Systems Integration, Modeling, and Analysis (SIMA)

FY04 Advanced Life Support Architecture and Technology Studies: Mid-year Presentation

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SIMA Telecon
April 15, 2004

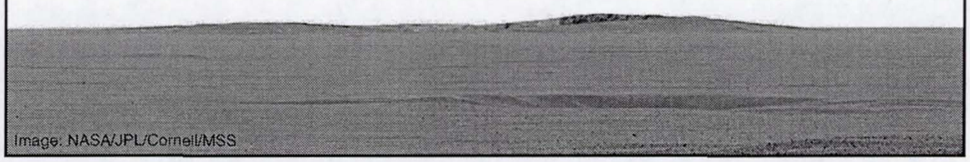


Image: NASA/JPL/Cornell/MSS

Long-Term Objective

Identify optimal advanced life support system designs <u>that meet existing and projected requirements for future human spaceflight missions</u>.

- Include failure-tolerance, reliability, and safe-haven requirements.
- Compare designs based on multiple criteria including equivalent system mass (ESM), technology readiness level (TRL), simplicity, commonality, etc.
- Develop and evaluate new, more optimal, architecture concepts and technology applications.

Complimentary Activities

- **Advanced Life Support Requirements Definition**
  - Draft ALS Requirements Document update due at end of FY04.
- **Analysis Tool Development**
  - Development of methodologies and software tools for performing more efficient and expanded system analyses.
- **Advanced Life Support Architecture Studies**
  - Integrated flowsheet development and optimization.
- **Advanced Life Support Technology Studies**
  - Atmosphere-Related
  - Water-Related
  - Food-Related
  - Waste-Related

3-year Roadmap

New Space Exploration Vision

FY03

- Focus on system interfaces.
- Perform detailed mass and water balances.
- Include low-water-use hygiene options.
- Include redundancy and contingency.
- Calculate radiation shielding ESM credit.
- Limited technologies; simplified sizing.
- Brute-force optimization.

FY04

- Include more technology and architecture options.
- Improve equipment sizing calculations (component based).
- Include lunar mission scenario.
- Define system design requirements.
- Investigate mass-balance-based failure tolerance analysis.
- Investigate reliability-based redundancy and sparing analysis.

FY05

- Include more technology and architecture options.
- Continue to improve component-based sizing calculations.
- Implement mass-balance-based failure tolerance analysis.
- Implement integrated reliability, redundancy, and sparing analysis.
- Investigate system optimization algorithms.

Carryover FY03 Hygiene Options
(with full accounting of each option's consumables)

Option	1	2	3	4	5	6
Hygiene Supplies						
Disposable Prewetted Wipes - HF	✓		✓			
Disposable Prewetted Wipes - WB	✓					
Disposable Non-prewetted Wipes - HF		✓		✓		
Disposable Non-prewetted Wipes - WB		✓				
Washable Washcloths			✓	✓	✓	✓
Washable Towels	✓	✓	✓	✓	✓	✓
Bar Soap					✓	✓
No-Rinse Body Bath			✓	✓		
No-Rinse Shampoo	✓	✓	✓	✓	✓	✓
Hygiene Facilities						
Handwash Station - OH					✓	✓
Shower						✓

HF = hand/face wash; WB = whole body wash; OH = with oral hygiene wastewater collection

Carryover FY03 Technology Options

- **Oxygen Storage**
  - Cryogenic
  - High Pressure
- **Oxygen Generation**
  - SPE Water Electrolysis (ISS OGA)
- **Carbon Dioxide Removal**
  - 4-Bed Molecular Sieve (4BMS; ISS CDRA)
  - Functionalized Carbon Molecular Sieve (FCMS) with Membrane Water Recouperator
  - FCMS with Lower Water Loss Membrane Recouperator
- **Carbon Dioxide Reduction**
  - Sabatier
- **Temperature & Humidity Control**
  - Common Cabin Air Assembly (ISS CCAA)
- **Laundry**
  - Washer/Dryer with Condenser
- **Combined Wastewater Processor**
  - Vapor-Phase Catalytic Ammonia Removal (VPCAR; uses generated oxygen if available)
  - VPCAR with Stored Oxygen
  - VPCAR with Variable Water Recovery (based on water balance)
  - VPCAR with Stored Oxygen and Variable Recovery
  - VPCAR with Lyophilization (for water recovery from VPCAR brine)
  - VPCAR with Stored Oxygen and Lyophilization
- **Food/Hygiene Waste Processor**
  - Air Dryer

