

- Design engineering
- Hardware
- Firmware
- Software
- Safety
- Cost
- LCC
- Cost as an independent variable (CAIV)
- Standardization and commonality
- T&E
- Test supportability

- Test design and planning
- Specialty requirements
- Environmental compatibility
- Survivability
- Reliability
- Availability
- Human factors
- Maintainability
- Production
- Industrial base
- Producibility
- Assurance and control

The survivability engineer applies the design process in concert with the systems engineer. This team pursues the following steps in the design process:

- Perform trade studies.
- Perform system and item analyses of the candidate design.
- Establish design criteria.
- Make detailed decisions that transform requirements, resources, and constraints into design.

The survivability engineer serves as the advocate for the survivability design, considering which of the feasible design alternatives would be best. The pertinent IPT functions are summarized as follows:

- **Identify** the Operational Requirements Document (ORD) survivability constraints and define the resulting survivability requirements (relative to each associated element) for each proposed design alternative (while the alternative exists only on paper). This difficult function requires analytical/engineering skills and the ability to communicate in the language of the design engineer.
- **Advocate** the selection of the most easily supported design alternative. This function involves communicating the survivability implications of each design alternative to the other members of the IPT.
- **Influence** the emergence of this design to help create cost-effective/supportable detailed design decisions.
- **Refine** the survivability requirements (relative to *each* element) to reflect the particulars of the emerging design. This function involves ensuring that the survivability requirements are defined to the same depth and at the same pace as the emerging design.

- **Plan and conduct** T&E, based on this real-time definition. This function involves planning survivability for the product or system during developmental/engineering tests and all early field/operational tests. Successful tests will validate the workability of the planned survivability designs.
- **Acquire** all necessary items of support for each survivability design. This function involves ensuring that the system definition and procurement include the system, product, or service, as well as all requisite items of support for each survivability element. Producing the system and its support items (in quantity) is a necessary follow-up task. The common interest of the manufacturing and logistics communities is in producing a quality product that conforms to the design through the reduction of variability in the manufactured design. Reduction of variability leads to products that perform better during the operational phase and require less maintenance because they break down less. Thus the manufacturing and logistics communities have a strong common area of interest with the design engineer.
- **Provide** the system to the customers in the right place, at the right time, and in the right quantities. Accomplishment of this function requires the execution of a good engineering plan.
- **Improve** the system through the inevitable change or modification process. This function is also important.

These functions represent the core activities of a survivability member of an IPT. Note that the execution of a modification program after the system has been produced requires each affected engineering function to be repeated. Thus acquisition survivability engineering (in a world of rapidly changing technology) never really goes away.

Acquisition Elements for Survivability Engineering

From a survivability engineering standpoint, the following acquisition elements are primary to the engineer:

- **Concept Development and Requirements Analysis**. Survivability engineering activities required under this element involve abstract or concept survivability designs that become subject to studies and analysis, requirements definition, preliminary planning, and evaluation of alternative technical approaches and associated costs for the development or enhancement of high-level general performance specifications of a system, project, mission, or activity. Typical associated tasks include, but are not limited to, survivability requirements analysis, cost-performance trade studies, feasibility analysis, regulatory compliance support, and technology conceptual designs.

- **System Design, Engineering, and Integration.** Survivability engineering involves translating a system (or subsystem, program, project, or activity) survivability concept into a preliminary and detailed design (including engineering plans and specifications); performing risk identification, analysis, and mitigation; ensuring traceability; and then integrating the various components to produce a survivable, working prototype or model of the system. Typical associated survivability tasks include, but are not limited to, computer-aided design, design studies and analysis, research and development, high-level detailed specification preparation, configuration management and document control, fabrication, assembly, and modeling and simulation.

- **Test and Evaluation.** This element involves the application of various techniques demonstrating that a prototype system (subsystem, program, project, or activity) performs in accordance with the survivability objectives outlined in the original design. Typical associated tasks include, but are not limited to, prototype and first-article(s) testing, environmental testing, independent verification and validation, reverse engineering, modeling and simulation (to test the feasibility of a concept), system safety, quality assurance, education/training, and physical testing of the product or system in developmental, operational, and live-fire T&E.

Milestone A and Concept and Technology Development Phase

One path into systems acquisition begins with examining alternative concepts to meet a stated mission need. This path begins with a decision to enter the concept and technology development phase at Milestone A. The phase ends with a selection of a system architecture and the completion of entrance criteria into Milestone B and the system development and demonstration phase.

Concept development and requirements analysis begin in the concept and technology development phase, which typically consists of competitive, parallel, short-term concept studies. These efforts focus on defining and evaluating the feasibility of alternative survivability concepts, as well as providing a basis for assessing the relative merits (i.e. advantages and disadvantages, degree of risk) of these concepts at the next milestone decision point. Analysis of alternatives is used as appropriate to help in comparisons of alternative concepts. The most promising system concepts are defined in terms of initial broad objectives for cost, schedule, performance, software requirements, opportunities for trades, overall acquisition strategy, and T&E strategy.

