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SPACECRAFT SYSTEMS WORKING GROUP REPORT

John Keigler, Chairman
RCA Astro-Electronics Division

Larry Rowell, Cochairman
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The Spacecraft Systems Group of the Spacecraft 2000 Workshop convened on the afternoon of Tuesday, 29 July 1986. Sessions were held that afternoon, and Wednesday all day and evening. Findings and recommendations were presented at the Thursday morning Plenary Session. A follow-up session was held on Thursday afternoon to incorporate findings of the various Subsystem Groups, and to make further recommendations to the Steering Committee.

The Spacecraft Systems Group was extremely large, consisting of twenty-eight members, including several members of the Steering Committee, who sat in on nearly all of the sessions. Dr. Jack Keigler, of RCA Astro Electronics Division, was Chairman, and Larry Rowell of NASA - Langley Research Center was Co-Chairman. The members participating in the group are listed in Attachment A.

The discussions were wide-ranging, reflecting the breadth of experience in the membership. Nevertheless, the group focused on the objectives of the workshop and on the issues assigned specifically to the Spacecraft Systems Group.

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WORKSHOP OBJECTIVES

TO IDENTIFY THE CRITICAL NEEDS AND TECHNOLOGIES FOR SPACECRAFT OF THE 21ST CENTURY, AND TO RECOMMEND TECHNOLOGY DEVELOPMENT PROGRAMS AND IN-SPACE VALIDATION PROGRAMS AND POSSIBLE GOVERNMENT AND INDUSTRIAL ROLES AND PARTNERSHIPS.

SPECIFIC OBJECTIVE OF THE SPACECRAFT SYSTEMS GROUP

DETERMINE METHODOLOGY & GROUND RULES FOR SELECTION OF DESIGN CONCEPTS AND TECHNOLOGIES

ISSUES TO BE ADDRESSED BY THE GROUP

- Definition of user/commercial/government needs by function
  - Criteria for prioritization of needs

- Overall criteria for technology assessment, prioritization of needs

- System configuration drivers
  - Key trade studies - mass, life, power, cost, performance, etc.

- Space infrastructure interface

- Cost Drivers
  - Pros & cons of standardization
  - Manufacturing/test/serviceability/supportability

Ground rules announced at the initial Plenary Session were adhered to by the group while pursuing its objectives. These were that recommendations should:

- Exclude STS, SPACE STATION, and other payloads as solutions to the SPACECRAFT 2000 objective.

- Be independent of the SPACE STATION and OMV/OTV

- Provide technology payoff by the year 2000

As a result of the Tuesday afternoon session, several viewfoils were prepared and presented at the Wednesday morning plenary. These focused on the objectives, approach, methodology, criteria for technology assessment and prioritization, and mission drivers.

The working sessions of Wednesday afternoon and evening resulted in a refined set of thirteen viewfoils, which were presented at the final plenary on Thursday. These are introduced as Charts 1 through 12 in the text that follows.

Based on the objectives and ground rules, Chart 1, the group arrived at a consensus that the methodology should provide credible, quantified models for mission, costs, and reliability/availability upon which a technology assessment for enhanced payload mass fraction could be made. There was general agreement that reduced mass fraction of the spacecraft bus would enable a nearly one-to-one increase in payload mass fraction, and that most savings would be realized by improvements in propulsion, power, and structure/thermal technology. This viewpoint was presented in Chart 2.

A system methodology was developed by which a technology ranking could be accomplished, and presented as Chart 3. Mission models and requirements for future Low Earth Orbit (LEO), Geostationary Earth Orbit (GEO) and Planetary missions would first be developed. From this effort, general Systems and Subsystems requirements would be defined for each mission category, and criteria for measurements of performance developed and utilized for prioritization. A cost and availability model would then be run for each mission to assess servicing, repairability, maintainability and operations considerations. This model must be fully developed, based on existing cost and availability models. Findings of the other spacecraft 2000 working groups could then be assessed against model results, with particular attention to the high pay-off subsystems. An iteration would result in a technology ranking which could then be used to prioritize technology experiments.