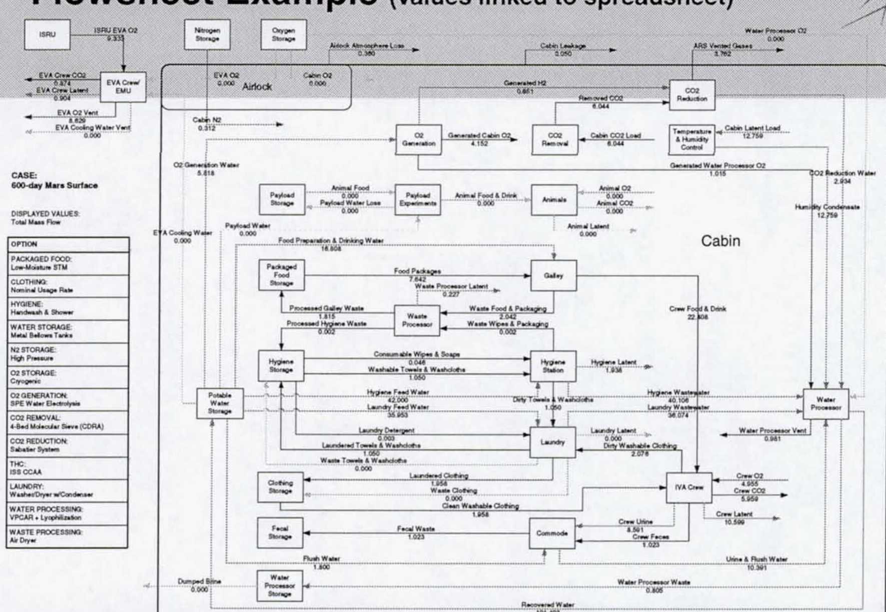
Other Carryover Options and Capabilities

- **Other Options**
  - 3 Packaged Food Systems
  - 3 Clothing Usage Rates
  - 4 Habitat Structures
  - 9 Radiation Shielding Materials
  - 4 Internal Atmosphere Compositions
  - Store/Dump Water Processor Brine
  - Day/Night Operation
  - Number of Active (Operational) Units
  - Number of Inactive (Standby) Units
- **Automated Trade Studies**
  - Macro runs combinations of options and allows ranking of cases based on equivalent system mass (ESM).
  - 14,000+ combinations takes < 1 hr.
- **Radiation Shielding ESM Credit Calculation**
  - Equivalent mass of dedicated radiation shielding material saved as a result of shielding provided by life support materials.
  - Assumed equivalency based on hydrogen mass content.
  - **Example:** 600 day mission; crew of 6; low-moisture STM food system; polyethylene radiation shielding

Food Storage Mass/Vol. ESM:	5870 kg
Radiation Shielding Credit:	3500 kg
Net Food Storage ESM:	2370 kg

- **Flowsheet Mass Balance Verification and Visualization**
  - Expanded from FY03.
  - Example on next slide.

Flowsheet Example (values linked to spreadsheet)



FY04 Technology Studies

- **Improve FY03 technology data and relations.**
- **Investigate additional technologies.**
  - Obtain technology information necessary for mass balance and sizing calculations.
    - Detailed Process Schematic
    - Input/Output Stream Definitions (including affected constituents)
    - Performance Data and Relations
    - Component Equipment List
    - Component Sizing Data and Relations
  - Basis for including technologies in FY04 studies:
    - Consultation with ALS Element Leads (preliminary list presented 11/17/03)
    - Potential Applicability to Nearer-term Moon/Mars Missions
    - Desire to Include Diverse Concepts
    - Data Availability
  - No technology readiness level (TRL) cutoff.
  - Many promising technologies remain to be investigated.