System Development and Demonstration Phase

As one or more concepts, design approaches, and/or parallel technologies are pursued as warranted, the program takes on definition. Assessments of the advantages and disadvantages of alternative survivability concepts are refined. Prototypes, demonstrations, and early operational assessments are considered and included as necessary to reduce risk so that technology, manufacturing, and support risks are well in hand before the next decision point. Cost drivers, life-cycle cost estimates, cost-performance trades, interoperability, and acquisition strategy alternatives are considered, with evolutionary and incremental software development an essential part of each consideration. The survivability engineer concentrates on design approaches.

The primary objectives in the system development and demonstration phase are to translate the most promising survivability design approach into a stable, interoperable, producible, supportable, and cost-effective design; validate the manufacturing or production process; and demonstrate system capabilities through testing.

A favorable Milestone C decision authorizes the PM to commence only low-rate initial production (LRIP). The PM is authorized to commence full-rate production only with further approval of the Milestone Decision Authority (MDA).

Normally no more than one decision (i.e., either low-rate or full-rate initial production) is made at the Defense Acquisition Executive (DAE) level for major defense acquisition programs. LRIP occurs during the Production and Deployment phase as test results and design fixes or upgrades are being incorporated.

The survivability engineer's role in this phase involves a variety of functions that depend on the type of system and the extent of new development necessary. Any or all of the following may be considered in addressing survivability enhancement:

- Accomplish functional analyses and allocations to identify the major operational and maintenance support functions that the system is to perform.
- Establish criteria (qualitative and quantitative technical parameters, bounds, and constraints) for system design.
- Evaluate alternative design approaches (concepts) by conducting system/cost effectiveness analyses and trade studies.
- Prepare system development, process, and material specifications.
- Select components for the system and recommend supplier sources.
- Assist the purchasing and contracting functions in the preparation of contractual documentation.
- Prepare functional design layouts, engineering drawings, parts and materials lists, etc., with the objective of thoroughly defining the product or process through documentation.
- Assess the design through predictions, analyses, and performance of periodic design reviews. This assessment is basically accomplished through a review of the engineering documentation.
- Develop breadboards, engineering models, and prototypes for system T&E purposes.
- Develop system software (computer programs), associated databases, and related documentation required to define, design, test, produce, operate, and maintain the system.
- Perform design modifications as necessary to correct deficiencies and/or improve the system design.

Survivability enhancement requirements for a system may be specified for all or some of the following categories, as applicable:

- Detection avoidance, including
  - Radar cross-section
  - IR signature
  - Aural signature
  - Visual signature
  - Engine smoke

- Threat avoidance, including
  - Radar warning
  - IR sensing
  - Directed-energy threat warning
  - Chemical-biological threat warning
  - Electronic countermeasures
  - Expendables
  - Decoys
  - Mission planning systems

- Threat suppression, including
  - Countermeasures
  - Lethal defense
  - Counter-countermeasures

- Damage tolerance (subsystem protection levels) for
  - Armor-piercing projectiles
  - Incendiary projectiles
  - High-velocity fragments
  - Blast overpressure
  - Other threats (e.g., laser, biological, chemical, high-power microwave)

- Multiple exposures (cumulative effects)

- Synergistic effects

- Target threat orientation (attack aspects)

- Verification

- Hardware assurance

In many cases the procurement agency may not specify firm numerical values for many of the elements listed above. Instead, the developer may be required to perform survivability enhancement trade studies to establish costs/penalties and MOEs for a variety of survival enhancement techniques. The methodology for these studies must be provided or approved by the procuring agency.

The results of these studies are intended to provide the optimum design-to criteria guidance, as well as detailed guidance on the content and conduct of these trade studies.

3.0 SURVIVABILITY ENHANCEMENT TECHNIQUES

This section contains a discussion of basic survivability enhancement techniques as they are applied during the following phases:

- **Concept and Technology Development Phase.** In studies, prototype programs, RFPs, RFIs, or other pre-full scale development effort, the guidelines of this section are intended to generate proposed solutions to survivability performance requirements, provide realistic signature-level requirements, and quantify performance cost and schedule allowances that must be made. Design studies are required.

- **System Development and Demonstration Phase.** During the system development and demonstration phase, insofar as possible, hard performance requirements and specific signature levels should be specified, along with requirements that these measures be met within contractual limits for cost, performance, and schedule. If it becomes necessary to enter the system development and demonstration phase without sufficient information to specify hard requirements, the Contract Data Requirements List (CDRL) should specify Design Studies to allow development of solutions to survivability performance requirements and definition of the associated performance cost and schedule penalties. (This qualifier may be applicable for aerospace system programs begun before publication of this section or for major rework, conversion, or programs to extend service life).

Reduction of Detection

Levels of radar reflection; IR, visual, and electromagnetic emission and reflection; and aural noise should be in accordance with the aerospace system performance specification. If no levels are specified, the contractor should conduct survivability enhancement trade studies and cost effectiveness analyses for each applicable threat-detectable signature combination defined in the mission threat analysis. In the survivability plan or supplement thereto, the contractor should recommend appropriate signature levels, based on effectiveness that can be achieved versus associated cost and penalties. These recommended levels should be supported by analysis and test. Once approved, the recommended levels should become binding system specification requirements.