Transportation costs as a percentage of total system cost are not expected to change by the year 2000 due to the interacting effects of competition, technology improvements, fuel specific impulse increases, insurance costs, and increased reliability and safety requirements. Chart 4 therefore makes the point that increases in payload capability requires improvement in the technology and associated costs for the Spacecraft Bus and for the Operations and Maintenance functions.

Much discussion centered on the mission operations tasks and associated cost drivers. Chart 5 describes mission operations as the "missing subsystem", and defines its functions and what it does. Increases in spacecraft autonomy and reliability-availability would reduce operations and maintenance costs, and are therefore believed to be of equal importance to that of reducing spacecraft bus weight. Chart 6 was developed from an effort to identify the most important criteria for technology assessment and prioritization of needs. The five most important needs were identified, and relative weighting factors assigned based on general agreement of the membership. Reduction of Spacecraft Bus weight and reduction of operations and maintenance costs were considered equally important, and for the purpose of comparison, assigned a weighting factor of 10. As previously stated, technology increases in these areas will directly result in bigger payloads, with associated reductions in overall cost - a "bigger bang for the buck" in terms of payload capability in space.

Discussions of the group resulted in agreement that reduction in Spacecraft Bus weight will be most easily attained by better, lighter propulsion subsystems (and propellants), power subsystems, and structural/thermal subsystems. Increased synergism between subsystems will allow more streamlined data management, fewer sensors, lighter structure and reduced power. For example, sensors used for attitude control might also be used as reference for payloads and for alignment of a large flexible structure.

Reduction of operations and maintenance costs will be natural fallouts of increased spacecraft autonomy and reliability/ availability. Spacecraft subsystems are gaining more autonomy with each new program, but true autonomy is many years away unless a concerted effort is made to develop fault tolerant subsystems. Then there must also be a concerted effort to reduce the huge number of operations personnel now in place, particularly for military spacecraft. Geosynchronous satellites require far fewer people now, because the tasks of tracking, command loading, and pointing are straight forward and require only one station once in orbit. The major targets for autonomous subsystem development are low earth orbit satellites and, to a lesser degree, interplanetary spacecraft. Autonomous navigation subsystems which would automatically determine orbit parameters, accomplish pointing of the spacecraft and/or its payloads, and maintain structural alignments, would greatly reduce ground operations manpower.

A reduction of number and bandwidth of data links between the space and ground will be partially accomplished by improving spacecraft autonomy. A far greater savings would be realized by more extensive onboard processing of payload data. While data compression techniques have been developed to some extent, the tendency to collect, down-link, and process all data persists. Onboard processing would also reduce operations and maintenance costs, previously targeted as one of the highest priority items.

A weighting factor of only 7 was agreed upon because a reduction in number and bandwidth of data links will eventually become a necessity as the available spectrum becomes saturated. This in turn will force more and more onboard processing into spacecraft design.

Standardization of subsystems and interfaces would add greatly to savings in cost while improving reliability/availability. Connectors, processors and software, thrusters, sensors, batteries, etc., currently are of different design for every line of spacecraft. Much of this is because of competition between many spacecraft contractors and vendors. Although competition breeds improvements in quality and technology, there is a feeling that standardization can and should be accomplished whenever possible, and that studies should be made to determine the best way of accomplishing the goal. The provisions for using standardized subsystems, components, and interfaces could be imposed by government specifications and the statement of work for each new program. This was given a weighting factor of 5 when compared to other criteria.

Reduced costs of manufacturing and test is considered a given criteria, with a weighting factor of 3. This lower factor was agreed upon because there has been and should continue to be many incentives to accomplish the goal through innovative spacecraft design, and efficient manufacturing and test techniques.

Mission drivers to technology needs were categorized by mission type and launch/injection technique as shown in Chart 7. The mission types; Planetary, GEO or LEO, each have demands and criticality levels that are different in terms of technology issues. Chart 8 is the result of the Spacecraft Systems Group attempt to identify the importance of technology issues in each mission category. It stands alone in terms of generally identifying critical needs. However, much more intensive study is needed to quantify these needs as a basis for prioritizing technology development.