Atmosphere-Related Technology Studies and Potential Trades

Carbon Dioxide Removal and Reduction

Option	Technology	Added FY04
4BMS + Sabatier	4-Bed Molecular Sieve (4BMS; ISS CDRA)	
	Sabatier Carbon Dioxide Reduction System (with compressor and accumulator)	
Integrated CO_2 Removal & Reduction	Integrated Carbon Dioxide Removal and Reduction System (fan replaces compressor; no accumulator; thermal integration; humidity removal capabilities)	✓

Trace Contaminant Control

Option	Technology	Added FY04
ISS TCCS	ISS Trace Contaminant Control System (uses expendable activated carbon bed)	✓
Regenerative TCCS	Regenerative Trace Contaminant Control System (uses regenerative sorbent bed)	✓

Atmosphere-Related Technology Studies and Potential Trades
(continued)

Cabin and Extravehicular Mobility Unit (EMU) Oxygen Supply[1]

Option	Technology	Added FY04
High-Pressure O_2	High-Pressure Oxygen Storage Tanks	
Cryogenic O_2	Cryogenic Oxygen Storage Tanks	
Cryogenic O2 with Cryocooler	Cryogenic Oxygen Storage Tanks	
	Pulse-Tube Cryocooler	✓
Low-Pressure H_2O Electrolysis + Compressor	SPE Water Electrolysis (ISS OGA)	
	Oxygen Compressor	✓
High-Pressure H_2O Electrolysis	High-Differential-Pressure Water Electrolysis	✓

[1]EMU application depends on EMU oxygen storage technology (cryogenic or high-pressure).

Water-Related Technology Studies and Potential Trades

Wastewater Processing

Option	Technology	Added FY04
VPCAR	Vapor-Phase Catalytic Ammonia Removal (VPCAR)	
ISS UPA + WPA	Vapor Compression Distillation (VCD) (for primary urine processing)	✓
	Multifiltration	✓
	Volatile Removal Assembly (VRA)	✓
BWP + RO + AES + PPS	Anaerobic Bioreactor (for organic degradation)	✓
	Aerobic Nitrification Bioreactor (for ammonia oxidation)	✓
	Reverse Osmosis (RO; for inorganic removal)	✓
	Air Evaporation (AES; for RO brine water recovery)	✓
	UV Photooxidation (for post-processing)	✓
	Ion Exchange (for post-processing)	✓

Water-Related Technology Studies and Potential Trades
(continued)

Wastewater Processing

Option	Technology	Added FY04
BWP + DOC	Anaerobic Bioreactor (for organic degradation)	✓
	Aerobic Nitrification Bioreactor (for ammonia oxidation)	✓
	Direct Osmotic Concentration (DOC; for inorganic removal)	✓
Others?	Other combinations of included technologies to achieve required water quality or more optimal configurations.	✓

Food-Related Technology Studies and Potential Trades

Packaged and Produced Food[1,2]

Option	Technology	Added FY04
STM	Shuttle Training Menu (STM)	
Low-Moisture STM	Shuttle Training Menu Substituted with Increased Low-Moisture Content Items	
STM + Frozen	*Shuttle Training Menu Substituted with Frozen Food Items*	
STM + Salad Machine	Shuttle Training Menu Substituted with Grown Salad Items	✓
Low-Moisture STM + Salad Machine	Shuttle Training Menu Substituted with Increased Low-Moisture Content Items and Grown Salad Items	✓

[1]Options include necessary food production, processing, and preparation equipment.

[2]STM-based food system data provided by Julie Levri/ARC (Food Data Spreadsheets 1-29-03.xls).

Food-Related Technology Studies and Potential Trades
(continued)

Packaged and Produced Food[1]

Option	Technology	Added FY04
High Bulk Packaging + Salad Machine	High Degree of Bulk Food Packaging with Grown Salad Items (includes bread maker and powdered drink dispenser)	✓
Moderate Bulk Packaging + Salad Machine	Bulk Packaging of Dehydrated Drinks and Flour with Grown Salad Items (includes bread maker and powdered drink dispenser)	✓
Individual Packaging + Salad Machine	Individually Packaged Food with Grown Salad Items	✓

[1]Options include necessary food production, processing, and preparation equipment.