Radar Cross-Section Reduction. The radar cross section (RCS) of the aerospace system, including the mission stores, should be reduced to the levels required to achieve the jamming-to-signal (J/S) ratio specified for each aspect angle-threat frequency combination called out in the aerospace system performance specification and the approved survivability plan. Areas which should be given special consideration include engine inlet ducts and engine front faces, engine exhausts, inherent structural corner reflectors, cavities (crew compartment, radomes, antenna and antenna apertures, radar-visible internal bulkheads, etc.), and external or semi-submerged stores.

Infrared Signature Reduction. The contractor should design to the IR emission requirements specified in the aerospace system performance specification or the survivability plan. Aerospace system areas to be given special attention are exposed engine hot sections, heated surfaces, engine exhaust, exhaust plume, aerospace system IR reflections from transparencies and metallic or IR reflective surfaces, and internal and external illumination devices.

Visual Signature Reduction. The contractor should design to the aerospace system visibility requirements specified in the aerospace system performance specification and the survivability plan, by reducing the contrast of the aerospace system with its background (both sky and surface), reducing the reflection of light, and reducing smoke or contrail emissions.

Aural Signature Reduction. The contractor should reduce or eliminate noise signature from propulsion and aerodynamic surfaces to the extent practicable and as specified in the survivability plan.

Electromagnetic Emission Reduction. Inadvertent electromagnetic emissions that can be detected by surveillance devices to locate the aerospace system should be eliminated or reduced so that no emitter in the standby mode of operation and no other equipment in full operation will emit radiation that exceeds the level specified in the aerospace system performance specification and the survivability plan.

Survivability Aids

The survivability of the aerospace system should be enhanced through the use of electronic warfare countermeasures and electronic warfare counter-countermeasures as required by the performance specifications for the aerospace and avionics systems. Selection of, and specification for, survivability aids should be based on survivability enhancement trade studies. The trade studies should consider all aspects of susceptibility reduction for specified threat weapons. The contractor should determine the J/S levels required to permit effective operation in the threat environment.

Damage Tolerance

For aerospace systems whose missions involve exposure to non-nuclear threats, protection of the system should be provided to the extent required by the aerospace system performance specification. Where no specific levels of protection are levied, the contractor should provide, upon approval by the government, the most effective combination of survivability enhancement features determined by the aerospace-system survivability assessment and system cost effectiveness analyses described in Volume 10.

Design Configuration

The general design configuration of the aerospace system should be arranged to obtain the highest level of protection practicable for the least penalties. Design considerations should include such matters as redundancy and separation of system components, lines, and structures;

natural masking of essential components; location of fuel cells in relation to engine inlets so as to minimize ingestion of fuel leakage; elimination of fire paths that jeopardize controls; integral armor; and isolation of hazardous elements such as armament, oxygen containers, and flammable fluids from sensitive or susceptible areas. Revisions should be incorporated to prevent or suppress hazardous fires in the isolation where they start (engine nacelle. fuel tank, dry bay, etc.) to decrease the possibility of aerospace system kill caused by fire. The flying qualities for safe flight after sustaining the specified hostile weapon effects should meet minimum levels specified in the performance specification.

Structure. The aerospace system structure should be of a fail-safe design achieved through the use of multiple load paths and crack stoppers to reduce the probability of catastrophic structural failure due to battle damage with the aircraft in full-*g* maneuvering flight. No flight-critical structural components or load paths should be vulnerable to a single detonation, impact, or other damage mechanism of threat specified in the implementing documentation that would preclude a safe return and landing (arrested landing in the case of aircraft equipped with an arresting hook). Additional requirements may be listed under Damage Tolerance or Crashworthiness in the performance specification.

Crew Station. Protection should be provided for the aircrew as required by the aircraft performance specification or as determined by the government-approved, contractor-conducted aircraft vulnerability analysis, as discussed in Volume 7. When ballistic protection is required, it should be for the V05 ballistic limit. The crew station design should minimize both the generation of hazardous spallation within the crew area and the probability of simultaneous incapacitation of more than one pilot (in a multipilot aircraft) because of a fragmenting round.

Fuel System. The fuel system should be designed to withstand the specific threats identified in the aerospace system performance specification and in the implementing documentation and to provide a specified quantity of protected “get-home” fuel. Fire and explosion suppression techniques should be employed throughout the fuel system. Such suppression techniques should include location of fuel tankage and lines away from ignition sources and employment of predictable nonhazardous fuel leakage paths following impact by the specified threats. For carrier-based aircraft, the fuel systems should be designed to contain the fuel with the aircraft engulfed in a fire for the time specified in the aircraft performance specification. Hydraulic ram protection should meet the specified requirements and should be designed to prevent the creation of hazardous secondary damage mechanisms such as fuel ingestion by the engine.

Propulsion System. The engine installation should be designed for protection from the weapon effects required by the aerospace system performance specification and by the implementing documentation of this section. Where multiple engines are employed, design techniques should be used to prevent the combat damage response of one engine from propagating to another engine, causing its failure or degradation. Fire detection and extinguishing should be provided in multiple engine propulsion systems and should be considered in single engine systems. Responsibility for engine vulnerability reduction and survivability enhancement of the installed engine is vested in the airframe contractor.

