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1992
LIFE SUPPORT SYSTEMS ANALYSIS WORKSHOP

Houston, Texas
May 12-14, 1992

WORKSHOP REPORT

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DEFINITIONS OF ACRONYMS

ACSL	Advanced Continuous Simulation Language
ARC	Ames Research Center
CGRC	Crop Growth Research Chamber
EDC	electrochemical depolarized carbon dioxide
EDO	Extended Duration Orbiter
EVA	extra-vehicular activity
g	measure of force of gravity
IVA	intra-vehicular activity
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
kg	kilogram
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt hour
I/O	input/output
LiSSA	Life Support Systems Analysis
LSS	life support system
m	meter
MDM	multipurpose data microprocessor
MEN	Mass Exchange Network
NASA	National Aeronautics and Space Administration
OAST	Office of Aeronautics and Space Technology
PID	position integral derivative
PMC	permanently manned configuration
RDDT&E	research, design, development, testing and evaluation
SDP	standard data processors
SIRF	Systems Integration Research Facility
SISO	single input, single output
SSF	Space Station Freedom
STS	space transportation system
VPGC	Variable Pressure Growth Chamber

1.0 1992 WORKSHOP OBJECTIVES AND SUMMARY

The *1992 Life Support Systems Analysis Workshop* was sponsored by NASA's Office of Aeronautics and Space Technology (OAST) to integrate the inputs from, disseminate information to, and foster communication among NASA, industry, and academic specialists. Life support technologies will require a broad base of systems modeling experience with adequate validation of models through experimentation. As life support systems approach closure, NASA will need the capability to better understand and predict performance and operation of the life support system in more detail.

The goal of this workshop was to continue discussion and definition of key issues identified in the 1991 workshop, including: (1) modeling and experimental validation; (2) definition of systems analysis evaluation criteria; (3) integration of modeling at multiple levels; and (4) assessment of process control modeling approaches. Through both the 1991 and 1992 workshops, NASA has continued to seek input from industry/university chemical process modeling and analysis expertise, and to introduce and utilize new systems analysis approaches to life support systems technologies.

1.1 Workshop Overview

The workshop was held over a 3-day period, 12-14 May 1992, in Houston, Texas near the Johnson Space Center. The program included technical presentations, discussions, and interactive planning, with sufficient time allocated for discussion of both technology status and technology development recommendations. Key personnel currently involved with life support technology developments from NASA, industry, and academia provided input to the status and priorities of current and future technologies. The detailed agenda is presented in Appendix A, pages 43-46.

The real-time model demonstrations were held at the Johnson Space Center. Models that were available for one-on-one and small-group experiences included: Life Support Systems Analysis (LiSSA) Tool, ASPEN PLUS, Advanced Continuous Simulation Language (ACSL), SimuSolv, Speedup, and the NASA Life Support Data Base. These models include dynamic simulation, component steady-state chemical processing analysis systems, and a data base of the various existing life support technologies.

Tours of the Johnson Space Center facilities included:

- Regenerative Life Support System Test Bed -- Ten Foot Chamber
- Systems Integration Research Facility (SIRF) -- Twenty Foot Chamber
- Advanced Life Support Laboratory -- Room 2004
    - Solid Amine Test Stand
    - Waste Water Membrane Test Stand
    - Air Membrane Test Stand
- Hybrid Regenerative Water Recovery System -- Building 241.

1.2 Overview of Working Groups at the 1992 Workshop

Four working groups were formed. A summary of the working group output is provided in Section 2 of this report, with more detailed discussion following in Sections 3 through 6. The presented results of the working groups are provided in Appendices C.1 through C.4.

1.2.1 Systems Analysis Modeling and Experimental Validation/Verification

1991 working group results cited the importance of iteration between systems analysis modeling and experimental validation and verification. The 1992 working group investigated, in more detail, the specifics of data exchange and performance validation and software verification procedures between systems analysis modeling and hardware development/testing. This working group also discussed the issue of scale-up as it applies to this modeling and test bed iteration. Group Leader: Dr. Liese Dall-Bauman, NASA/JSC.

1.2.2 Application of Systems Analysis to Process Controls

Systems analysis based on steady state operation is adequate to assess system parameters such as mass, volume, average power demand, and other valuable resources. However, stable operation within any given control envelope during start-up, shut-down, and other transients, as well as during various emergency conditions, requires dynamic process modeling and analysis of dynamic system behavior. This working group attempted to identify dynamic systems attributes to be estimated through dynamic process models and interactive control models, and discussed the relationship of dynamic systems attributes to actual systems control. Group Leader: Dr. P.K. Seshan, JPL.

1.2.3 Integration of Component, Subsystem, System, and Mission Level Models

Life support systems analysis modeling must integrate and coordinate data (both inputs and outputs) of modeling at subsystem and component levels as well as the integrated systems levels. Modeling must also support production of performance and operational characteristics for technologies at varied levels of development. This working group focused on ways to make modeling algorithms, input data, and output data more compatible at different levels of analysis. Group Leader: Dr. Chin Lin, NASA/JSC.

1.2.4 Evaluation Criteria

The definition of the evaluation criteria for assessment of life support systems is crucial to selection of proper system configuration, subsystems technologies, and component designs. This Working group defined classes of evaluation criteria which satisfy performance and operational requirements that are carried down from top-level mission requirements to the component level, and performance at and across individual subsystems and components. Group Leader: William Likens, NASA/ARC.

1.3 Overview of Presentations at the 1992 Workshop

1.3.1 NASA's Life Support Systems Analysis (LiSSA) Tool

Dr. P.K. Seshan provided an overview of the systems analysis capability of the LiSSA. LiSSA combines chemical process analysis through generic modular flow schematics, simulation of mass and energy flows with ASPEN PLUS, scale-up correlations, and integration of mission-related parameters in a Lotus 1-2-3 user tool. LiSSA is planned to be released for Beta testing in December 1992. The ultimate objective of LiSSA is to provide an integrated simulation and trade tool for the analysis and assessment of system and technology alternatives for life support mission applications. The modeling structure provides a rigorous accounting of mass and energy exchanges among process units, subsystems, and systems through accurate computation of flow rates, compositions, temperatures, pressures and other flow stream characteristics. Thus, this approach eliminates general use of empirical data and "rules of thumb" in developing mass, power, and volume estimates of future integrated life support systems.

1.3.2 Experimental Evaluation of Systems Analysis Models

Papers were presented which highlighted experiences, lessons learned, and plans for developing test bed activities that utilize and validate systems analysis analytical models. Papers discussed use of test data to validate subsystem and process models, and use of laboratory data to provide kinetic and transport data of process models. Presenters identified specific benefits, disadvantages, and methods of iterating systems analysis and experimental test beds.

Systems Analysis for System Integration Research Facility (SIRF) Test Bed
Dr. Naresh Rohatgi, JPL, and Dr. Liese Dall-Bauman, NASA/JSC

The SIRF is designed to provide system-level integration, operational test experience, and performance data necessary to proceed with the design, development, fabrication, test, and certification of a regenerative physical/chemical life support system required for future human space exploration. Various technologies may be tested in the facility and compared against modeling results. Current and planned technologies within SIRF and related modeling using the LiSSA tool were reviewed. To date, LiSSA has been used to estimate mass, volume, power, and resupply requirements for LSS configurations supporting a crew of four for ninety days. A total of thirty cases were evaluated (although only 27 have been completed at this time) to incorporate various combinations of technologies for air revitalization (CO_2 removal and reduction and O_2 generation) and water treatment (potable, hygiene, and urine water recovery).

Bench Scale Testing and Modeling of Mass and Heat Transfers in the Adsorption of CO_2 and H_2O Vapor on Solid Amine
Frank F. Jeng, Lockheed ESC and Fred Ouellette, NASA/JSC

A solid amine CO_2 removal technology is being developed for the Extended Duration Orbiter (EDO) and consists of a two-bed system with chemical adsorption and regeneration through vacuum desorption. The presentation summarized prototype testing and analytical model development. Both an adsorption model and a heat transfer model were developed to estimate the performance of the test bed. Issues of scale-up were also addressed.

1.3.3 Analogous Systems Analysis Approaches and Tools

Systems analysis not directly related to life support systems and operations can provide significant input to the development and implementation of life support systems analysis. Papers described the analysis methods used in non-space and non-life support areas and how these methods might be applied to life support systems analysis.

Availability Analysis as a Design Tool for Closed-Loop Life Support Systems
Dr. Richard C. Seagrave and Sharmista Chatterjee, Iowa State University

Availability analysis, or exergy analysis, utilizes the first and second laws of thermodynamics to characterize the thermodynamic efficiency of energy conversion systems, or other systems in which entropy is generated in a quantifiable way. Long-duration, closed-loop life support systems are ideal candidates for such an approach, since the ultimate goal of the designer must be not only to conserve mass and energy, but also to limit the production of entropy to a level compatible with organized life. Living systems require a source of negative entropy, in addition to material and energy requirements. Availability analysis is useful in putting this need in perspective, as well as in evaluating competing technologies for water and air treatment, waste processing, food production, and air conditioning. The closed nature of life support systems allows thermodynamic analysis to proceed more effectively than in many other engineering applications, although the application to such systems is fairly recent.

Dynamics Modeling and Optimization Approaches and Examples Using Speed-Up
Dr. Glen Dissinger and Scott A. Ray, ASPEN Technologies

An overview of Speed-Up was presented including the dynamic simulation, steady state modeling, process optimization, parameter estimation, and data reconciliation capabilities. An overall description of the capabilities was provided, as well as process analysis and simulation examples.

Dynamics Modeling Approaches and Examples Using SimuSolv
Dr. Patrick S. McCroskey, Dow Chemical

SimuSolv is an integrated, multi-functional software package for modeling and analyzing the dynamic behavior of various physical systems through simulation of system characteristics and behavior, estimating model parameters, and optimizing model performance. The model is based on the Advanced Continuous Simulation Language, with additional libraries of basic processes and commonly needed functions and a macro language. The model allows input from experimental data, numerical integration, optimization, sensitivity analysis, statistical analysis, and graphical presentation of results.

1.3.4 Analytical Modeling for Process Dynamics and Control

Papers focused on past, current, and future methods and approaches to process control. Control hierarchies and methodologies need to address potential levels of stability, effects of off-nominal operation, levels of sensing and monitoring needed, potential for singularities and instabilities, and control mechanisms for safety, redundancy, and reliability.

Experiences and Modeling Approaches for Dynamic Systems Analysis
Dr. Robert J. Farrell, Polytechnic University of New York

Dr. Farrell provided a review of systems analysis approaches used in the chemical processing industries. He discussed the status of process design and control systems design, including computational requirements, modeling tools, limitations, and current practices. He also presented examples of applications of complex dynamic models including a multi-pass heat exchanger, distillation columns and absorbers, reactors, and crystallizers. Dr. Farrell summarized the solid amine CO_2 removal system modeling results he obtained using ACSL. The approaches used by the chemical processing industries are most appropriate for analysis of life support systems processes and technologies.

Dynamic Evaluation of Technologies for Life Support Systems
Dr. Vasilios Manousiouthakis, University of California at Los Angeles

Dr. Manousiouthakis described the Mass Exchange Network (MEN) Synthesis approach as it applies to life support systems analysis and discussed the need for simultaneously optimal control. The MEN Synthesis supports the assessment of the best approach to transfer mass from the rich streams within a flow to the lean streams, minimizing pre-defined evaluation parameters under built-in constraints and flow stream characteristics. This technique works extremely well with multi-component systems and flow streams. Control of life support systems can similarly be addressed to optimize the control over several variables and operational circumstances.

Modeling and Simulation Tools for Process Control Analysis
Stephen Rowe, Allied Signal

Computer-aided engineering tools and approaches used by AiResearch controls engineers for modeling and simulation process control problems were reviewed. Software packages included simulation of dynamic systems and pre- and post-processing of simulation data.

An Approach to the Integration of a Closed Ecological Life Support System
Dr. W. Lo, C.H. Lin, Dr. G. Tsao; Purdue University

This paper presented an approach to the integration of a closed controlled ecological life support system. A hybrid conceptual design of closed controlled ecological life support systems that incorporated both physical and bioregenerative technologies was established for simulation and integration. A top-down functional framework was employed to classify the life support system into four subsystems: crew chamber, biomass production, waste management, and food processing. The proposed conceptual design was integrated using an approach which recognizes the crew chamber subsystem as the central subsystem setting the performance of all other subsystems. A chemical process simulation tool, ASPEN PLUS, was employed to perform steady-state simulations and manipulated to perform quasi-transient simulations. A simple dynamic crew chamber model is integrated with pseudo-steady-state subsystem models for system assessment and analysis.

1.3.5 Various Approaches to Systems Analysis

Papers discussed various approaches and special topic issues related to life support systems analysis. The ultimate goal is to provide quantitative estimation of life support system performance in terms of mass, power, volume, thermal control, resupply, reliability, and maintainability.

Probabilistic Risk Assessment
William C. Likens; NASA/ARC

This paper addressed a fault-tree approach to quantify the safety and reliability of a life support system. Safety and reliability "rules of thumb" were identified.