Waste-Related Technology Studies and Potential Trades

Physicochemical Waste Processing

Option	Technology	Added FY04
Air Dryer	Air Dryer (for non-hazardous food/hygiene wastes; employs heat and water exchange with cabin air)	
Batch Incineration	Batch Incineration (initially considered for feces only; includes necessary pre and post processors)	✓
Pyrolysis	Pyrolysis (initially considered for feces only; includes necessary pre and post processors)	✓
Sublimation	Sublimation (or lyophilization; for feces, toilet paper, food wastes, and waste brines)	✓[1]

[1]Sublimation (lyophilization) included in FY03 for VPCAR brine only.

Waste-Related Technology Studies and Potential Trades
(continued)

Biological Waste Processing[1]

Option	Technology	Added FY04
Aerobic Composting	Aerobic Composting	✓
Anaerobic Composting	Anaerobic Digestion/Composting	✓

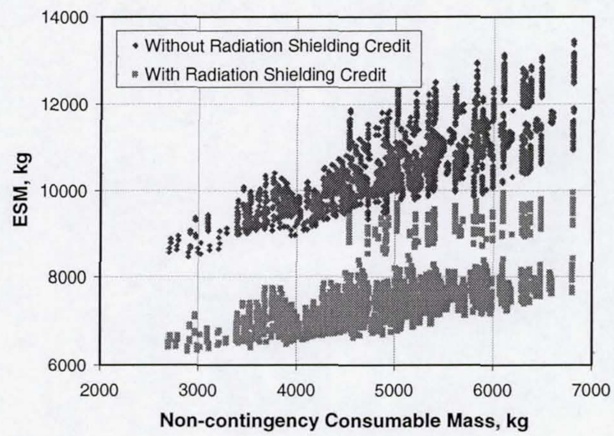
[1]For feces, compatible food/hygiene wastes, biomass, paper, and waste brines. Options include necessary pre and post processors.

FY04 Trade Studies

- FY04 ALS architecture and technology trade studies will be completed by June 30 in time to provide recommended design configurations for the FY04 ALS Metric.
- Technologies included in these studies will be prioritized based on the following criteria:
  1. Availability and quality of required performance/sizing data and relations.
  2. Assessed potential for greatest reduction in system ESM based on updated FY03 results.
  3. Ability of the technology to provide a required or potentially required system capability (e.g., waste sterilization) not included in FY03 studies.

Example FY03 Results for Mars Transit Mission

- Multiple system configurations examined based on combinations of FY03 technology and interface options.
- ESM does not include some non-traded functions (e.g., pressure control).
- *Many configurations* yield close to lowest ESM. Some trade consumables against equipment.
- Simplicity, reliability, development cost, etc. may drive selection.



Including System Failure Tolerance and Reliability
General Approach

- Establish the required failure tolerance for each technology in a candidate life support system architecture.
- Define relations between system reliability and technology reliability as a function of success/failure criteria, system design *(including redundancy approach), and mission length.*
- Define relations between technology reliability and number of component spares.
- Integrate with sizing analysis to compare the total ESM of systems *(including redundancy and spares)* that meet failure tolerance and reliability requirements.

Including System Failure Tolerance and Reliability
Initial Steps

Establish high-level system failure-tolerance and reliability requirements.

↓

Flow down failure tolerance requirements to lower-level life support capabilities by functional decomposition and fault tree analysis.