Power-Train System. Power-rain systems, such as those employed by V/STOL or turboprop aircraft, should be designed to be damage tolerant against the level of threats required by the mission specified in the performance specification, the operational requirements, and implementing documentation. Redundancy, reserve capacity, damage tolerance, and ballistically protected elements should be evaluated as methods to obtain the specified or established protection levels. Design techniques to delay failure upon loss of lubrication should be used for essential power train elements. Rotating shafts and blade assemblies should be ballistically tolerant to the threats specified in the implementing documentation of this section and should not be the source of secondary damage mechanisms for other critical components.

Flight-Control System. The primary flight-control system should be designed to minimize failure or malfunction from the non-nuclear weapon effects specified in the implementing documentation of this section. No single hit by the specified threat, on the flight control subsystem should kill the aerospace system. The design of the flight control subsystem should be such that, if the actuating elements of the control surfaces fail, they return the control surfaces to a position to maintain level flight. The design of the flight control subsystem should be such that:

- Failure of the primary system does not result in a jammed system. For ship-based aircraft, control functions necessary for safe recovery of the aircraft aboard the ship should be as specified in the aircraft performance specification.
- Secondary controls such as slats, flaps, speed brakes, etc., are designed so that their response to weapon effects will not result in hazardous flight and recovery operations.
- Applicable techniques such as redundancy, separation, miniaturization, exploitation of inherent shielding, damage-tolerant and damage-resistant components, ballistic armor, fly-by-wire devices, emergency backup subsystems, and integrated power packages should be evaluated as methods to achieve the desired protection levels. Routing and separation should be such that:
  - Maximum protection against hostile threats is afforded by the aerospace system engines, structure, or other subsystems.
  - Points where a single hit from a specified threat will result in loss of more than one control axis, or result in an uncontrollable aerospace system, are eliminated.
  - Damage resulting from multiple fragment hits is minimized.

Fluid Power System. Protection for the fluid power systems (hydraulic and/or pneumatic) should be provided to the extent required by the aerospace system performance specification. The following survivability design techniques should be evaluated to achieve the required protection levels:

- Less flammable hydraulic fluids
- Hydraulic circuit monitoring and control
- Redundant systems
- Shatterproof components

- Miniaturization
- Separation
- High-heat-tolerant components or lines
- Component manifolding (the combination of several hydraulic functions in a single damage-resistant package with concurrent reductions in the presented area)

Electrical Power System. The electrical power generation and distribution system, including emergency backup systems, should be designed to survive the specified non-nuclear weapon effects. Circuits for essential functions, including active countermeasures, should be given priority for protection and should not fail as a result of a single hit by the specified threat. Hazardous circuits should be isolated from potential sources of short-circuit actuation or failure from primary or secondary weapon effects. Multiple or cascading failures in electrical bus systems should be avoided.

Armament System. Armament systems should be designed to minimize or prevent hazardous effects from hostile weapons on the aerospace system, as specified in the performance specification and in the implementing documentation of this section. Provisions should be incorporated to delay the hazardous response of the aerospace system's internal and external armament loadings when subjected to fuel fire, such as from JP-4, JP- 5, JP-8, and NATO fuels.

Environmental Control System. The environmental control system should be designed to minimize the effect on the aircrew and essential components caused by hazardous conditions from the specified weapon effects. Such conditions include explosive decompression, shattering of liquid oxygen containers, hot gas line rupture, etc. Protection should be provided when high-temperature bleed gases or engine exhaust fumes are routed through or adjacent to compartments containing combustibles or temperature-sensitive structures.

Launch/Recovery System. The takeoff and landing system should be designed to allow recovery of the aerospace system when it is exposed to the weapon effects specified in the aerospace system's performance specification and in the implementing documentation of this section.

Avionics System. The installation of government-furnished equipment (GFE) and the design and installation of contractor-furnished equipment (CFE) in electronic and weapon-delivery systems should include methods to minimize equipment failure or malfunction from the weapon effects specified in the aerospace system performance specification and in the implementing documentation of this section. Such considerations should be primary design factors in the installation of any such equipment for aerospace system application. Provisions to delay failure from loss of normal environmental conditions should be included so that operations can be performed in degraded modes. The following features should be included:

- The avionics system (including interconnecting wiring) should incorporate design features that minimize, within the limits of practicality, the loss of mission-essential functions because of a single hit from a specified threat. Avionics components supporting nonessential functions may be used to provide shielding for components supporting essential functions.

- Special attention should be given to reduction of the vulnerability of avionics components employed in flight- or mission-essential functions. These essential components include electronic flight control system components, engine and inlet controls, and any other components in which electronic or fiber-optic technology has been substituted for mechanical, electromechanical, or hydraulic power and control. The assessment and design should also consider the degradation in survivability that can result from the loss of countermeasures, navigation, fire-control, target acquisition, or communication capabilities.
- The aerospace system should not be vulnerable to mission kill from non-nuclear electromagnetic pulses.