Integration of Detailed User Component Models in ASPEN PLUS Simulations
Dr. Kevin E. Lange; Lockheed ESC

Detailed FORTRAN models of life support system components can be interfaced with the chemical process simulator ASPEN PLUS in cases where the built-in models are inadequate to describe detailed component behavior. Model integration can take the form of a user unit operation model, or one or more user subroutines employed with a built-in unit operation model, such as a chemical reactor. User models have access to the extensive thermodynamic- and physical-property estimation methods and data banks. Capabilities for process optimization and design specifications (feedback control) can also be applied to user models. These features, as well as requirements and techniques for interfacing user models with ASPEN PLUS, were illustrated for a detailed model of an electrochemical depolarized carbon dioxide (EDC) concentrator and a detailed one-dimensional model of a catalytic combustor.

Modeling of Metabolic Species Mass Flow Rates in an Engineered Closed/Controlled Ecosystem - Human Model

Dr. Willy Z. Sadeh; Colorado State University

An overview of a human model characterized the metabolic species flow rates, input/output metabolic species, human body mass, and physical activity categories. In a closed/controlled ecosystem, the human requirements are the driving force for performance of the system. The overall goal of the ecosystem design and operation is to economically sustain human life. Data and relationships developed for and used in the model were presented and integrated into an overall ecosystem flow stream.

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2.0 SUMMARY OF 1992 CONCLUSIONS AND RECOMMENDATIONS

The 1992 NASA Life Support Systems Analysis Workshop assembled government, industry and university expertise to collaborate on analysis modeling and prototype testing of advanced regenerative life support technologies. The contributions of expertise in many disciplines yielded valuable results, which are summarized in this section. Overall results are provided below, followed by summaries of more specific results of each of the four working groups and the summary panel.

- Life support systems analysis to date has lacked the input of rigorous chemical process analysis.
- Chemical engineering and process industry talents and expertise are available to support such analysis and should be utilized for the life support application.
- Other innovative analyses (e.g., thermodynamic) may be valuable for technology trade-offs and sensitivity studies.
- A wide range of chemical process analysis is needed from steady state for initial simulation to dynamic simulation for control system studies.
- Commonality of assumptions and data inputs is necessary to make valid comparisons of various technologies, subsystems, and systems.
- Weight, power, and volume considerations may be adequate for initial analyses, but other considerations, including those related to operational characteristics, should be raised early in the technology development stages.
- Working groups highlighted the need for guidelines in which systems analysis data and tools are developed, implemented, and validated.
- The workshop environment supported communication between NASA center, university, and industrial participants and encouraged continued communication.

2.1 Summary of System Analysis Modeling and Experimental Validation

The results of the 1991 workshop working groups cited the importance of iteration between systems analysis modeling and experimental validation and verification. During the 1992 workshop, this working group investigated in more detail specifics of data exchange and performance validation and software verification procedures between systems analysis modeling and hardware development and testing. This working group also discussed the issue of scale-up as it applies to this modeling and test bed iteration.

- Parameters to be validated are dependent on the subsystem (e.g., in/out flow streams, materials/media).
  - Minimum data set must be defined to assure validation
  - Fundamental operating principles and trends should be validated
  - Performance over lifetime should be validated

- Establish baseline guidelines for subsystems process/prototype.
  - Test conditions which represent actual application conditions
  - Standardized feed compositions
  - Minimum acceptable scale

- Modeling tools and prototype hardware should be "co-developed."
  - Requirements and acceptable bounds on performance parameters
  - Data uncertainty
  - Instrumentation and sampling frequency
  - Baseline assumptions in modeling and testing

- Additional information is needed to adequately scale-up hardware.
  - Characterization of each component (e.g., throughput, materials, drawings)
  - Expected non-linearities and boundary conditions in scale-up

- Guidelines for experimentation and model validation are needed.

- Communication protocol is needed between modeling and experimentation efforts, and among the modeling/experimentation efforts at the various organizations.

2.2 Application of Systems Analysis to Process Control

Systems analysis based on steady state operation is adequate to assess system parameters such as mass, volume, average power demand, and other valuable resources. However, stable operation within any given control envelope during start-up, shut-down, and other transients, as well as during various emergency conditions, requires dynamic process modeling and analysis of dynamic system behavior. This working group attempted to identify dynamic systems attributes to be estimated through dynamic process models and interactive control models, and also discussed the relationship of dynamic systems attributes to actual systems control.

- The number of control variables changes with the mission duration, the degree of closure of the life support system, and the degree of integration with other systems.
  - Shuttle - CO_2, humidity, temperature, and pressure
  - SSF - O_2, CO_2, H_2O (vapor and liquid), temperature, and pressure
  - Minimum short duration mission
    - O_2, CO_2, H_2O (vapor and liquid), temperature, and pressure
    - Technology specific species
    - Key toxins in crew quarters

- The controls methodology must be robust and provide adequate system health management.
- The controls methodology must balance control system strategy and complexity with available on-board computational resources.
- Control system modeling is needed to address trade-offs and sensitivities.
- A dynamic simulation tool must be developed to address nonlinear, interactive systems.

2.3 Integration of Component, Subsystem, System, and Mission Models

Life support systems analysis modeling must integrate and coordinate data (both inputs and outputs) of modeling at subsystem and component levels, as well as modeling at the integrated systems levels. This working group focused on ways to make modeling algorithms, input data, and output data more compatible at different levels of analysis.

- A wide variety of tools is used for various levels of detail and various systems levels
- Many of the tools are developed independently, which makes integration of the data input and output difficult or impossible.
- A standard set of tools for all system levels and all levels of detail is impractical.
- Guidelines should be established for modeling objectives at the various levels and for tools used at the various levels.
  - Assumptions
  - Physical/chemical data
  - Data input/output flows from one level to another

2.4 Evaluation Criteria

Defining the evaluation criteria for assessment of life support systems is crucial to the selection of proper system configuration, subsystems technologies, and component designs. This working group defined classes of evaluation criteria which satisfy performance and operational requirements carried down from top-level mission requirements to the component level, and performance at and across individual subsystems and components.

- Quantitative systems analysis methodologies
  - Safety: failure, hazard, and repair
  - Equivalent mass: mass, pressurized volume, energy, heat rejection, manpower
  - Research, design, development, testing and evaluation (RDDT&E) and life cycle cost

- Establish accessible standard data
  - Conversion factors for mass equivalents
  - Human requirements
  - Waste streams
  - Uncertainty factors

- Evaluation criteria ranking (note these are not official NASA criteria, but working group output):

1. Total Life Cycle Cost
   Equivalent Mass
   Safety/Risk

2. Up-Front Cost
   System Mass
   Expendable Mass
   Resupply Mass

3. Power
   Thermal Rejection
   Non-LSS Integration

4. Crew Time
   Support EVA
   Support IVA

5. Operational Characteristics
   Commonality
   Availability
   Reliability
   Repairability
   Redundancy
   Spares
   Processor Endurance

6. Interface Complexity
   Internal Complexity

7. Current Year Costs

8. Specific Transport Costs

9. RDDT&E Cost
   Design Cost
   Prototype Cost
   Development Risk
   Technical Maturity
   Volume

10. Fabrication Cost
    Modularity

11. Expandability

12. LSS Closure

2.5 Summary of Systems Analysis Panel

A panel summarized conclusions of the workshop, provided individual comments on life support systems analysis, and answered specific questions from participants. Members of the panel included Dr. Chin Lin of NASA/JSC, Dr. John Sager of NASA/KSC, William Likens of NASA/ARC, and Dr. Richard Seagrave of Iowa State University.

Dr. Lin commented that the workshop provides the communication necessary among government, industry, and university organizations conducting systems analysis modeling and testing. However, activity reports from NASA would have been valuable to this communication. He recommended follow-up working relationships be pursued as necessary for increasing the effectiveness of life support systems modeling and testing efforts. These continued communications and working relationships may alleviate some of the very strong problems of obtaining data for various systems and technologies because of "proprietary" type data.

William Likens indicated that the working groups made progress far beyond that made during the 1991 workshop. He reinforced the ideas resulting from all four working groups that testing and modeling guidelines are necessary for comparisons and integration of efforts throughout government, industry, and university organizations. He recommended that flight testing and data collection be conducted at early stages of research and development. An effort should be made to list the various tests that should be conducted in the next five years aboard reduced gravity simulation aircraft, such as the KC-135, and the Shuttle. Dr. Lin added that the majority of testing on systems to date has been short-duration 1-g testing which needs to evolve to longer-duration 1-g testing and flight testing.

Dr. Richard Seagrave commented that more communication is needed at the working level for integration of data and requirements. He indicated that additional focus toward gathering consistent data on the requirements and goals of application missions should be applied. He noted that there appears to be a lack of regard for analysis and testing of integrated components, subsystem and system elements. Such integration analysis must include trade-off and sensitivity studies on the various technologies and variabilities on the human element. Life support systems analysis must be much more extensively integrated into the design and development process.

Dr. John Sager reinforced the need for parallel modeling and testing. Although the development approaches used in the systems analysis community have improved significantly even from one year ago, he feels that we tend to lock into the old technologies because of the lack of available data on new technologies. On this comment, Dr. Seagrave added that the life support systems must push technology development in areas identified as being high pay-off rather than being pulled by technology developers. A basic scientific research base should be "shored up" to support such a transition. Dr. Sager also commented that the development of guidelines and standards should not be "splintered off" into an effort by a separate NASA committee but, instead, be developed by experts with actual experience in modeling, testing, and operating life support systems.

Additional comments from workshop participants are summarized as follows:

- Chemical process engineering talent, techniques, and tools must be much more prominent in future systems analysis. These resources are not new and have been proven and refined by the chemical processing industry and supporting university community. The life support systems analysis problems are not very different from standard analysis done for researching, evaluating, and developing commercial chemical processing plants.

- Both physical/chemical and biological life support technologies must be analyzed in similar manners and compared across similar baseline assumptions. Ultimately, the optimum system may be a hybrid of the two classes of technology.

- When analysis is conducted, the results should be accompanied by a rigorous and complete set of assumptions such that the results are not misinterpreted or unfairly compared to results of other analyses.

- The problem of analyzing, developing, and implementing a regenerative life support system is so multi-disciplinary that civil and developmental engineering firms may be valuable contributors to future workshops.

3.0 SYSTEMS ANALYSIS MODELING AND EXPERIMENTAL VALIDATION/VERIFICATION

The basic premise for prototype testing and systems analysis is to determine and predict component, subsystem, and system performance accurately over a wide range of operating conditions. Analysis and modeling can support the understanding of performance with great versatility in assessing operational, design, and technology alternatives; however, analysis and modeling is not fully reliable in providing solutions that correspond in all instances to real hardware performance. On the other hand, prototype testing provides actual experience and performance data, but cannot cost-effectively be conducted to determine performance over a wide range of operational, design, or technology alternatives. Thus, both approaches must be used interactively to provide a performance estimation capability that is both accurate to actual hardware/software implementations and flexible to address a wide range of alternatives.

The importance of iteration between systems analysis modeling and experimental validation and verification was initially cited by working groups during the 1991 workshop. During the 1992 workshop, this working group investigated in more detail specifics of data exchange and performance validation and software verification procedures between systems analysis modeling and hardware development/testing. The working group also discussed the issue of scale-up as it applies to this modeling/test bed iteration. The working group report is contained in Appendix C.1. A summary of the working group results is followed by more in-depth discussion.

- Parameters to be validated are dependent on the subsystem (e.g., in/out flow streams, materials/media).
  - Minimum data set must be defined to assure validation
  - Fundamental operating principles and trends should be validated
  - Performance over lifetime should be validated

- Establish baseline guidelines for subsystems process/prototype.
  - "Real" application conditions
  - Standardized feed compositions
  - Minimum acceptable scale

- Model and prototype hardware should be "co-developed."
  - Requirements and acceptable bounds on performance parameters
  - Data uncertainty
  - Instrumentation and sampling frequency
  - Baseline assumptions in modeling and testing

- Additional information is needed to adequately scale-up hardware.
  - Characterization of each component (e.g., throughput, materials, drawings)
  - Expected non-linearities and boundary conditions in scale-up

- Guidelines for experimentation and model validation are needed.
- Communication protocol is needed between groups involved in modeling and experimentation efforts, and among the modeling/experimentation effort at the various organizations.

3.1 Validation Parameters

The working group discussed test data which would be necessary to assure that a particular model or analysis tool was valid. Several factors influence the needed data items including the inputs, assumptions, and actual modeling parameters being used, the data needed to determine performance, definition of the data that can be collected from the tests, and data that represent or are indicative of the basic performance of the technology. Much of this data identification is specific to the technology being modeled and tested, and would be defined by the fundamental operating principles of the technology. This data could be refined through sensitivity analysis to determine which data most influences the ultimate performance.

The working group recommended that a minimum number of data be identified and compared between models and hardware tests that would assure that the analysis models will predict accurate results. Basic parameters necessary for validation include: (1) characterization of the flow streams in and out of the component, (2) power consumption, and (3) thermal control requirements. Additional data should be taken to characterize the flow or performance of any special materials or media used such as sorbents, membranes, etc. Performance validation data must be addressed over the lifetime of the component.