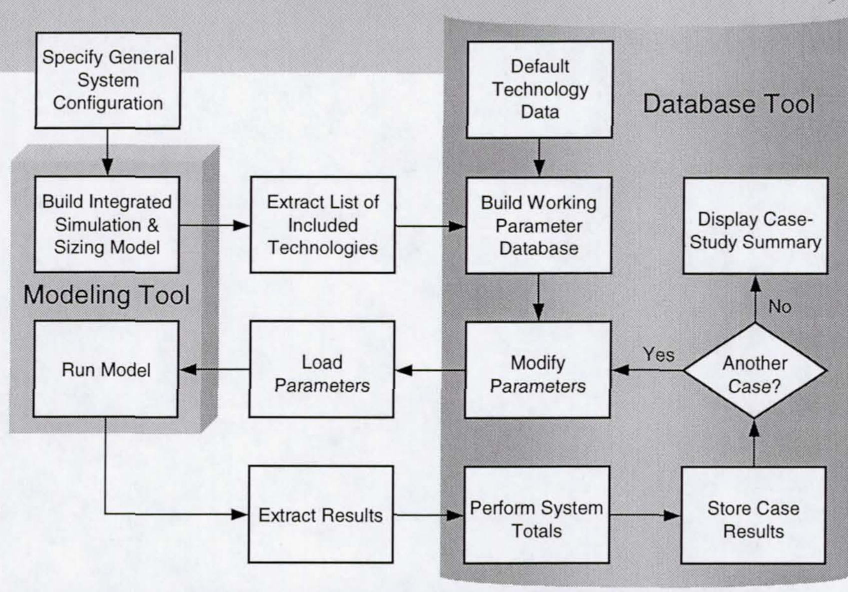
↓

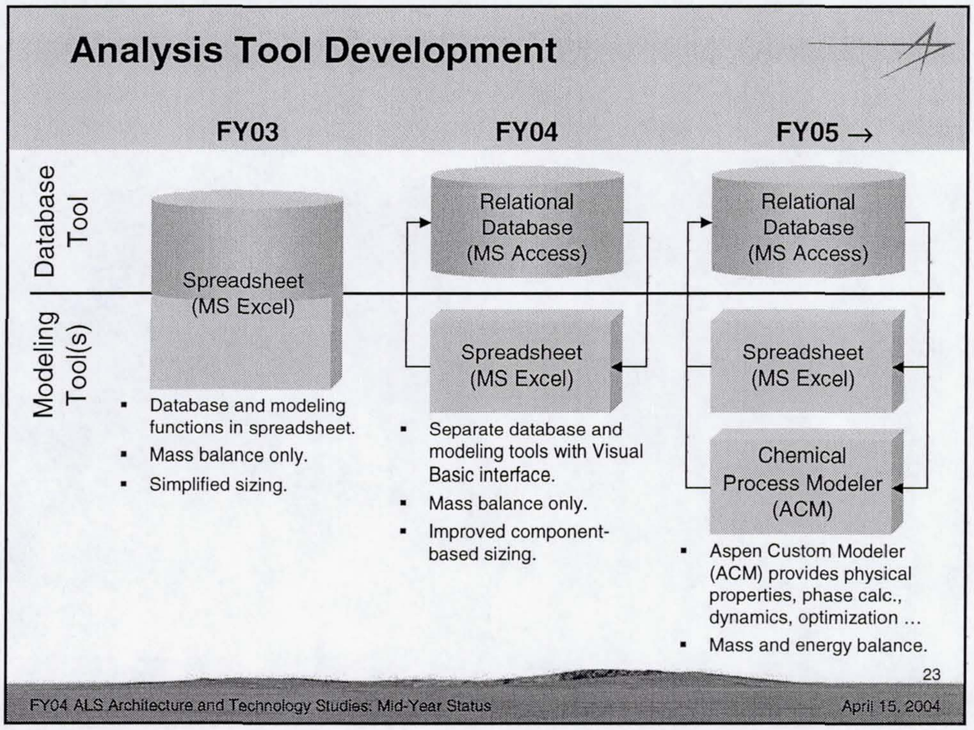
Determine failure tolerance of life support technologies from failure-state flowsheet mass-balance calculations.

Base on human-rating and historical mission requirements documents.

Failure tolerance is linked to the system mass balance. For example, carbon dioxide reduction produces water that can be used for multiple purposes (oxygen generation, crew consumption, crew hygiene, laundry, etc.). A prioritized water balance is needed to determine the criticality of loss of CO_2 reduction.

General Analysis Flowchart




Analysis Tool Development
FY03
FY04
FY05 →
Database Tool
Modeling Tool(s)
Spreadsheet (MS Excel)
Database and modeling functions in spreadsheet.
Mass balance only.
Simplified sizing.
Relational Database (MS Access)
Spreadsheet (MS Excel)
Separate database and modeling tools with Visual Basic interface.
Mass balance only.
Improved component-based sizing.
Relational Database (MS Access)
Spreadsheet (MS Excel)
Chemical Process Modeler (ACM)
Aspen Custom Modeler (ACM) provides physical properties, phase calc., dynamics, optimization …
Mass and energy balance.
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