Laser Vulnerability Reduction

When laser weapons are included among the specified threats, the contractor should design the aerospace system to withstand the specified levels of laser radiation. Techniques for laser vulnerability reduction often follow the same guidelines as for ballistic vulnerability reduction, such as providing redundancy, separation, and burnthrough tolerance. These techniques should be supplemented with techniques to reflect or block the laser energy, where required, for crew and airframe survivability. Structural tolerance to low-level heating should be incorporated as specified in the implementing documentation.

4.0 SURVIVABILITY VERIFICATION AND DEMONSTRATION

Susceptibility Verification and Demonstration

Tests and analyses are required to determine aerospace system susceptibility to threat systems and to verify the performance of reduced signatures, threat warning systems, and countermeasures.

The goal of T&E is finding and correcting problems early. In general, maximizing the use of digital pilot-in-the-loop M&S and in-flight simulation and ground testing (in SILs, HITL facilities, and ISTFs) prior to and during flight tests reduces overall test costs, since open environment flight tests are the most costly portion per capita of the T&E resource categories. The relationship of cost to each type of test is shown in Figure 2.

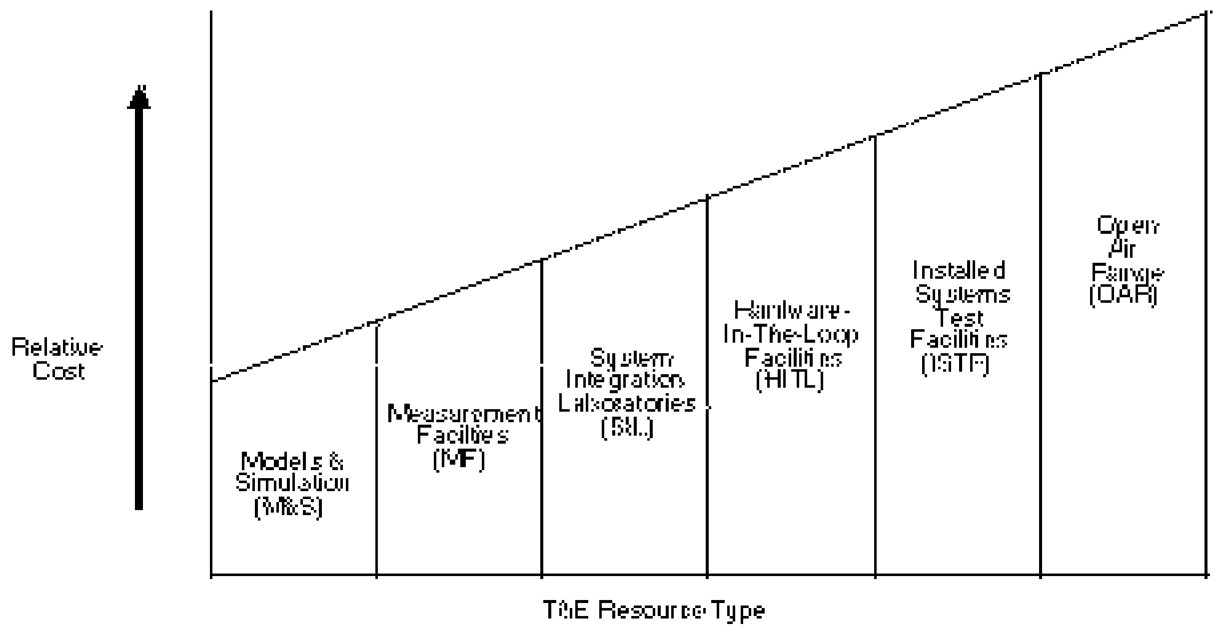

Figure 2. Relative Costs, T&E Resource Utilization

Digital models and computer simulations are used to represent systems, host platforms, other friendly players, the combat environment, and threat systems. Such threat simulations and missile flyout models can be used to help design and define EW systems and testing. Because of the relatively low cost of exercising these models, this type of activity can be run many times to check what-ifs and explore the widest possible range of system parameters without concern for flight safety. These models may run interactively in real or simulated time and space domains, along with other aspects of a combat environment, to support the entire T&E process.

Throughout the acquisition process, a system will be continuously evaluated to ensure that operational effectiveness, operational suitability, and performance requirements can be met. As each candidate system evolves, vulnerability/susceptibility analyses and survivability assessments are conducted to evaluate the effectiveness of individual survivability design features.

Vulnerability Verification and Demonstration

Tests and analyses are required to determine aerospace-system vulnerability and show that the various aerospace systems will meet the requirements. The purpose of this program is to determine system, subsystem, and component combat sensitivity, as well as to verify the design and materials. The program should include ballistic firing, controlled damage tests, and a vulnerability reduction demonstration. The tests should be conducted on actual or simulated components (of the same material and design as the actual components), and on complete subsystems or portions thereof.

Title 10 United States Code Section 2366 mandates LFT&E for all covered systems, programs, or covered product improvement programs. The term “covered system” means a system that the Director, OT&E, has determined to be a major system within the meaning of that term in *10 USC 2302(5)* that is one of the following:

- User-occupied and designed to provide some degree of protection to the system or its occupants in combat.
- A conventional munitions program or missile program.
- A conventional munitions program for which more than 1,000,000 rounds are planned for acquisition.
- A modification to a covered system that is likely to affect significantly the survivability or lethality of such a system.