3.2 Guidelines for Prototype Development and Testing

Prototypes must be developed to yield test data that are meaningful to "real" applications. The working group identified potential problems that have been existent in developing and testing hardware prototypes, and made recommendations that would alleviate some of these problems. Past prototypes have been designed at a much smaller scale than needed for their ultimate applications, and appropriate data has been used to scale up hardware. Feed compositions have been relatively pure and theoretically optimal with little investigation of the performance sensitivity of the prototype under the suboptimal feed compositions that are much more likely to occur in true application.

The working group recommended that guidelines be developed and implemented for developing and testing prototypes. These guidelines would support determination of the appropriate sizes of prototypes, compositions of feed stocks, and test conditions. The guidelines for sizing should include recommendations based on the mission applications (such as the number of persons to support, and the mission duration) and integration considerations with other components and other systems. The working group felt that there was some minimum prototype size that could be identified as the smallest scale prototype for any given life support technology. Guidelines on feed stock compositions should outline baseline feed stocks for various components, as well as feed stock variances from the baseline that represent potential real application conditions. These feed stocks would also accommodate sensitivity studies on the variable aspects of humans as processing elements.

3.3 Co-Development of Models and Development Hardware

The working group recommended that analysis models and hardware prototypes be developed in parallel and interactively. In this way, modeling could influence hardware testing designs to accommodate appropriate instrumentation, while hardware development could influence modeling through identification of specific performance requirements and operational/design boundary conditions and envelopes. Figure 1 provides a recommended track of co-development of analysis/models and hardware prototypes. The level of detail in testing and modeling increases for both the models and the hardware as one approaches implementation.

Modeling and analysis results will provide insight to high pay-off operation and design approached to be tested and verified. This should more rapidly evolve the technology development to higher performance. Hardware testing verifies the accuracy of modeling results and predictions, and also gives indication of estimation uncertainties and accuracies. Through this parallelism and interaction, NASA may be assured to have modeled the best solution to the entire problem that can realistically be developed and operated with the predicted performance. Likewise, hardware developments will not proceed to final stages without consideration of operations and design alternatives that increase performance at the component, system, or mission level.

A recommended approach in data generation and collection in the co-development of hardware and model is as follows:

- Establish a minimum data set needed to validate model (see Section 3.1)
- Quantify acceptable bounds of operation and data collection
- Determine and record uncertainty of data predicted and collected
- Establish appropriate method for instrumentation of chemical analysis
- Determine most appropriate sensors and sites for measuring parameters
- Establish appropriate sampling frequency
- Verify accuracy of predicted vs. actual results between test and model
    - Experimental protocol should be well documented
    - Model assumptions should agree with test protocol
    - Protocol should incorporate minimum number of trials required for statistical significance

A rigorous communication protocol is needed between modeling and experimentation efforts within the same organization and among government, industry, and university sectors. Not only will this promote more coordinated modeling and testing, but it will also reduce duplication of effort, and enhance the comparability of results from various sources.

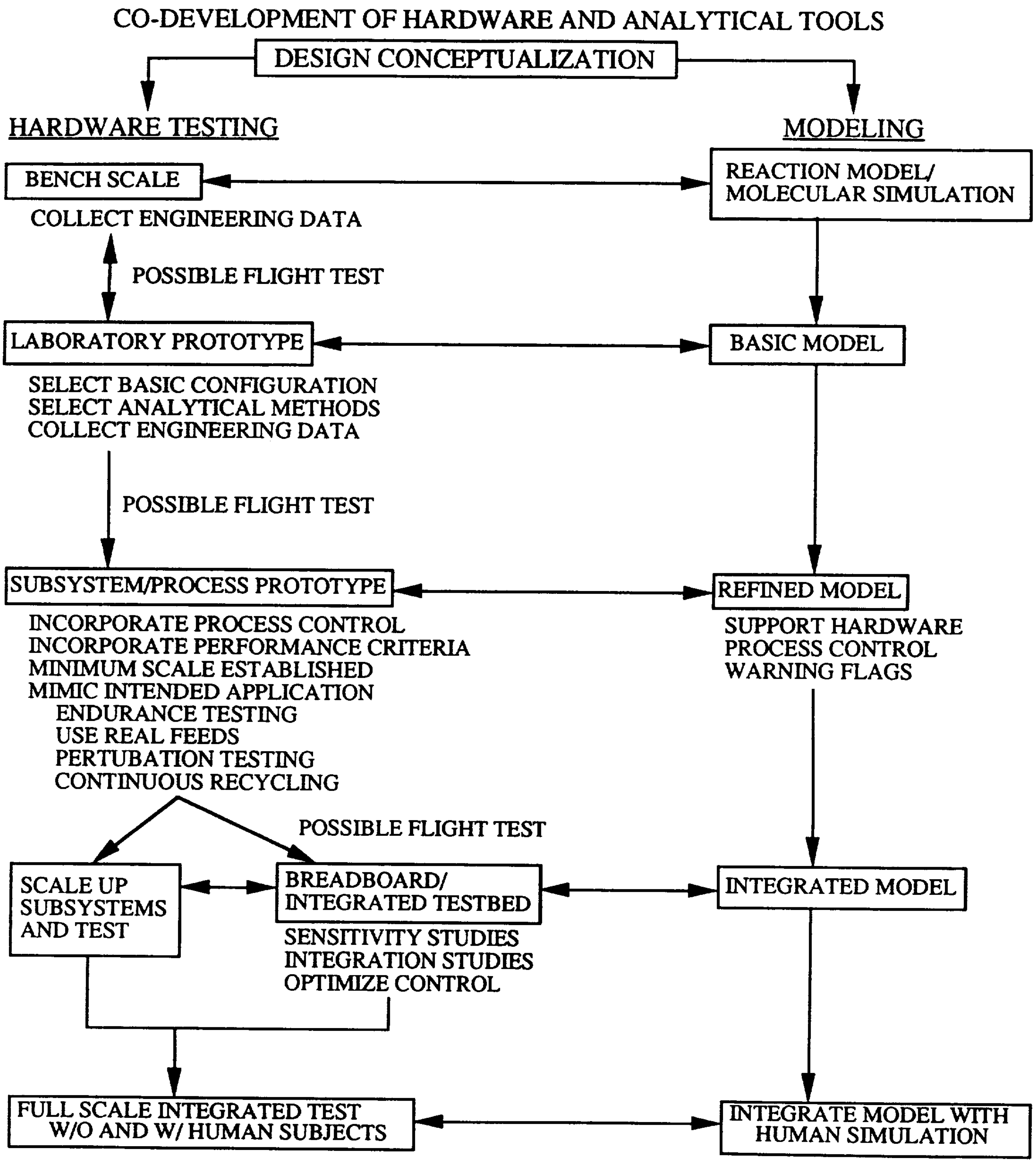


Figure 1. Analysis Models and Hardware Prototypes Should Be Co-Developed

Guidelines instituted by NASA would help establish the communication protocol and promote more standardized and integrated modeling and validation efforts within the life support community. The result would be improved and more accurate modeling and testing results, more usable and reliable data from research for modeling and analysis, and integration of more trade-off and sensitivity studies within the testing and experimentation.

3.4 Data Necessary for Scale-up

Accurate scaling analysis within life support systems analysis is very important to increase the versatility of the model and to address a wide range of mission and systems applications. Scaling up from small-scale prototype results can be very inaccurate, and is especially inaccurate if the proper data is not considered. Each component needs to be considered during the scaling process with at least the following information:

- Dimensioned engineering drawings
- Mass, energy, and composition throughputs
- Construction materials
- Data base of user experience

In addition, the component small-scale prototypes should include identification of limits of applicable scaling, including non-linearities and boundaries, for which extrapolation are no longer realistic. For example, a certain technology may have been prototyped at a ¼ scale of a 4-person lunar base. Of course, non-linear scaling laws must be followed where necessary to include volumes of storage vessels and flow system masses. Scaling of that prototype may be valid for the 4-person crew but not valid for a 16-person crew, where a significantly different technology would be used within the system.

3.5 Additional Analysis and Effort Needed for Planned Experimentation

The working group identified several areas of study and analysis efforts that should be integrated with currently planned tests and experiments:

- Variable Pressure Growth Chamber (VPGC)
  - Characterization of local chamber environment (e.g., irradiance, temperature, nutrient distribution, etc.)
  - Predict effect of local environment on plants
  - Substrate-nutrient solution interactions
  - Effect of plant-produced contaminants on physiochemical hardware and vice-versa

- Systems Integration Research Facility (SIRF)
  - Nominal mass balance assessment
  - Determine measurements and instrumentation
  - Mass, energy, and chemical interactions of plants and humans
  - Determination of metabolic profile and approach of the human simulator

- Crop Growth Research Chamber (CGRC)
  - Total systems characterization and modeling
  - Definition of limits of performance from biological interactions of multiple species

- General Life Support System Experimentation
  - Identify and prioritize goals of the life support systems developments (i.e., strategic plan)
  - Identify, in more detail and with more standard assumptions, the input and output flow streams of the existing life support system components
  - Identify standard instrumentation and measurement approaches
  - Total systems characterization of the prototypes and test beds
  - Determination of control schemes
  - Collect as much existing data as possible and integrate into the modeling.

3.6 Systems Analysis Modeling and Experimental Validation/Verification Working Group Participants

Dr. Liese Dall-Bauman (Lead)	NASA Johnson Space Center
Grant Bue	Lockheed
Dr. Susan Fuhs	AiResearch
Stephen Gustavino	McDonnell Douglas
Gary Hudman	Space Biosphere Ventures
Dr. Jimmy L. Humphrey	JL Humphrey & Associates
Frank F. Jeng	Lockheed
Kevin E. Lange	Lockheed
Andrew McGough	Aspen Technology
Dr. Naresh Rohatgi	JPL
Firooz Rasouli	ElectroCom GARD
Dr. John C. Sager	NASA KSC
Dr. Jack M. Spurlock	S&A Automated Systems

4.0 APPLICATION OF SYSTEMS ANALYSIS TO PROCESS CONTROLS

The control system for any life support system can range from a totally automated, quick-response system with system health management and evasive action capability to a very simple open loop control system with significant human interaction. The degree of automation, level of control, and sophistication of the control system are major decisions that can be made only with accurate data on the effects of these alternatives on life support system performance, trade-off and sensitivity analysis relating to the power, mass, computation, human, and other resources required by the control system as a function of the reliability, operational performance (nominal operation as well as start-up, shut-down, and other transients), and maintainability of the system.

Systems analysis based on steady state operation is adequate to assess system parameters such as mass, volume, average power demand, and other valuable resources for a given state of operation. However, stable operation within any given control envelope during start-up, shut-down, and other transients, as well as during various emergency conditions, requires dynamic process modeling and analysis of dynamic system behavior. This working group attempted to identify dynamic systems attributes to be estimated through dynamic process models and interactive control models, and also discussed the relationship of dynamic systems attributes to actual systems control.

Definition of the parts of the system that should be controlled, and the degree to which the system should be controlled, are the first issues which must be addressed. Systems analysis and modeling of the control system could address key considerations against the resource expenditure required to develop and provide various levels of control. Key design considerations include:

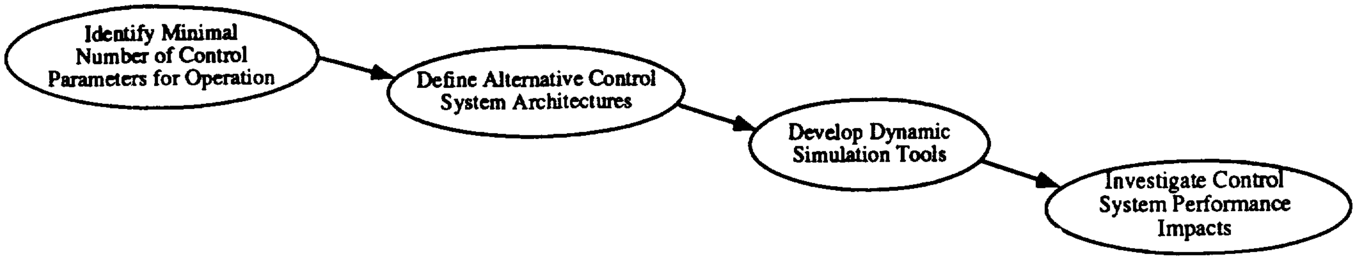
- How many control parameters are necessary for reliable life support system operation?

- How simplistic can the method of control be while maintaining adequate robustness and providing adequate system health management?

- What level of sophistication is needed and desired given limited computational resources available on-board?

- Is operational control optimization necessary?
    - Optimization on which parameters?
    - Do these parameters change in different operating regimes?
    - How many parameters are necessary for optimization?

In all of these questions and issues, basic effects of the control system on performance and operation of the entire life support system need to be understood. One approach to addressing key issues is as follows:



In summary, a whole range of control system alternatives exists and must be of value, but require some dynamic simulation capability to determine quantitative benefits on the life support system level as a function of these control system alternatives. This will require first establishment of a steady-state model, followed by various level tools and models of dynamic simulation which can then be used to conduct the trade-offs and sensitivities of the control system.