The National Space Needs summarized in Chart 9 are the result of evaluating the general technology issues, cost drivers, and polling the members of the panel. Of primary importance is the recognition that space assets needed for technology development have diminished over the past ten years because of reduced R&D budgets. Technology Development spacecraft, such as ATS and NIMBUS, no longer exist: virtually every program now focuses on current needs, not future needs. It was a strong opinion of the group that only orbital test platforms, dedicated to technology advancement, would enable and validate new technology.

Experiments to develop advanced large structures, attitude control subsystems and other subsystems can not possibly be conducted to the extent required on STS, on the Space Station or as piggyback on operational satellites because of the mutual impact between the experiment and host.

Certainly the kinds of technology development that are needed will require ground development and testing and much can be accomplished with the Space Station and STS, but only an orbital platform (or platforms) will enable the required total development needed.

The group compiled a list of candidate developments that an orbital test bed should be used for. These are listed in Chart 10, further classified as Technology Enabling or Technology Enhancing. Many were independently suggested by the various Subsystem Groups.

The characteristics of a Spacecraft 2000 were developed by the group and presented in Chart 11. These characteristics can be achieved by the deliberate, dedicated and funded technology development program recommended by the Spacecraft 2000 Workshop.

Recommendations of the Spacecraft Systems Group are summarized in Chart 12. The first recommendation is to develop system level analysis tools to assess subsystem technologies. These tools would be used in conjunction with the methodology for technology ranking previously discussed (Chart 3). Those developments selected could then be the subject of funded development, first with ground development and test, and then for development in space. Priority would be given to those identified as having the highest performance and cost benefits.

The second recommendation of the group is that NASA lead the development of a flexible, multidisciplinary Orbital Test Bed Program for the basic reasons listed on the chart. Test Beds should encompass one or more platforms which could be independent satellites or the Shuttle. Development experiments and tests would be systematically manifested onto and off of the test beds emphasizing co-utilization with compatible payloads.

On Thursday afternoon, the Spacecraft Systems group met to assess recommendations by the Subsystem Groups delivered at the morning plenary. It was agreed that their recommendations generally supported those of the Spacecraft Systems Group. Likewise the group concurred with Subsystem recommendations, but believes that design concepts and technology development program must first be well defined for prioritization and subsequent selection.

The methodology and ground rules have been generally outlined in this report and must be further developed. The selection process also requires development of adequate models to define costs, servicing, repairability, maintainability and operations characteristics.

Recommendations to the Steering Committee were:

1) NASA should solicit from industry and universities proposals for funded definition of in-space technology experiments. NASA Langley Research Center volunteered to perform this solicitation for proposals.

2) A separate solicitation should be made for proposals to develop in parallel the required system analysis tools to be used for evaluating and ranking of the proposed experiments.

Two 3-5 month (2-3 man-years) studies were recommended:

- o Develop a mission model (updated) which derives system and subsystem requirements that are then grouped into common technical (quantitative) requirements.

- o Develop cost and availability models (decision criteria) for technology assessment.

One study (3-4 month), perhaps by NASA in-house, was also recommended:

- o Introduce discipline technology trade-offs into two above models to determine ranking.

At the end of these parallel studies, models should be exposed to industry review and critique.

NASA-HQ-OAST probably should lead this effort and select the best contractor.

3) After (1) and (2) are accomplished, an RFP should be issued to obtain the most suitable contractor to evaluate the proposed experiments based on the models and to provide a technology ranking OAST or NASA/LeRC could lead this effort.

4) Funded development of various experiments should then be accomplished on a competitive basis and contractors selected to define and construct the orbital test bed platforms, integrate and operate experiments, and provide launch capability and services.

These recommendations were given to the Steering Committee on the afternoon of 31 July 1986 and the Spacecraft Systems Group adjourned.