Vulnerability reduction substantiation, verification, and demonstration tests should be integrated and “piggybacked” on other existing endurance, fatigue, and failure types of test programs to the fullest extent possible. Below is a brief description of the three general types of test and their procedures. The contractor should specify proposed tests in the Survivability Program Plan.

Gunfire Tests. For gunfire tests the following brief information should be provided for each component:

- Component identification
- Number of specimens
- Threat caliber(s) and type(s)
- Type of structural loading during impact, if any
- Type of structural post-damage test, if any

Ballistic Firing Tests. Ballistic tests should be conducted to determine the extent of damage to a critical component by an impact whether or not armor or other integral shielding is present, and the resultant component or specimen failure mode, reaction, and secondary effects. The "worse-case" conditions should be used for gunfire tests, with the following considerations taken into account: projectile type, projectile orientation (straight-in versus degree of tumble), angle of attack, obliquity, projectile striking velocity, load and speed characteristics, and the most vulnerable location. Components should be under load to simulate operation during ballistic impacts. In general, post-damage structural tests should be of the same type used to qualify that component (static, fatigue, or operational run). Qualification and acceptance tests of armor materials should be of the V50 type. Armor installation adequacy should also be determined.

Controlled-Damage Tests. Controlled-damage tests simulate the secondary effects of projectile damage. Where primary damage can be accurately predicted and is not solely responsible for component or subsystem failure, tests should be conducted without using gunfire to initiate the failure sequence. Typical measures collected during these tests are for oil leakage rate, oil starvation, fuel leakage and drainage, fire detection and prevention, adequate or redundant designs, and adequacy of hydraulic subsystem leakage and redundancy. These tests should be conducted under the direction of cognizant contractor personnel of the particular functional area. Whenever possible the tests should be "piggybacked" on other endurance, fatigue, or failure types of test programs.

Vulnerability Demonstration

A vulnerability demonstration should be conducted with an aerospace system to assure that the design concept, configuration, integration, and subsystem designs meet the system specification requirements for the ground test vehicle, static test article, or other production representative test article.

The program should include ballistic firing tests or destructive secondary-damage tests, conducted as follows:

- **Fire/explosion prevention plus hydraulic ram effect** tests involve firing threat projectiles at fuel plumbing and tanks or other structures above and below the fuel level under typical environmental conditions.
- **Crew compartment** tests involve firing threat projectiles to determine the level of ballistic, spall, and debris protection for the pilot and co-pilot with all shielding (including armor) and hazardous items in their proper place.
- Tests of **support systems' control systems and engines** involve firing threat projectiles at various mechanical, hydraulic, and electrical system areas to qualify adequate separation of redundant components and to prevent one failed component from destroying a second one.
- **Structural response to internal blast** involves firing threat projectiles against critical structural areas.

Component Selection

Critical components for testing should be selected based on the vulnerability analysis and verification tests. Additional components and subsystems, which can best be tested when they are installed, should be included to determine the secondary effects such as jamming, spall, redundancy, separation, shielding, and fire or explosion. Other conditions to be tested involve multiple subsystems, "kills" by a single projectile, and kills of one subsystem by another because of the two subsystems' close proximity. Some items and subsystems may have reactions to ballistic testing that will produce effects not otherwise readily determinable. Representative aerospace-system components, for example, may be previously tested or reject items.

The following is a list of subsystems with some examples of typical critical components that should be subjected, where applicable, to verification tests:

- **Fuel Subsystem** — fuel cells, fittings, pumps, sumps, and ullage inerting or void area-protection systems.
- **Control Subsystem** — rods, bellcranks, mixing units, combining units, actuators, pitch change links, cables, swashplates.
- **Drive Subsystem** — Driveshafts, hangar bearing assemblies, main transmission, gearboxes, lubricant sumps, and reservoirs.
- **Support Subsystems** — hydraulic actuators, wire bundles, fluid lines.
- **Rotor** — blades and hub assemblies.
- **Crew Station** — pilot and co-pilot seat armor, instrument panel material, canopy, windshield, crew separation barrier.
- **Structure** — fuselage, tailboom, and structural attachment fittings for transmissions, gearboxes, and vertical stabilizer.
- **Engine Installation** — mounts, separation structure, controls.
- **Ammunition Feed and Storage** — ammo magazine, ammo conveyors, missile pods.

Reports on Results

In each of the test/verification efforts above, the contractor should document:

- The methods of testing, facilities used, and test instrumentation.
- The criteria for establishing failure modes.
- The procedures for comparing test data with analytical data.

Test results should be reported in periodic progress reports, if required by the Contract Data Requirements List (CDRL), or quarterly if no other progress report is specified.