4.1 Control Variables and Parameters

The number of control variables to maintain a particular level of reliability and optimization is a function of the mission duration, the degree of closure of the life support system, and the degree of integration with other systems. One of the first needs in assessing the control system is to determine a prioritized list of control parameters. Previously monitored parameters include:

- Shuttle - CO_2, humidity, temperature, and pressure
- SSF - O_2, CO_2, H_2O (vapor and liquid), temperature, and pressure
- Minimum for short duration missions
    - O_2, CO_2, H_2O (vapor and liquid), temperature, and pressure
    - Technology specific species
    - Key toxins in crew quarters

The first control parameters to consider are the various chemical species which need to be monitored and potentially controlled. For example, what are the key parameters to be monitored and controlled to assure that water quality requirements are being maintained? Other parameters may need to be included for longer duration missions and should address critical parameters for specialized subsystem technologies (e.g., adsorption beds, resource recovery processes, plant growth systems). These parameters may be similar to those parameters used in modeling and experimental validation of the component or subsystem (see Section 3.1 Validation Parameters).

Figure 2 shows the basic relationship between the control system complexity and the number of control parameters for open and regenerative life support systems. Typically, regenerative (or closed) systems will require more parameters of control even with similar approaches

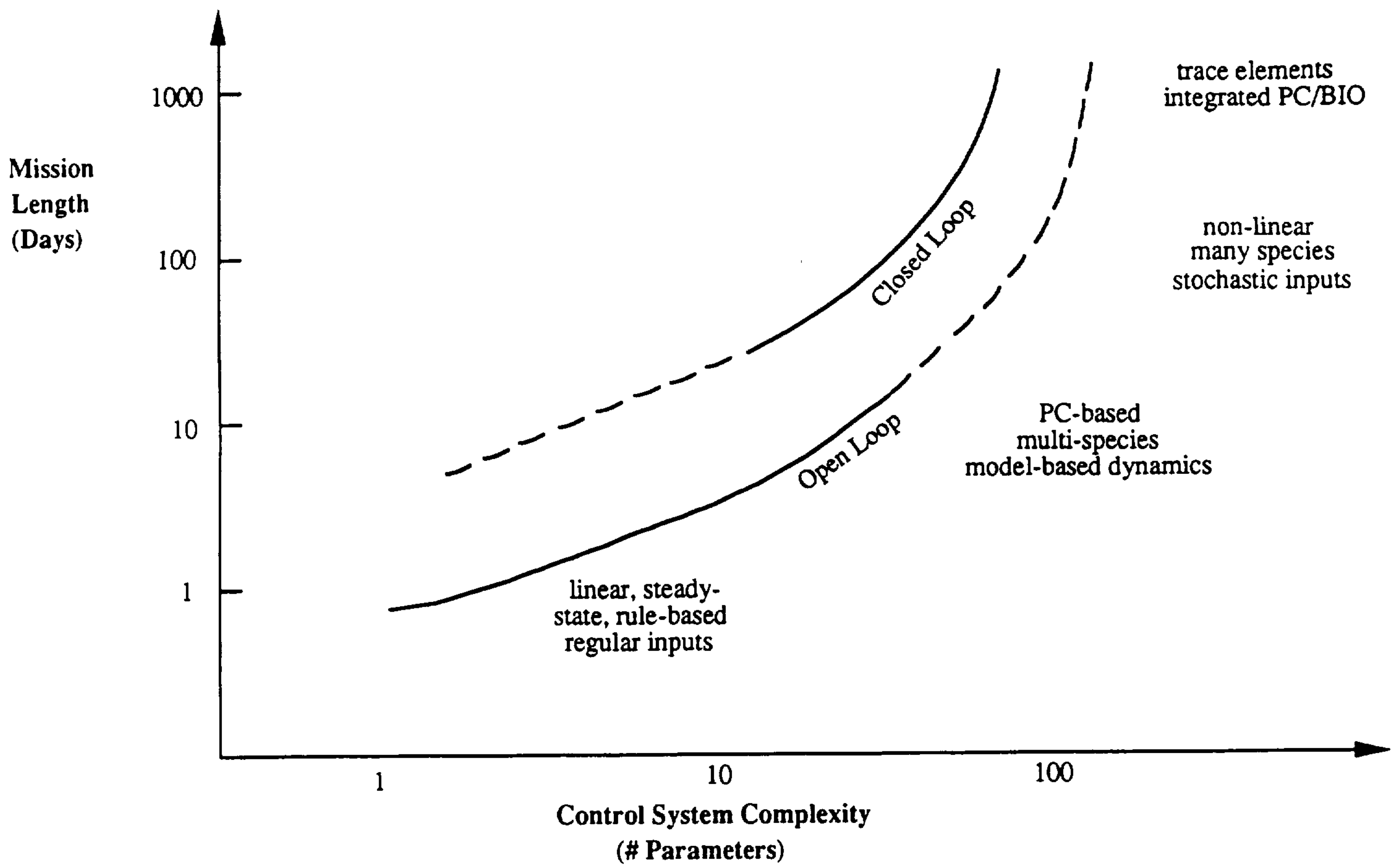


Figure 2. Control System Complexity Relates to the Number of Control Parameters

and complexity of control because the material is recycled within the system to such a great extent. The additional control parameters for regenerative systems could relate to updating system operational parameters more often, monitoring of more components of the flow, modeling nonlinear characteristics more accurately, and tracking trace elements or other elements which have significant effect on system performance.

4.2 Control Methodology

The capabilities of specific control methodologies and approaches influence: (1) the accuracy of the control system to interpret the operational condition of the life support system, (2) the ability of the control system to make a decision of corrective or mitigative action, and (3) the ability of the system to affect the necessary controls to return the system to more optimum performance. In addition, the timeliness of the control system to complete the above is also a major factor and influenced by the number of parameters of control and optimization, and the level of computational capability allotted to the control system. More sophisticated control methodologies and approaches can improve the performance (including reliability and robustness) of the overall life support system.

Figure 3 shows a trend of expected operational cost of the life support system as a function of the control system sophistication. The reductions of operational performance may be accomplished through: (1) closer maintenance of system operation to optimum performance; (2) increased operational bandwidth and increased knowledge of the system that allows the ability to respond to variances; and (3) reduced crew time and other support resources to conduct health management and maintenance of the system. Several different control methods may be implemented from the more rudimentary equation-based architectures such as position-integral-derivative (PID) and single-input, single-output (SISO) to the more model-based and rule-based control approaches, and from centralized control to

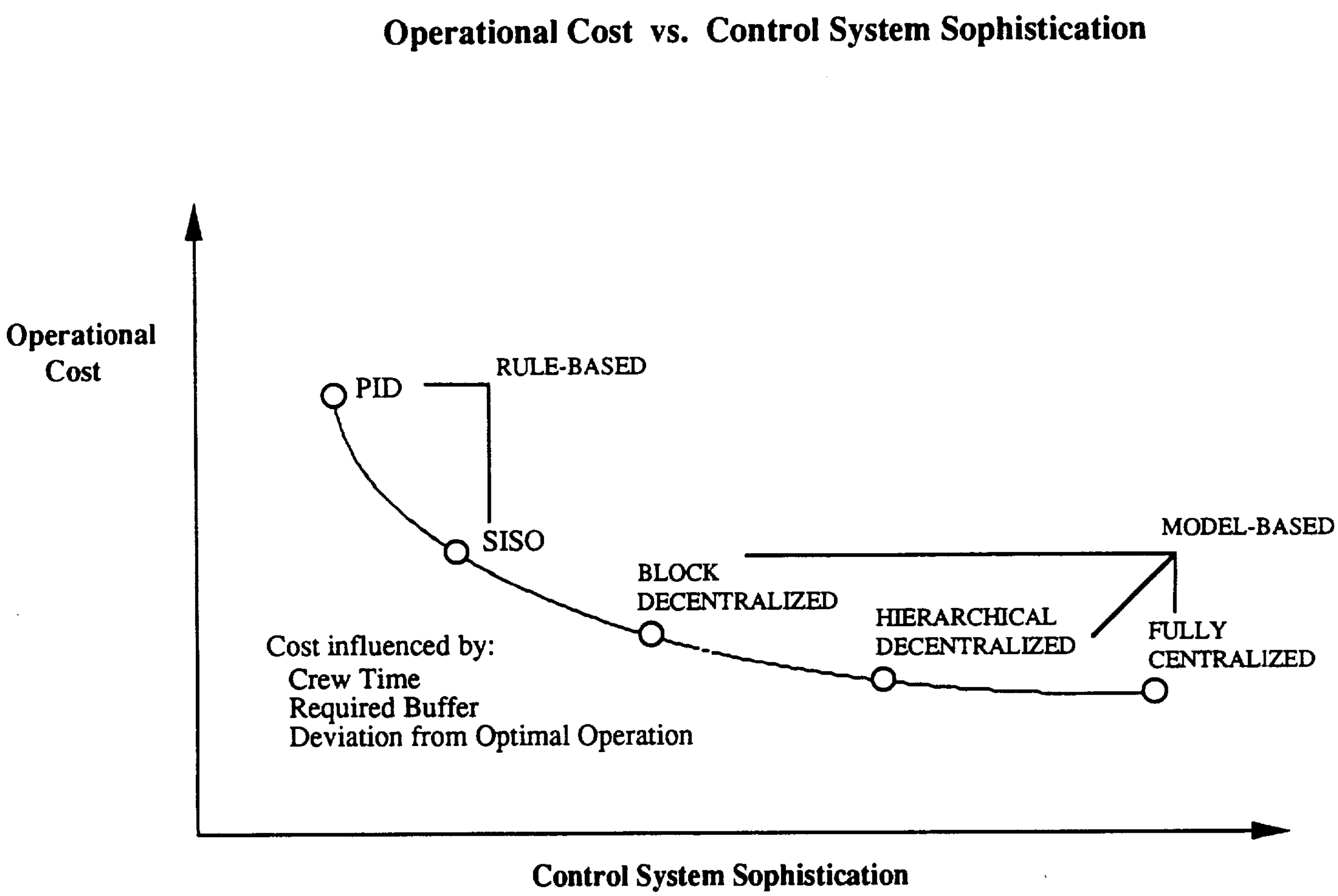


Figure 3. Life Support Systems Operational Performance Can Be Increased Through Increased Control Sophistication

decentralized control. The ultimate goal of choosing a specific control approach will be to: (1) optimize performance of the life support system; (2) and maximize the reliability, robustness and maintainability of the life support system; and (3) minimize the requirements of computational resources and other support resources. Trade-off and sensitivity analyses need to be conducted on the various methods and approaches and the specific implementations of the control system within these approaches to identify the overall benefits to the life support system. This will require dynamic simulation tools to model the control system and life support subsystems which are discussed in the next section.

4.3 Dynamic Simulation

Modeling and assessment of the control system of the life support system will require some degree of dynamic simulation. Dynamics modeling can provide significant insight and prediction of operational performance during start-up, shut-down and transient conditions in operations within the life support system. Dynamic simulation of the control system will also allow identification of life support system design parameters that may be changed or altered to allow easier control of the system with higher control performance or reduced research requirements needed for control. However, the degree of dynamic simulation is not yet well determined. The level of dynamic simulation required will depend on the time frame and frequency resonance of the interacting flows and components within the life support system, the linearity of the life support system as a whole or the ability to assemble linear sub-models within the life support system, and the level of detail of the results desired and the input data available. Typically, in the chemical process industry, dynamic modeling of a chemical process begins with an accurate steady-state model from which point designs and point conditions can be validated in experimentation by also be used to validate the dynamic model under certain constraining conditions. Currently, the life support systems do not have a valid full-scale steady-state model representation that is validated through experimentation. Thus, this should be the first step in developing dynamic modeling: develop a good steady-state model of the life support system.

Once the steady-state model is established and verified, dynamic modeling can reliably evolve; however, it is undetermined what level of detail is required or what level of sophistication within the dynamics control dynamic modeling is required to adequately understand and represent the life support system hardware. The level of detail required will only be determined through an iteration of dynamic modeling and experimentation beginning at a top-level of detail to verify accurate results of such dynamic modeling. If accurate modeling can be accomplished with a top-level dynamic model, more detailed modeling may not be required. Through this iteration, developers will learn whether linear representation of certain components and subsystems is adequate and where non-linearities exist, and also where non-linearities do and do not affect significantly the performance of the system. Developers will also learn whether simple equation-based control systems may be adequate over model-based control systems.

Determination of whether the life support system is dynamically stable enough to run with open-loop control can be made in this iteration of dynamic modeling and experimentation.

Determination of whether the life support system is dynamically stable enough to run with open-loop control can be made in this iteration of dynamic modeling and experimentation.

Ultimately, the appropriate degree of closed-loop control necessary to provide reliable operation can be determined through such modeling and testing. This assessment can be done at the life support system level, subsystem level, and component level. An indication of this degree of closure is a resiliency index, where P represents parameters of control and C represents the complexity of control, which can be used to compare controllability of one control system to another:

$$\text{Resiliency index} = \min f(P,C) < 1 \quad \text{and} \quad \max t \left\{ \frac{y_1(t)}{2}, \frac{y_2(t)}{2} \right\} \leq 1$$

Once the level of necessary dynamic simulation is defined and the modeling is pursued to the point of verification with experimentation, trade-off and sensitivity analyses may proceed to determine the performance benefits as a function of the control methodology and approach.