ATTACHMENT A
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SPACECRAFT SYSTEMS GROUP MEMBERSHIP

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SPACECRAFT SYSTEMS GROUP

OBJECTIVE DETERMINE METHODOLOGY AND GROUND RULES FOR SELECTION OF DESIGN CONCEPTS AND TECHNOLOGIES

GROUND RULES

- EXCLUDE STS, SPACE STATION, PAYLOADS
- INDEPENDENT OF SPACE STATION & OMV / OTV
- TECHNOLOGY PAYOFF BY YEAR 2000

CHART 01

SYSTEMS METHODOLOGY

- CREDIBLE, QUANTIFIED MODELS FOR
  - MISSIONS
  - COSTS
  - RELIABILITY / AVAILABILITY

- TECHNOLOGY ASSESSMENT FOR ENHANCED PAYLOAD MASS FRACTION
  - PROPULSION
  - POWER
  - STRUCTURE / THERMAL

CHART 02

SYSTEMS METHODOLOGY FOR TECHNOLOGY RANKING

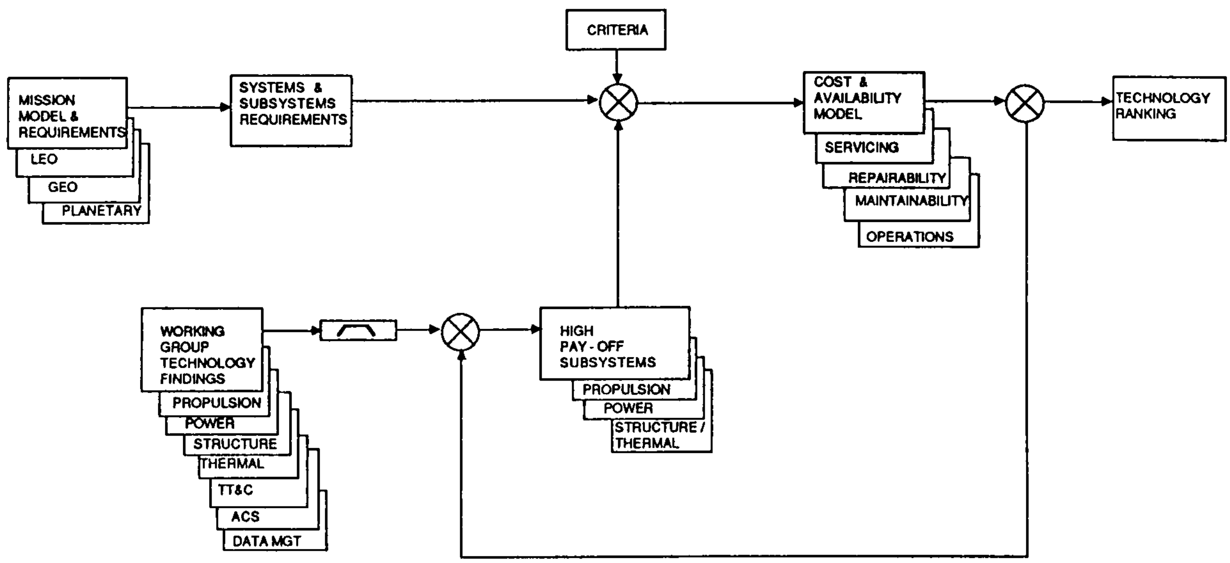
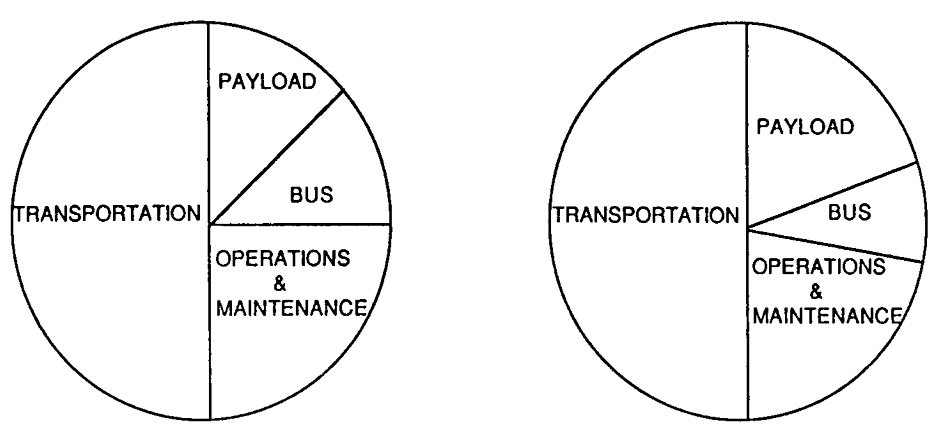


CHART 03

SYSTEM COST DRIVERS



CURRENT TECHNOLOGY **S/C 2000 TECHNOLOGY**

CHART 04

MISSION OPERATIONS - THE "MISSING SUBSYSTEM"

WHAT IS IT ?