5.0 ADDITIONAL CONSIDERATIONS

Survivability Enhancement Trade Studies

The developer should conduct survivability enhancement trade studies. These studies should identify the effects of variations in each significant survivability analysis parameter (e.g., threat, mission, operational utilization, performance, and incorporation of survivability enhancement techniques) on overall combat effectiveness, cost, and schedule. The developer should continuously evaluate trades affecting survivability enhancement and should take appropriate design or design-change action to ensure optimum aerospace system survivability in terms of overall combat effectiveness, cost, and schedule. The trade study should contain information on the following:

- Survivability enhancement techniques considered.
- Vulnerability reduction realized with respect to specified threats and kill criteria.
- Susceptibility reduction with respect to specified threats.
- Impacts on weight, performance, cost, reliability, maintainability, safety, ease of reparability, producibility schedule, etc.
- Verification test requirements, if needed to verify improvement in survivability.
- Recommendations and alternatives regarding optimum design and configuration.
- Details on installation and removal if "kit form" techniques are recommended for use.

System Cost Effectiveness Analysis

The contractor should conduct a cost effectiveness analysis to support trade studies of candidate survivability enhancement techniques. The methodology may be government-provided or government-approved (as specified in the procurement document). The method should provide MOEs with which to compare the relative effectiveness of proposed survivability techniques along with their associated costs. These techniques should involve reduction of detection and survivability aids as well as vulnerability reduction. Cost analysis activity in support of trade studies should be documented to include the data rationale and procedures used in developing cost estimates.

Management of Product Changes

Design is seldom if ever a one-step process. Throughout the acquisition life cycle, changes to the design will occur. These changes may result from advances in technology, improved manufacturing capability, feedback from the field, changes in user requirements, etc. Each change drives another visit to the systems engineering process — the fundamental problem-solving tool — whereby requirements are analyzed, allocated, designed to, and finally fielded.

The program manager, along with technical support from the systems engineering community, has the job of ensuring that all the changes to the design are reasonable and resulting variances in cost, manufacturability, reliability, supportability, and performance are acceptable from a systems point of view before such changes are implemented.

Engineering Use of M&S in the System Development and Demonstration Phase

A major focus of M&S in the system development and demonstration phase is on engineering-level models, which are used for detailed survivability design, engineering trades, test planning and support, subsystem and system performance, and verification of compliance with specifications. Models and simulations also support cost/performance analysis and ORD updates, Developmental Tests (DT) and OT&E, and preparations for production and deployment of the system.

Several uses of M&S in this phase are described below:

- Engineering-level M&S of proposed systems and subsystems are used for survivability detailed design and assembly of subsystems, components, and piece parts. Performance requirements are verified using a combination of testing and simulation.

- Hardware/software in the loop (HW/SWIL) simulations are used in a model-test-model process for survivability-related pre-test planning, test execution, and post-test analysis. Such simulations are able to identify problems in actual test hardware before conducting live tests (i.e., live simulations) on the range. The simulations also provide for parameter variation studies and augment the matrix of test conditions. The performance estimates from simulations during this phase along with live simulation (test) data provide input for M&S at other levels or of other classes.

- Cost models are able to incorporate survivability cost data from engineering models and actual LRIP hardware for the program cost estimates and cost/performance analysis updates.

- Engagement and mission/battle M&S are used, again to evaluate how well the survivability designs allow the proposed system to achieve the necessary MOE. Theater/campaign-level M&S are used to assess the proposed system and determine its impact on conflict outcomes.

- Human interactive simulations will continue to examine tactics within the above framework of constructive models, but will be more likely to focus on continued refinement of human-machine interfaces associated with survivability.

- Virtual simulations can be used to evaluate systems performance and effectiveness. A virtual prototype can be used to support development efforts including survivability design, support (such as maintenance walk-throughs), manufacturing, and training. Members from every functional discipline share the same electronic representation of the system, thus facilitating integrated product and process development. As weapon system trainers learn their tasks, they should take maximum advantage of the M&S used in developing the system itself. As these trainers are developed and made available, they may be used for training test crews and mission rehearsal for live simulations (such as OT&E planning).

- Live survivability simulations may take the form of live exercises, or instrumented prototype tests, including Initial Operational Test and Evaluation (IOT&E). Managers should insist that data obtained in these tests are used for further M&S validation.

- A combination of engineering, engagement, mission and campaign simulations, as described in the program Test and Evaluation Master Plan (T), will be required to augment the developmental and operational test program during the system development and demonstration phase. Earlier program efforts to define the appropriate survivability models and simulations; perform verification, validation and accreditation (VV&A) on them; and determine the relationships among MOEs and Measures of Performance (MOPs) are critical to the successful application of M&S to support or augment the test program.

Models and simulations not only support detailed survivability design during this phase, but also continue as key tools for the IPPD. M&S will reduce design risk by allowing all of the functional disciplines to work from the same design database. A reduced number of engineering change proposals (ECP) will be an important result of this activity. HW/SWIL simulations will result in significant risk reduction in T&E through planning, hardware checkout, and mission rehearsal. Finally, the transition to production will take place with reduced risk because digital design data will be electronically transferred directly to the manufacturing floor.

At the end of the system development and demonstration phase, the system's detailed survivability design, including definition of production and support processes, is complete. In accordance with M&S planning conducted beginning in the concept and technology development phase, the program office should be prepared to maintain the survivability M&S that will be needed for continued support of the weapon system during its life cycle. The PM also needs to consider how to make representations (models) of the system available to others outside the program office who may have a need to use them.