4.4 Control System Modeling to address Trade-offs and Sensitivities

The dynamic simulation discussed above should be used to address control system alternatives in the overall performance of the life support system. As was shown in Figure 3, operational performances can be increased through use of more sophisticated control methodologies and approaches; however, there are additional costs such as computational resources and development resources which must be also considered in these trade-off and sensitivity analyses. Ideally, the value of each of the various control methods and approaches would be assessed and their relative value would be determined; however, investigation of trends from a few baseline alternatives may be sufficient. In other words, we need to quantify such things as the impacts of different control approaches (e.g., model-based control, position-integral-derivative control).

Another trade-off which needs to be considered in these analyses is: how much of the control system needs to be real-time and on-board vs. off-loading some of the control system to off-line ground-based systems that are activated on an as-needed basis.

4.5 Application of Systems Analysis to Process Controls Working Group Participants

Dr. P.K. Seshan (Lead)	JPL
Dr. Richard Chu	Lockheed
Thomas M. Crabb	ORBITEC
Gani Ganipathi	JPL
Dr. Patrick McCroskey	Dow Chemical
Carl McFadden	McDonnell Douglas
Dr. Robert Farrell	NY Polytechnic University
Linda Jerng	Lockheed
Dr. Thomas Lo	Purdue University
Dr. Vasilios Manousiouthakis	UCLA
Dr. Richard Seagrave	Iowa State University
Dr. Randy Stahl	NASA JSC (currently at Texas A&M)
Steve Rowe	AiResearch

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5.0 INTEGRATION OF COMPONENT, SUBSYSTEM, SYSTEM AND MISSION LEVEL MODELS

Several levels of modeling are required to assess a technology. The basic performance and operational characteristics can be modeled through chemical process models in static and dynamic conditions. The components may be integrated into subsystem and system models for estimation of performance. These integrated models may take many forms, ranging from detailed static and dynamic chemical process models to flow sheets, relational spreadsheets and data bases. In all life support systems analysis modeling, the models must integrate and coordinate modeling data (both inputs and outputs) of modeling at subsystem and component levels, as well as the modeling at the integrated systems levels. This working group focused on ways to make modeling algorithms, input data, and output data more compatible at different levels of analysis. The following statements summarize the discussion results of the working group.

- A wide variety of tools is used for various levels of detail and various systems levels.
- Many of the tools are developed independently of one another which makes integration of the data input and output difficult or impossible.
- Attempting to generate a standard set of tools for all system levels and all levels of detail may be difficult.
- Guidelines should be established for the modeling objectives at the various levels and for the tools used at the various levels.
  - Assumptions
  - Physical/Chemical Data
  - Data input/output flows from one level to another

5.1 Wide Variety of Tools

The wide range of modeling from detailed chemical process analysis to mission-level trades of life support technologies requires an equally wide variety of tools. Some of the detailed modeling may be substituted by bench testing. In some cases, bench testing may be required to support rigorous detailed chemical process modeling. However, the chemical process industry does not attempt a large-scale experiment without some basic theoretical understanding of the process through modeling.

For life support applications, some modeling at the detailed level has been accomplished for the air revitalization applications including ASPEN PLUS models of chemical processes used in CO_2 collection and reduction and water electrolysis. Less detailed modeling and analysis can be found for the water systems for space application.

The working group resolved that additional detailed modeling of the components should be pursued but integrated into the higher level modeling and the testing efforts.

Modeling is required for analysis at several levels of design and technology development. The working group divided the levels of modeling into four major areas where modeling parameters and approaches may be grouped and categorized. These include:

- **Technology Assessment / Mission Analysis:** The screening of technologies and subsystems designs on a top-level-type analysis. This analysis is used for sensitivity and trade-off studies based on mission requirements.

- **System Flowsheet Analysis:** A more detailed performance assessment and subsystem sizing of integrated subsystems (can also be used to assess integration alternatives but requires use of detailed process data). This type of analysis is typical of Phase A and Phase B studies.

- **System Level Detailed Modeling:** A detailed analysis and modeling of integrated subsystems and components for system design verification and validation for meeting mission requirements and system operation support. These models do not typically include their own process models for the integration of components and are used in Phase C/D.

- **Detailed Component and Subsystems Modeling:** The detailed chemical process modeling to predict performance and fundamental characteristics of the component or subsystem level. This type of analysis and modeling is used for hardware performance and operational verification.

Figure 4 shows the modeling tools cited by the working group (not an all-inclusive list) to characterize some general capabilities at the various levels of analysis. In this figure, an indication is made as to whether certain models apply with a static, transient, or dynamic capability. The recommendation made by the working group included an agreement that various approaches and analysis capabilities should contain the standardized guidelines for anyone conducting life support systems analysis. This recommendation does not necessarily mandate a single tool as the standard, but suggests that certain analytical calculations be made for certain levels and for certain types of modeling applications. Figure 5 shows the working group's approach for modeling at different levels of analysis.

Another problem cited by the working group was the lack of input data available from the original developers of component hardware. In some cases, no modeling was required by the procuring contract and, thus, either none was available, or the modeling and results were considered proprietary and non-releasable. Every contractor has an approach to modeling and testing hardware that includes the conduct of sensitivity/trade-off studies and validation of performance. Each approach includes use of several tools, some of which are unique to the supplier. Future contracting for hardware should require some baseline level of modeling and reporting of data, including assumptions, basic modeling algorithms, and results.

LEVEL	DEFINITION	USE
1	TRADE OFF ANALYSIS BASED ON MISSION REQUIREMENTS AND POTENTIAL TECHNOLOGY CANDIDATES	TECHNOLOGY ASSESSMENT
2	CONCEPTUAL FLOWSHEET ANALYSIS FOR INTEGRATED LSS AND SIZING OF MAJOR FUNCTIONAL COMPONENTS	PRE-PHASE A ⟶ PHASE B (MISSION DEFINITION)
3	SYSTEM DESIGN VERIFICATION FOR MEETING MISSION REQUIREMENT AND SYSTEM OPERATION SUPPORT	PHASE C/D ⟶ OPERATION
4	DETAILED PHENOMENOLOGICAL ANALYSIS	DETAILED PERFORMANCE MAPPING, HARDWARE VERIFICATION, TEST SUPPORT
5	ANALYSIS FOR CONTROL AND OPERATION	ASSESMENT AND DESIGN OF CONTROL SYSTEM

Figure 4. Modeling Capabilities Relate Directly to the Function of Modeling Level

5.2 Common Data and Assumptions

One of the most pervasive problems to date in life support systems analysis modeling has been a lack of coordination and communication among modeling efforts at the various levels. The ultimate goal is the ability to model and estimate performance of life support systems based on certain evaluation factors.

Evaluation factors must at least consider mass, power, and volume, but should also ultimately consider cost over the life cycle of the system. If resources are shared and traded

LEVEL	1	2	3	4
1		CANDIDATE SUBSYSTEM/ TECHNOLOGY MISSION PARAMETERS LEVEL 1 TO LEVEL 2	MISSION PARAMETERS INTERFACE REQ. IDENTIFICATION BETWEEN COMPONENTS	INTERFACE REQ. IDENTIFICATION
2	SYSTEM SIZING & FLOWSHEET BALANCE (LiSSA)		FEED STREAM DATA	FEED STREAM DATA
3	SYSTEM INTEGRATION EVALUATION	SIZING AND INTEGRATION VERIFICATION		DETAILED CHARACTERISTICS OF INTERFACE/ OPERATING REQs
4	TECHNOLOGY DATA UPDATE	SIZING FEEDBACK	PERFORMANCE MAPS	DETAILED CHARACTERISTICS OF INTERFACES

Figure 5. Modeling Approaches Recommended for Various Levels of Analysis

among components and subsystems, the consideration of where to optimize performance is critical. In some cases like these, the optimum performance of the system does not rely on optimum performance of each component, but more on the integrated performance. Only analysis with an integrated system level model can optimize the integrated performance.

Data may emanate from a large number of diverse sources. The modelers must be assured that the input data is valid and accurate. If this is not fully achievable, then the next best step is to assure that all modelers have access to the same data for input, such that the base assumptions and underlying data from which the results emanate are similar and comparable. This data includes standard physical and chemical properties which are essential to comparable modeling results. The working group has had experience with ASPEN PLUS, which provides a "clearinghouse" service from basic properties. Collection and use of data in this manner should be explored for use in future modeling efforts.

Guidelines should be established for the modeling objectives and tools used at the various levels. Assumptions must be standardized or, at the minimum, be listed as a part of the results such that the results of various analyses are not unjustifiably compared. Physical and chemical properties and data must also be standardized for similar reasons. Standardized flow stream assumptions would also improve the consistency and comparability of analyses. Documented guidelines for analysis could be developed throughout the modeling and analysis community.

5.3 Integration of Component, Subsystem, System and Mission Level Models Working Group Participants

Dr. Chin Lin (Lead)	NASA Johnson Space Center
Allen Bacskay	NASA Marshall Space Flight Center
Dr. Hal Couch	Hamilton Standard
Joe Ferrall	Jet Propulsion Laboratory
Scott Gilley	Sverdrup
Matt Kolodney	Lockheed ESC
Roger von Jouanna	Boeing
Sassan Yerushalmi	Lockheed ESC

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6.0 SYSTEMS ANALYSIS APPROACHES AND EVALUATION CRITERIA

Evaluation criteria that quantify the performance of life support systems must adequately represent the mission and system requirements throughout the analysis and testing efforts. Proper determination and prioritization of the criteria will support proper selection of technologies through the sensitivity and trade-off analyses, and also guide the modeling, testing, and control system development through definition of important parameters to be modeled and monitored. Thus, subjective criteria are to be avoided, and quantifiable criteria should form the basis of all analysis and testing.

Within the trade-off and sensitivity studies, the definition of the evaluation criteria for assessment of life support systems is crucial to selection of proper system configuration, subsystems technologies, and component designs. This working group defined classes of evaluation criteria which satisfy performance and operational requirements carried down from top-level mission requirements to the component level, and performance at and across individual subsystems and components. A summary of the working group recommendations follows:

- Evaluation criteria ranking must not be subjective and must be quantifiable, indicating the performance of the life support system with respect to life cycle costs.

- Quantitative systems analysis methodologies
  - Safety: failure, hazard, and repair
  - Equivalent mass: mass, pressurized volume, energy, heat rejection, manpower
  - Research, design, development, testing and evaluation (RDDT&E) and life cycle cost

- Established accessible standard data
  - Conversion factors for mass equivalents
  - Human requirements
  - Waste streams
  - Uncertainty factors

6.1 Evaluation Criteria Selection

The basis for all evaluation criteria should, at a minimum, consider mass, power, and volume, with an ultimate tie to life cycle cost of the life support system. The life support system may be divided into the RDDT&E, operations, and supportability. The RDDT&E costs must be amortized across the life of the system. Typically, a system or technology which has a high RDDT&E cost must have low operation and support costs to justify the initial costs. Safety considerations are also very important to consider in the life support system and must be quantifiable in the evaluation criteria. The working group went through an exhaustive effort to list possible evaluation criteria and then prioritized them. The results follow:

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1. Total Life Cycle Cost
   - Equivalent Mass
   - Safety/Risk
2. Up-Front Cost
   - System Mass
   - Expendable Mass
   - Resupply Mass
3. Power
   - Thermal Rejection
   - Non-LSS Integration
4. Crew Time
   - Support EVA
   - Support IVA
5. Operational Characteristics
   - Commonality
   - Availability
   - Reliability
   - Repairability
   - Redundancy
   - Spares
   - Processor Endurance
6. Interface Complexity
   - Internal Complexity
7. Current Year Costs
8. Specific Transport Costs
9. RDDT&E Cost
   - Design Cost
   - Prototype Cost
   - Development Risk
   - Technical Maturity
   - Volume
10. Fabrication Cost
    - Modularity
11. Expandability
12. LSS Closure

A system of components will not be evaluated on all of the above criteria. A consideration of refinement to the evaluation criteria listed above must address the overlapping nature of several of the criteria. One solution is to convert or define equivalences among various evaluation criteria.

6.2 Standardized and Accessible Data

The working group endorsed provision of standardized data, including conversion factors, human requirements, waste stream compositions and flow rate and uncertainty factors, would support more comparable results in quantifying performance and the related evaluation criteria.

Relationships among evaluation criteria may be used to quantify equivalents among those criteria through the specific system technologies and designs. Conversions to mass equivalents from power, volume, heat rejection, manpower (IVA and EVA), and other important parameters would allow technology, component, and systems on a single parameter, with some basic historical relationships between system mass and development, launch, and operations. In addition, standardized human performance data should be considered in these conversion efficiencies. Key conversion factors to consider include:

- Pressurized volume (in kg/m^3): SSF, Skylab, and inflatable prototypes may be used in development of example conversion parameters.

- Energy (in kg/kWh): solar, battery, regenerative fuel cells, and nuclear may be used in development of standard conversion parameters.

- Heat rejection (in kg/kWh): two-phase radiator, cold plates, and various heat exchangers may be used in development of standard conversion parameters.

- Crew hours (in kg/crew-hour): IVA and EVA costs may be accumulated to some pre-defined level for the development of standard conversion parameters.

Human characteristics should also be standardized including metabolic inputs and outputs for nominal conditions and a nominal size crew, and for off-nominal conditioned. In this way, the evaluations of technologies, components, and systems may be considered in both nominal and off-nominal conditions to determine flexibility and robustness of the performance. The same standards and variances of composition and flow rates must be considered for flow streams among components and subsystems.

Uncertainty of input data and resulting output should be included with the data. Such estimates and error bars are required to indicate the resolution of sensitivity and trade-off studies such that evaluation conclusions are not drawn when results fall under the error of the analysis.

6.3 Analysis Methodologies for Specific Criteria

Standardized or recommended analysis methodologies were identified by the working group in areas of safety, equivalent mass, and RDDT&E costs. Safety analysis methodologies require failure rates by failure mode, hazards, and repair rates. Equivalent mass analysis methodologies must define specific scope for calculation of the equivalents such as:

- mass (kg): spares, systems hardware, process & distribution, expendables, consumables

- pressurized volume (m^3): volumes for storage, operations, hardware

- energy (kWh): power generation/collection, storage, and distribution for average and peak levels

- manpower (crew-hour): crew time for maintenance, operation, regeneration, or other similar function during EVA and IVA

- heat rejection (kWh): heat collection, transfer/distribution, and rejection for average and peak levels.

RDDT&E costs must have a well-defined scope of what is included and not included. These costs should be cast in the terms of a "return on investment" analysis. Significant support from the contractors to provide actual anticipated RDDT&E costs for various components would provide a more accurate data base on these costs.

6.4 Evaluation Criteria Working Group Participants

William Likens (Lead)	NASA Ames Research Center
Susan Doll	Boeing
Dr. Alan Drysdale	McDonnell Douglas
Marybeth Edeen	NASA Johnson Space Center
Martha Evert	Lockheed ESC
Robert Henson	Lockheed ESC
Kristin McCarthy	Rockwell International
Dr. Willy Sadeh	Colorado State University
Paul Shafer	Lockheed ESC

APPENDICES

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APPENDIX A Detailed Agenda

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NASA OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY 1992 LIFE SUPPORT SYSTEMS ANALYSIS WORKSHOP AGENDA

TUESDAY, 12 May 1992

7:30 Check-in and Registration JSC Annex Facility, One Harbor Drive, League City, TX

8:00 1. Welcome and Introduction **Al Behrend, NASA/JSC**
Update to NASA's Life Support Technology Programs, the role of systems analysis and modeling, and the goals of the *1992 Life Support Systems Analysis Workshop*

8:20 2. NASA's Life Support Systems Analysis (LiSSA) Tool **Dr. P.K. Seshan, JPL**

9:00 3. Experimental Evaluation of Systems Analysis Models **Dr. Liese Dall-Bauman**
Papers will be presented which highlight experiences, lessons learned, and plans for developing test bed activities that utilize and validate systems analysis analytical models. Papers will discuss use of test data to validate subsystem and process models, and use of laboratory data to provide kinetic and transport data of process models. Presenters should identify specific benefits, disadvantages, and methods of iterating systems analysis and experimental test beds.

9:00 Systems Analysis for SIRF Test Bed
Dr. Naresh Rohatgi, JPL and Dr. Liese Dall-Bauman, NASA/JSC

9:30 Experiences with System Model Validation for Various Applications **(Not Presented)**
Kevin Barr, Allied Signal

10:00 Bench Scale Testing & Modeling of Mass & Heat Transfers - Adsorption of CO_2 & H_2O Vapor on Solid Amine
Frank F. Jeng, Lockheed Engineering and Sciences Company

10:30 Break

11:00 4. Analogous Systems Analysis Approaches and Tools **Dr. Chin Lin, NASA/JSC**
Systems analysis not directly related to life support systems and operations can provide significant input to the development and implementation of life support systems analysis. Papers will describe the analysis methods used in non-space areas and how these methods might be applied to life support systems analysis.

11:00 Availability Analysis as a Design Tool for Closed-Loop Life Support System
Dr. Richard C. Seagrave, Iowa State University

11:30 Dynamics Modeling and Optimization Approaches and Examples Using Speed-Up
Dr. Glen Dissinger, ASPEN Technologies

12:00 Dynamics Modeling Approaches and Examples Using SimuSolv
Dr. Patrick McCroskey, Dow Chemical

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12:30 Lunch

1:30 - 5:00 5. Working Group Meetings - Parallel working session #1 for the Working Groups

Systems Analysis Modeling and Experimental Validation/Verification - The importance of iteration between systems analysis modeling and experimental validation and verification was cited by working groups at last year's workshop. This working group will investigate in more detail specifics of data exchange and performance validation and software verification procedures between systems analysis modeling and hardware development/testing. This working group should also discuss the issue of scale-up as it applies to this modeling/test bed iteration. Group Leader: Dr. Liese Dall-Bauman, NASA/JSC.

Evaluation Criteria - The definition of the evaluation criteria for assessment of life support systems is crucial to selection of proper system configuration, subsystems technologies, and component designs. This working group will work toward defining classes of evaluation criteria which satisfy performance and operational requirements that are carried down from top-level mission requirements to the component level, and performance at and across individual subsystems and components. Group Leader: Vince Bilardo, NASA/ARC.

Integration of Component, Subsystem, System, and Mission Level Models - Life support systems analysis modeling must integrate and coordinate data (both inputs and outputs) of modeling at subsystem and component levels as well as the modeling at the integrated systems levels. This working group will focus on means in which to make modeling algorithms, input data, and output data more compatible at different levels of analysis. Group Leader: Dr. Chin Lin, NASA/JSC.

Application of Systems Analysis to Process Control - Systems analysis based on steady state operation is adequate to assess system parameters such as mass, volume, average power demand, and other valuable resources. However, stable operation within any given control envelope during start-up, shut-down, and other transients, as well as during various emergency conditions, requires dynamic process modeling and analysis of dynamic system behavior. This working group will attempt to identify dynamic systems attributes to be estimated through dynamic process models and interactive control models, and will also discuss the relationship of dynamic systems attributes to actual systems control. Group Leader: Dr. P.K. Seshan, JPL.

6:00 Dinner and Speaker **South Shore Harbor**

William Huffstetler, Manager, New Initiatives Office, NASA/JSC

WEDNESDAY, 13 May 1992

8:00 6. Dynamics Analytical Modeling and Process Control **Dr. P.K. Seshan, JPL**
Papers will focus on the past, current, and future methods and approaches to process control. Control hierarchies and methodologies should address potential levels of stability; effects of off-nominal operation; levels of sensing and monitoring needed; potential for singularities and instabilities; and control mechanisms for safety, redundancy, and reliability.

8:05 Steady State and Dynamic Systems Analysis in the Chemical Process Industries
Dr. Robert J. Farrell, Polytechnic University

8:35 Dynamic Evaluation of Technologies for Life Support Systems
Dr. Vasilios Manousiouthakis, UCLA

9:05 Modeling and Simulation Tools for Process Control Analysis
Stephen Rowe, Allied Signal

9:35 An Approach to the Integration of a Closed Ecological Life Support System
Dr. W. Lo, Dr. C.H. Lin, Dr. George Tsao; Purdue University

10:00 Break

10:30 7. Systems Analysis Approaches & Evaluation Criteria **William Likens, NASA/ARC**
Papers will discuss various approaches and special topic issues related to life support systems analysis. The ultimate goal is to provide quantitative estimation of life support system performance in terms of mass, power, volume, thermal, resupply, reliability, and maintainability.

10:30 Future Development of Life Support Systems Evaluation Criteria **(Not Presented)**
Vince Bilardo, NASA/ARC

10:50 Probabilistic Risk Assessment (PRA)
William C. Likens; NASA/ARC

11:10 Integration of Detailed User Component Models in ASPEN PLUS Simulations
Dr. Kevin E. Lange; Lockheed Engineering and Sciences Company

11:30 Modeling of Metabolic Flow-rates in a Closed Ecosystem
Dr. Willy Z. Sadeh; Colorado State University

11:50 Lunch

12:30 - 4:30 8. Working Group Meetings - Parallel working session #2 for the Working Groups

5:00 9. Model Demonstrations - small groups and one-on-one
On-site demonstrations of models will be available for individuals and small groups that desire to investigate general modeling capabilities, specific modeling approaches, specific model examples.

THURSDAY, 14 May 1992

8:00 10. Working Group Presentations
Each of the working groups will present a list of key issues, a description of the status, and recommendations for future efforts and developments within their respective scope.

10:00 Break

10:30 11. Systems Analysis Panel Wrap-Up
A panel will summarize conclusions of the workshop, provide individualized comments on life support systems analysis, and to answer specific questions from participants.

11:30 Bus from Annex to Johnson Space Center
(Bus will provide return transportation back to Annex)

12:00 12. Tour of NASA Johnson Space Center Life Support Facilities **NASA/JSC**

12:00 Tour Building 7: SIRF, 10-foot chamber (plants), and life support laboratory.

1:00 Depart Building 7

1:10 Tour Building 241: Hybrid regenerative water recovery system site.

1:30 ADJOURN

APPENDIX B Workshop Participants

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LIFE SUPPORT SYSTEMS ANALYSIS WORKSHOP
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WORKSHOP SUPPORT

Marie L. Davis (Orbital Technologies Corporation)
Wynona Ellison (Lockheed ESC)
Barbara Angelo (Lockheed ESC)

APPENDIX C Original Working Group Presentations

C.1	**Working Group 1:**	Systems Analysis Modeling and Experimental Validation/Verification
C.2	**Working Group 2:**	Application of Systems Analysis to Process Control
C.3	**Working Group 3:**	Integration of Component, Subsystem, System, and Mission Level Models
C.4	**Working Group 4:**	Evaluation Criteria

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Systems Analysis Modeling and Experimental Validation/Verification Working Group

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IMPORTANT PARAMETERS TO BE VALIDATED

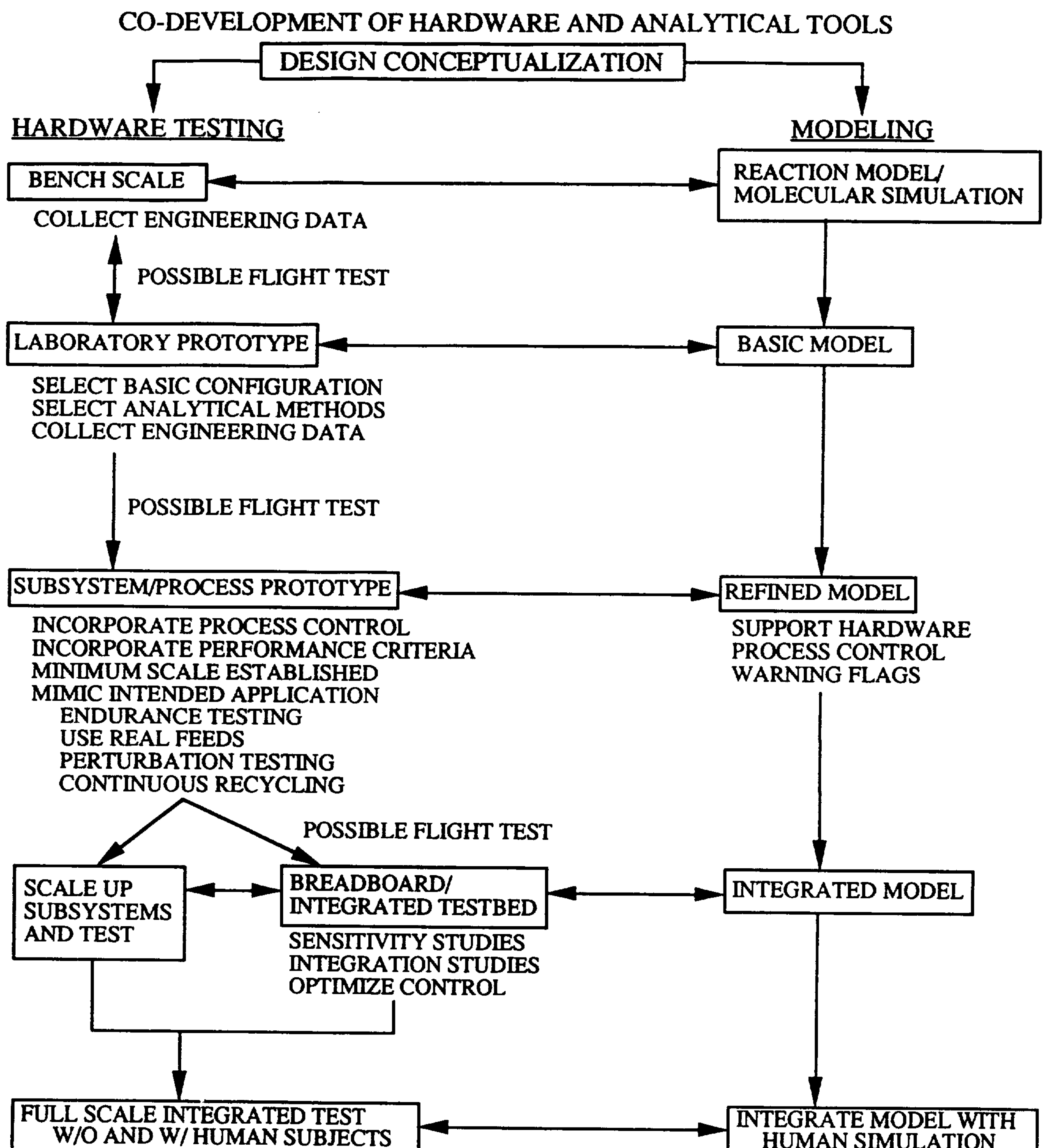
- For the most part, Important Parameters are Apparent for a Given Subsystem
  - Apply Sensitivity Analysis to Determine Relative Importance
- Fundamental Operating Principles
- Performance Over Lifetime