One tool the survivability engineer will find particularly useful from concept to production is virtual prototyping, a computer-based simulation that possesses functional realism comparable to that of a physical prototype. This technology can maximize benefits of integrated product teams through the use of scientific data visualization, three-dimensional drawings, and animated simulations. Rapid multidisciplinary communication translates to more robust designs, lower design and manufacturing costs, and compressed cycle time; and it facilitates the DoD dual-use thrust because of its electrical transportability, its capability of reusing designs, and its ability to rapidly reconfigure system characteristics throughout the engineering design process.

6.0 SUMMARY

The survivability engineer supports the technical program efforts of design engineering, specialty engineering, production engineering, and integrated test planning including, but not limited to, the engineering effort to transform a survivability operational need or statement of deficiency into a description of system requirements and a preferred system configuration; and the technical planning and control effort to plan, monitor, measure, evaluate, direct, and replan management of the technical program. If a prime contract is in force, the design engineering and production engineering directly related to the products or services of a deliverable end item are the responsibility of the prime contractor.

The design process follows from a set of stated requirements for a system and evolves through (1) conceptual design (establishment of performance parameters, operational requirements, and support policies), (2) preliminary systems design, and (3) detailed design. This process generally begins with a visualization of what is required and extends through the development, test, and evaluation of an engineering or prototype model of the system. The output constitutes a configuration that can be directly produced or constructed.

From a systems engineering standpoint, the survivability engineer becomes a primary participant in design synthesis and verification activities that translate functional and performance requirements into design solutions. These solutions need to be in sufficient detail to verify that requirements have been met. Verification of the design must include a cost-effective combination of design analysis, design M&S, demonstration, and testing. The verification process must address the design tools, products, and processes.

Inherent within the systems engineering process is an ongoing analytical effort. Throughout the design and development of a system, many different alternatives (or concepts) require evaluation and trades. The process of investigating and evaluating these alternatives constitutes an ongoing analytical effort. To accomplish this activity in an effective manner, the engineer and/or analyst relies on the use of analytical techniques/tools for early trades and to facilitate the quantitative system analysis process delineated below:

- Define the problem.
- Identify analysis requirements.
- Select evaluation criteria.
- Establish models and simulation requirements.
- Acquire necessary models and simulation.
- Generate input data.
- Perform analysis.

A typical work breakdown structure for survivability enhancement is provided below:

Enhancements

> Aircraft design enhancement
- Signature suppression
  - √ Radar
  - √ Infrared
  - √ Acoustical
  - √ Optical, etc.
- Low vulnerability
  - √ Threats
    - - Conventional (ballistic projectiles and missile warheads)
    - - Weapons bay/munitions vulnerability
    - - Chemical, biological, and radiological
    - - Directed energy (high- and low-energy lasers and other directed energy)
    - - Nuclear
  - √ Component
    - - Component elimination
    - - Component relocation
    - - Component shielding
    - - Component material improvement
  - √ System/subsystem design enhancement (redundancy, active damage suppression, passive damage suppression)
    - - Fuselage tank fire and explosion
    - - Fire-protected APU bay
    - - Engine bay fire protection
  - √ Integrated fire/explosion protection
    - - Fire/explosion protection systems for next-generation aircraft
    - - Weapons bay/munitions vulnerability
  - √ Fire detection and extinguishing system
- Susceptibility enhancement (reduction)
  - √ Susceptibility reduction through EO/IR techniques
    - - Pointing and tracking Countermeasures
    - - Imaging seeker IRCM
    - - Off-board laser CM flight test
    - - Short-pulse laser effectiveness
    - - Post-burnout missile tracking/cued detection
    - - IR kinematic special decor (KSD)
  - √ Susceptibility reduction through RF techniques
    - - Innovative radar countermeasures
    - - Radar deception and jamming ATD
  - √Susceptibility reduction through LO techniques

- Ceramic insulation for helicopter engine nacelles
- Active control of external helicopter noise
- Low observables material operational usage evaluation

√ Acoustic
√ Visual

> Aircraft utilization enhancements
- Tactics
- Countermeasures
- Self- protection systems
  √ Intercept weapons
  √ Attack weapons
  √ Antiradiation weapons

> Subsystem design enhancement
- Redundancy
- Active damage suppression
- Passive damage suppression

Survivability engineering design documentation/data

> Design-discipline data/reports of analytical data
- RCS and jamming-to-signal (J/S) ratio
- Threat and operational scenario database
- Survivability assessment database
- Alarm database development

> Technical manuals
> Logistic support data
> Supplier data
> Management data
> Field data/failure reports
> Database (depository)
> Combat and accident data
> Documentation
- Specifications
- Manuals
- Standards

Training requirements

> Training services
> Training equipment
> Training data
> Training facilities

Provisioning

> Spare parts
> Repair parts, all levels
> Consumable materials

Inventory control

Facilities (warehousing)

> Personnel facilities
> Test and evaluation facilities
> Maintenance facilities

Capital equipment

Utilities