RECOMMENDATIONS

- Model Formulation Requires that Certain Parameters Be Well Characterized
  - Flow Streams, In and Out
  - Materials/Media Used, e.g., Sorbents
  - Usage of Power, Heating and Cooling

Systems Analysis Modeling and Experimental Validation/Verification Working Group

VALIDATION TEST SERIES



Systems Analysis Modeling and Experimental Validation/Verification Working Group

RECOMMENDATIONS FOR VALIDATION TEST SERIES

- Establish Standardized Feed Compositions for all Components at Each Level of Testing
- Establish Minimum Scale Size for Subsystem/Process Prototype
- Conduct Flight Testing, if necessary, at Earliest Possible Developmental Stage

Systems Analysis Modeling and Experimental Validation/Verification Working Group

ESTABLISH BASELINE

- "Real" Application Conditions, e.g., Duration of Test
- Well Defined Feed Compositions, including Trace Contaminants
- Minimum Scale
- Operating Conditions (Environment)
- Product Specifications

Systems Analysis Modeling and Experimental Validation/Verification Working Group

DATA GENERATION AND COLLECTION APPROACHES IN CO-DEVELOPMENT OF HARDWARE AND MODEL

- Establish Minimum Data Set Needed to Validate Model
  - Determine Most Appropriate Site(s) for Measuring Parameter
- Quantify Acceptable Bounds
- Determine/Record Uncertainty of Data
- Establish Appropriate Method for Instrumentation of Chemical Analysis
- Establish Appropriate Sampling Frequency
- Verify Accuracy of Interface Between Test and Model
  - Experimental Protocol should be Well Documented
  - Model Assumptions should Agree with Test Protocol
  - Protocol should Incorporate Minimum Number of Trials for Statistical Significance

Systems Analysis Modeling and Experimental Validation/Verification Working Group

INFORMATION NEEDED FOR SCALE-UP OF MODEL

- Characterize Each Component in System
  - Dimensioned Engineering Drawings
  - Throughputs
  - Construction Materials
  - Use Experience Base
- Determine Nonlinearities and Boundaries in Process Scaling

Systems Analysis Modeling and Experimental Validation/Verification Working Group

INITIAL ANALYSIS NEEDED TO SUPPORT PLANNED EXPERIMENTATION

- Variable Pressure Growth Chamber (VPGC)
  - Characterization of Local Chamber Environment: Irradience, Temperature, Nutrient Distribution, etc.
  - Predict Effect of Local Environment on Plants
  - Substrate - Nutrient Solution Interactions
  - Effect of Plant-Produced Contaminants on Physiochemical Hardware and vice versa

- Systems Integration Research Facility (SIRF)
  - Nominal Mass Balance
  - Determine Measurements to be Made
  - Interactions of Computer - Plant - Human
  - Determine Profile and Method for Human Simulator

- Crop Growth Research Chamber (CGRC)
  - Total System Characterization
  - Define Parameter Limits re: Biological Interactions

Systems Analysis Modeling and Experimental Validation/Verification Working Group

INITIAL ANALYSIS NEEDED TO SUPPORT PLANNED EXPERIMENTATION (Continued)

- Generic
  - Identify and Prioritize Goals
  - Identify Components, Inputs, and Outputs
  - Total System Characterization
  - Decide What to Measure
  - Determine Control Scheme
  - Find and Use as much Existing Data as possible

ADDITIONAL RECOMMENDATIONS

- Establish Communication Protocol Between Experimentation and Modeling Efforts
- Establish Better Communication Between Centers about Planned Experiments

WORKING GROUP PARTICIPANTS

Application of Systems Analysis To Process Control

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APPLICATION OF SYSTEMS ANALYSIS TO PROCESS CONTROL WORKING GROUP

TOPIC/ISSUE: List All Controlled Variables

STATEMENT OF PROBLEM:

The number of measurements needed for control is highly dependent on the mission duration and the degree of closure. Key measurement parameters of control need to be identified and defined as a function of degree of life support system closure.

DESCRIPTION OF STATE OF THE ART:

For Shuttle: CO_2, Humidity, Temperature, and Pressure

For Space Station: O_2, H_2O (both vapor and liquid), CO_2, temperature, and pressure (reported 5 measurements currently tracked by the Space Station Program for developing control algorithms).

OBSERVATIONS:

The general consensus in identifying the control parameters is to first identify and track by computer: (1) the number of desirable chemical species and (2) all possible toxins and/or undesirable by-products produced from the individual subsystems during the technology development stage. Adhering to the quality standards of certain equipment (i.e., fuel cell water) can also dictate the number and types of chemical species to be tracked.

RECOMMENDATIONS FOR RESEARCH AND TECHNOLOGY DEVELOPMENT:

- Minimum variables for short-duration mission: CO_2, H_2O, O_2, N_2, and Pressure
  - Technology specific species
  - Toxins to crew quarters

- For long-duration mission: Number of variables is highly dependent on the mission duration.

APPLICATION OF SYSTEMS ANALYSIS TO PROCESS CONTROL WORKING GROUP

TOPIC/ISSUE: Control Methodology

STATEMENT OF PROBLEM: Selection of Control Methodology

DESCRIPTION OF STATE OF THE ART:

- Space Station Freedom: 1553 serial interface
  - connected to: 6 MDMs
    2 SDPs
    3 386/486s
    w/firmware controllers

- Chevron El Segundo Refinery: block decentralization

OBSERVATIONS:

One commented that a totally centralized control system is the best way to achieve maximum performance, provided that there is no limitation on the computer resources. Another commented that a distributed system is the most feasible methodology that permits systems flexibilities (e.g., diagnostic purposes) and may reduce computer resource requirements. It was generally agreed that a high-fidelity integrated model is the top priority for off-line stimulating and characterizing behavior of the systems. One noted that, during the development of one single subsystem, 80 percent of the control algorithms are devoted to fault detection, safeguarding the equipment, and process performance.

RECOMMENDATIONS FOR RESEARCH AND TECHNOLOGY DEVELOPMENT:

- Develop high-fidelity integrated model

- Start from simplest control method and add degrees of sophistication as needed

- For a non-linear system: use non-linear model predictive method
  For a highly-interactive system: use state-space linear system method

- Total centralized control methodology results in better control, but is not feasible for large systems

APPLICATION OF SYSTEMS ANALYSIS TO PROCESS CONTROL WORKING GROUP

TOPIC/ISSUE: Dynamic Simulation Tool

STATEMENT OF PROBLEM:

What dynamic simulation model is best suited for life support systems?

DESCRIPTION OF STATE OF THE ART:

GENERAL PURPOSE	CHEMICAL PROCESS
ACSL	SPEEDUP
MatrixX/SYSTEM BUILD	EASY5
MATLAB/SIMULAB	Japanese Approach
CACSD	Others
XANALOG	
Others	

OBSERVATIONS:

One participant favored pull-down, menu-driven interface to the simulation computer. Another commented that a general purpose computer that allowed a high degree of user programmable capabilities is absolutely necessary. One commented that SPEEDUP, which is equation driven, may not predict adequate initial guesses and has limited user programmable capability. However, SPEEDUP has the advantage of built-in dynamic modeling and control capabilities. Simulation tools listed under the General Purpose category require massive modeling efforts as they are offered as a "shell" only to dynamic modeling. One suggested that the rigorous dynamic modeling would be the first and good approach to controlling non-linear, interactive systems.

RECOMMENDATION FOR RESEARCH AND TECHNOLOGY DEVELOPMENT:

Development of a more open and adaptive dynamic simulation tool is highly desirable.

APPLICATION OF SYSTEMS ANALYSIS TO PROCESS CONTROL WORKING GROUP

TOPIC/ISSUE: Control Technology Development

STATEMENT OF PROBLEM:

What are the benefits of increasing the sophistication of control technology within the life support system?

OBSERVATIONS:

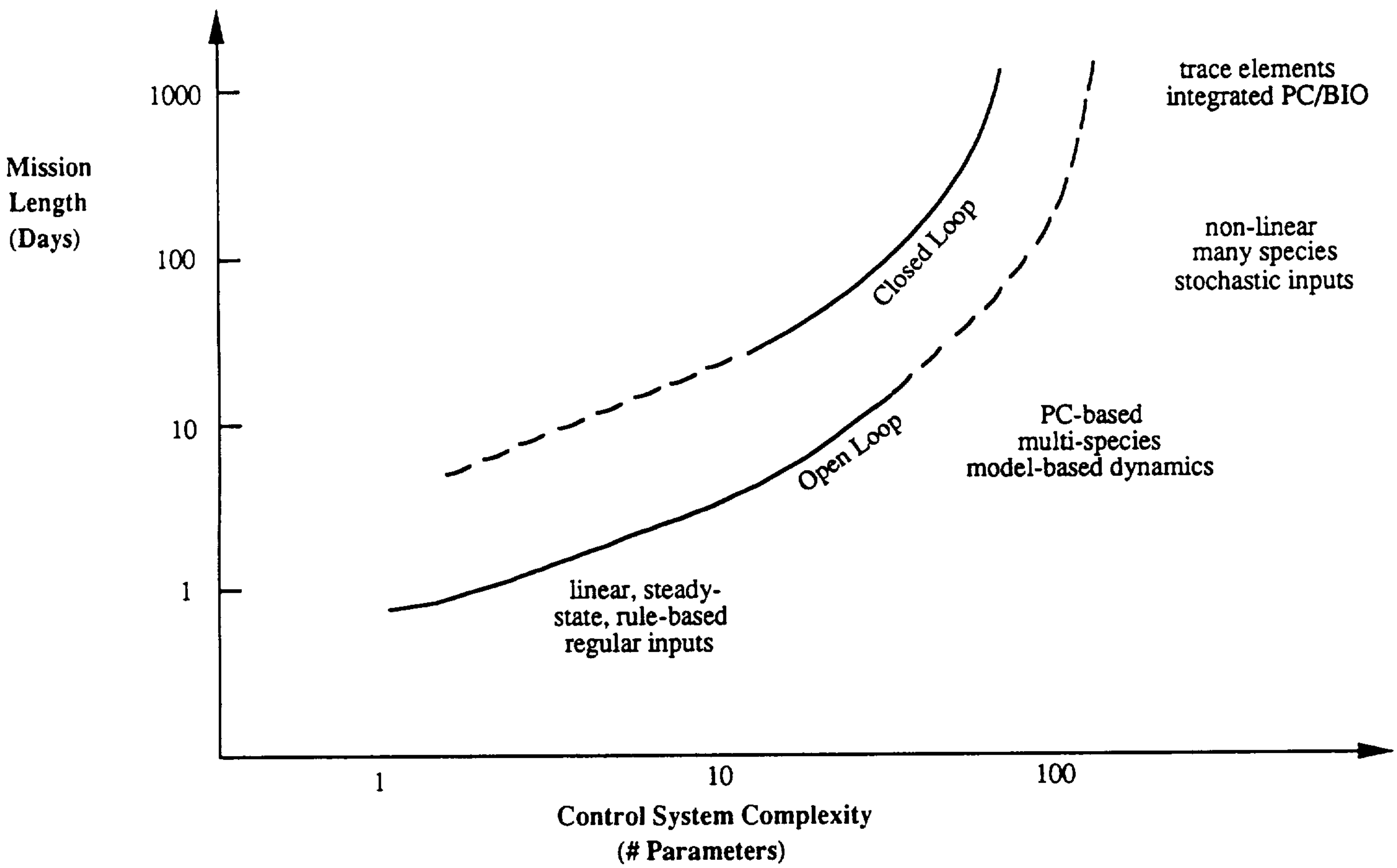
Potential benefits of highly sophisticated control algorithms include, but are not limited to: increased safety measure, reduction in crew maintenance time, reduction in buffer size, utility savings, possible weight savings (increased performance). However, risk associated with a system that relies highly on the control system must be properly assessed. Subjects on the stability and resiliency or degree of robustness of any complex control system should be fully investigated.

RECOMMENDATIONS FOR RESEARCH AND TECHNOLOGY DEVELOPMENT:

- Conduct quantitative analyses of trade-offs and sensitivities of control system complexity and sophistication with respect to life support system performance and reliability.

- Determine minimum requirements of control system approach for regenerative life support systems.

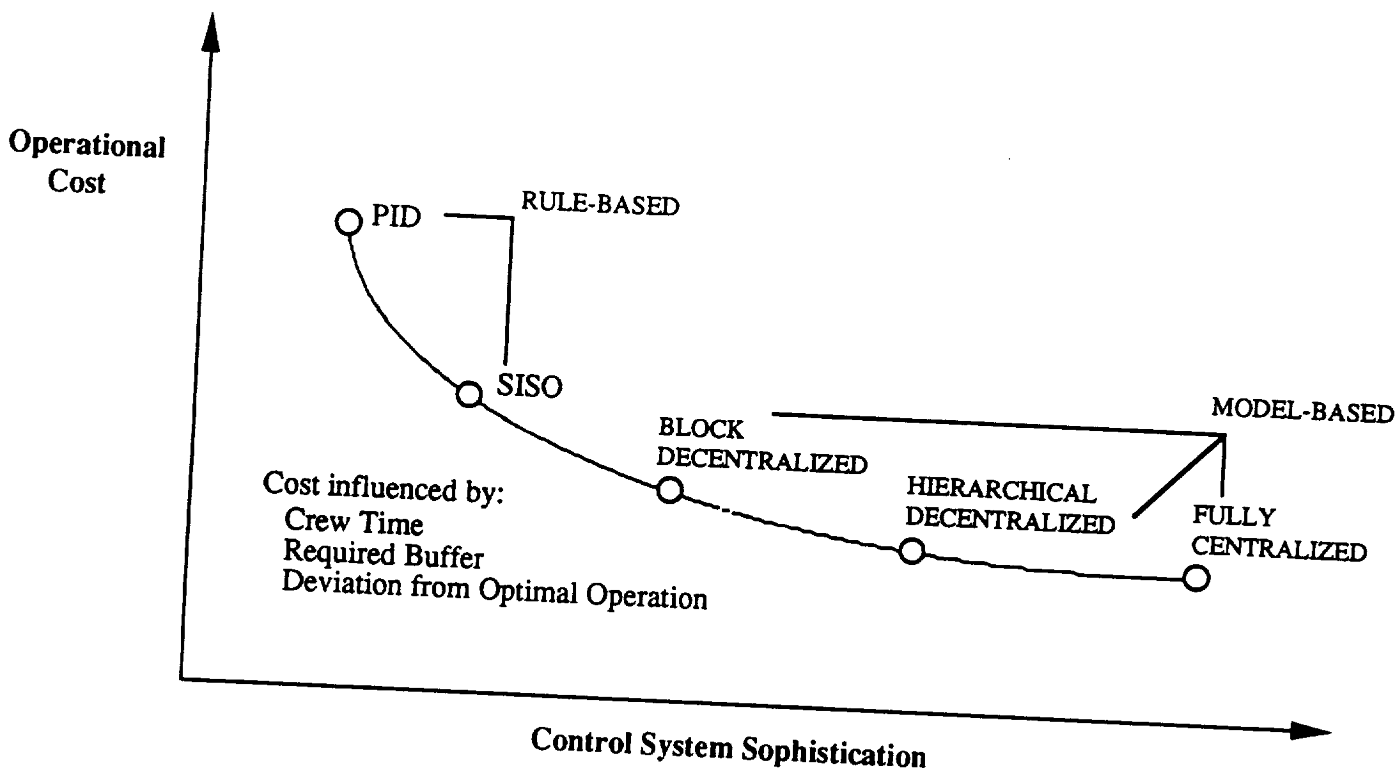
APPLICATION OF SYSTEMS ANALYSIS TO PROCESS CONTROL WORKING GROUP



MISSION LENGTH vs. CONTROL SYSTEMS COMPLEXITY

APPLICATION OF SYSTEMS ANALYSIS TO PROCESS CONTROL WORKING GROUP

Operational Cost vs. Control System Sophistication



APPLICATION OF SYSTEMS ANALYSIS TO PROCESS CONTROL WORKING GROUP

WORKING GROUP PARTICIPANTS

Integration of Component, Subsystem, System and Mission Level Models

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TOPIC/ISSUE: Tools of Various Levels of Analysis

STATEMENT OF PROBLEM:

What modeling tool can be used to conduct system analysis at the component, subsystem, system, mission-related models?

DESCRIPTION OF STATE OF THE ART:

- Definition and application of levels of analysis are ambiguous
- Different tools are used for different analyses

RECOMMENDATIONS FOR RESEARCH AND TECHNOLOGY DEVELOPMENT:

- Develop better definition and objectives of computer-aided analysis at various levels (strawman provided)
- Identify modeling tools which can be used for each level of analysis (strawman provided)
- Establish "guidelines" for tools to use for each level of analysis
- Standard set of tools are impractical, however, coordinated data and assumptions among many software tools is practical and useful

INTEGRATION OF COMPONENT, SUBSYSTEM, SYSTEM AND MISSION LEVEL MODELS WORKING GROUP

LEVEL	DEFINITION	USE
1	TRADE OFF ANALYSIS BASED ON MISSION REQUIREMENTS AND POTENTIAL TECHNOLOGY CANDIDATES	TECHNOLOGY ASSESSMENT
2	CONCEPTUAL FLOWSHEET ANALYSIS FOR INTEGRATED LSS AND SIZING OF MAJOR FUNCTIONAL COMPONENTS	PRE-PHASE A ⟶ PHASE B (MISSION DEFINITION)
3	SYSTEM DESIGN VERIFICATION FOR MEETING MISSION REQUIREMENT AND SYSTEM OPERATION SUPPORT	PHASE C/D ⟶ OPERATION
4	DETAILED PHENOMENOLOGICAL ANALYSIS	DETAILED PERFORMANCE MAPPING, HARDWARE VERIFICATION, TEST SUPPORT
5	ANALYSIS FOR CONTROL AND OPERATION	ASSESMENT AND DESIGN OF CONTROL SYSTEM

INTEGRATION OF COMPONENT, SUBSYSTEM, SYSTEM AND MISSION LEVEL MODELS WORKING GROUP

PROGRAM	TECHNOLGY ASSESSMENT/MISSION ANALYSIS (SCREENING)	SYSTEM FLOWSHEET ANALYSIS (1)	SYSTEM LEVEL COMPONENT AND SYSTEM ANALYSIS (1)	DETAILED COMPONENTS/ SUBSYSTEM MODEL
G189A		S, T	S, T	T
CASE/A		S, T	S, T	T
TRIALS	X			
LISSA	X	S		
SEQUENTIAL MODULAR STEADY STATE CHEMICAL PROCESS SIMULATOR, e.g., ASPEN		S	S	S
TRANSIENT EQUATION BASED CHEMICQL PROCESS STIMULATOR, e.g., SPEED UP		S, T	S, T	S, T
GENERIC TRANSIENT SYSTEM SIMULATOR, e.g., SIMUSOLVE			S, T (2)	S, T
SINDA				S, T
USER WRITTEN		Spreadsheets		S, T

(1) = S = Steady State T = Transient *(2)* = Component

INTEGRATION OF COMPONENT, SUBSYSTEM, SYSTEM AND MISSION LEVEL MODELS WORKING GROUP

TOPIC/ISSUE: Integration of Various Levels of Analysis

STATEMENT OF PROBLEM:

What interface guidelines and standards are necessary and appropriate to allow integration of modeling output or directly interfacing analytical models?

DESCRIPTION OF STATE OF THE ART:

- Models at various levels are mostly developed independently
- Very little flow of data and information among models

RECOMMENDATIONS FOR RESEARCH AND TECHNOLOGY DEVELOPMENT:

- Establish common (non-conflicting) assumptions among models
- Establish standard physical/chemical data for common use by models
- Regular update of models at various levels with technology advances
- When defining requirements for model development, provide input/output requirements for flow of information between models (see strawman requirements chart)
- Improve flow of information throughout various levels
- Identify limitations, assumptions, and constraints for models at all levels

INTEGRATION OF COMPONENT, SUBSYSTEM, SYSTEM AND MISSION LEVEL MODELS WORKING GROUP

ANALYSIS "INTERFACES" FOR INPUT/OUTPUT DATA

LEVEL	1	2	3	4
1		CANDIDATE SUBSYSTEM/ TECHNOLOGY MISSION PARAMETERS LEVEL 1 TO LEVEL 2	MISSION PARAMETERS INTERFACE REQ. IDENTIFICATION BETWEEN COMPONENTS	INTERFACE REQ. IDENTIFICATION
2	SYSTEM SIZING & FLOWSHEET BALANCE (LiSSA)		FEED STREAM DATA	FEED STREAM DATA
3	SYSTEM INTEGRATION EVALUATION	SIZING AND INTEGRATION VERIFICATION		DETAILED CHARACTERISTICS OF INTERFACE/ OPERATING REQs
4	TECHNOLOGY DATA UPDATE	SIZING FEEDBACK	PERFORMANCE MAPS	DETAILED CHARACTERISTICS OF INTERFACES

INTEGRATION OF COMPONENT, SUBSYSTEM, SYSTEM AND MISSION LEVEL MODELS WORKING GROUP

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Evaluation Criteria

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EVALUATION CRITERIA WORKING GROUP

RATING CRITERIA
Ranked by Importance

1. Total Life Cycle Cost
   Equivalent Mass
   Safety/Risk

2. Near-Term Cost
   Mass: System
   Expendables
   Resupply

3. Interface to Other Systems
   Power Requirements
   Heat Requirements

4. Crew Time
   Support EVA

5. Commonality
   Availability
   Reliability
   Repairability
   Redundancy
   Spares
   Processor Endurance

6. Interface Complexity
   Internal Complexity

7. Current Year Costs

8. Specific Transport Costs

9. RDDT&E Cost
   Design Cost
   Prototype Cost
   Development Risk
   Technical Maturity
   (Point Values or Error Bars)
   Volume

10. Fabrication Cost
    Modularity

11. Expandability

12. LSS Closure

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EVALUATION CRITERIA WORKING GROUP

QUANTITATIVE ANALYSIS METHODOLOGIES ARE REQUIRED IN THESE AREAS

1. SAFETY

- Define Risk Analysis Methodology

- Data Required
  - Failure Rates by Failure Mode
  - Hazards
  - Repair Rates

2. EQUIVALENT MASS

- Develop a standard Methodology and Conversion Factors for Equivalent Mass Calculation Including the Following Factors:
  - Mass (kg) - Include Spares, Systems Hardware, Process and Distribution, Expendables, Consumables
  - Pressurized Volume (m^3) - include "mass" for one supply interval
  - Energy (kWh) - Average and Peak
  - Manpower (crew-hour) - Include Maintenance, Operation
  - Heat Rejection (kw)

3. TOTAL LIFE CYCLE COSTS
(Research to Flight Qualified Hardware)

- Return on Investment
  - Must Establish Baseline (i.e., SSF@PMC, STS, etc.)

- Have Contractor Provide Complete RDDT&E Cost Estimate and Rationale

EVALUATION CRITERIA WORKING GROUP

ESTABLISH ACCESSIBLE STANDARD DATA

Standardized data and data conversion factors need to be defined by NASA and should be readily accessible by the life support community (e.g., ARC LSS Data Base)

1. Conversion Factors (To Equivalent Mass)

   - Pressurized volume (kg/m^3): SSF, STS, Skylab, Inflatable
   - Energy (kg/kWh): Solar, Battery, Solar with Fuel Cell, Nuclear
   - Heat Rejection (kg/kWh)
   - Crew-Hours (kg/crew-hour): Equivalent Crew (Mission = 90 days, 1 Crew = 180 crew-hour, Support in kg)

2. Human Requirements

   - Current Requirements Not Really Comprehensive
   - Metabolic I/O
   - NASA Std-3000 (Need to Address Gravity Effects)
   - Product Stream Quality Standards (Water/Air for Human Use)

3. Waste Streams Composition and Flow Rate

   - Water
   - Air
   - Solids

4. UNCERTAINTY FACTORS (i.e., standardized)
   Error Bars for Technology Readiness

EVALUATION CRITERIA WORKING GROUP

CONCLUSIONS

- NASA should establish a vehicle to facilitate development of standardized analysis methods and data.

- NASA should create a task force (or committee or scientific council) to establish the criteria or standardized analysis methods and reference data. The committee should be charged to publish a report or manual for standard analysis methods.

- Apply standardized analysis methods and data to all LSS technology candidates.

- Most evaluation criteria can and should be quantified (avoid subjective criteria)

- Top level technology selection criteria:

    - Safety
    - Equivalent Mass
    - Total Life Cycle Costs

APPENDIX D Workshop Report Distribution

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The *1992 Life Support Systems Analysis Workshop* was sponsored by NASA's Office of Aeronautics and Space Technology (OAST) to integrate the inputs from, disseminate information to, and foster communication among NASA, industry, and academic specialists. The workshop continued discussion and definition of key issues identified in the 1991 workshop, including: (1) modeling and experimental validation; (2) definition of systems analysis evaluation criteria; (3) integration of modeling at multiple levels; and (4) assessment of process control modeling approaches. Through both the 1991 and 1992 workshops, NASA has continued to seek input from industry and university chemical process modeling and analysis experts, and to introduce and apply new systems analysis approaches to life support systems. The workshop included technical presentations, discussions, and interactive planning, with sufficient time allocated for discussion of both technology status and technology development recommendations. Key personnel currently involved with life support technology developments from NASA, industry, and academia provided input to the status and priorities of current and future systems analysis methods and requirements.

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