- THE SOFTWARE AND HARDWARE NEEDED TO OPERATE AND CONTROL SPACE SYSTEMS
- A SUPER SUBSYSTEM CONSISTING OF MANY GROUND AND SPACE ELEMENTS PLUS COMMUNICATIONS LINKS

WHAT IT DOES.

- SUBSYSTEM INTEGRATION
- COMMAND AND CONTROL INTERFACES
- RESOURCE MANAGEMENT
- FAULT MANAGEMENT
- USER INTERFACES
- SERVICING SUPPORT

CHART 05

CRITERIA FOR TECHNOLOGY ASSESSMENT AND PRIORITIZATION OF NEEDS

	WEIGHTING FACTOR
• REDUCTION OF S/C BUS WEIGHT • PROPULSION, POWER, STRUCTURE • SYNERGISM (SUBSYSTEM)	10
• REDUCTION OF OPERATIONS AND MAINTENANCE COSTS • INCREASED S/C AUTONOMY • INCREASED RELIABILITY / AVAILABILITY	10
• REDUCTION OF DATA LINK DEMANDS • ON - BOARD PROCESSING	7
• STANDARDIZATION OF SUBSYSTEMS AND INTERFACES • INCLUDING SOFTWARE	5
• REDUCED COST OF MANUFACTURING AND TEST	3

CHART 06

MISSION DRIVERS TO TECHNOLOGY NEEDS

- MISSION TYPE
  - LEO
  - GEO
  - PLANETARY

- LAUNCH AND INJECTION TECHNIQUE
  - ELV VS SHUTTLE
  - SPACE STATION VS DIRECT
  - GROUND VS IN - SPACE ASSEMBLY

CHART 07

CRITICAL TECHNOLOGY AREAS

TECHNOLOGY ISSUES	GENERIC MISSION CATEGORIES		
CRITERIA	PLANETARY	GEO	LEO
WEIGHT	• MOST CRITICAL	• CRITICAL	• LEAST CRITICAL
OPERATION OR MAINTENANCE	• HI AUTONOMY DEMAND • EXPERT SYSTEM DRIVER • ALLOCATE FUNCTION TO SOFTWARE	• REDUCE GROUND DEPENDENCY • SMART SOFTWARE FOR TELEOPERATION	• REDUCE GROUND DEPENDENCY • USE SOFTWARE TO RELIEVE MAN
DATA	• IN SPACE LINKS NEEDED	• INTERFERENCE FROM MULTIPLE USERS	• BANDWIDTH DRIVER • ON BOARD DATA REDUCTION REQUIRED
INTERFACES & STANDARDS	• NOT CRITICAL	• STANDARDS FOR SERVICING • ON - ORBIT MAINTENANCE STANDARDS	• MODULAR SUBSYSTEMS • MAN & MACHINE INTERFACE STANDARDS • ON - ORBIT MAINTENANCE STANDARDS

CHART 08
1 OF 2

CRITICAL TECHNOLOGY AREAS

TECHNOLOGY ISSUES	GENERIC MISSION CATEGORIES		
CRITERIA	PLANETARY	GEO	LEO
REPAIR	• SELF - REPAIR • TREND ANALYSIS	• TELEROBOTICS	• DESIGN TOOLS FOR SUPPORT ABILITY • MAN SUPERVISE / MACHINE DO
ENVIRONMENTS			
INDUCED	• AVIOD CONTAMINATION OF SUBJECT	• AVIOD CONTAMINATION OF INSTRUMENTS	• IN SITU SERVICING DOCKING CONTAMINATION • DEBRIS
NATURAL	• HI LOADS/ SOLAR AREA	• EMI	• MATERIALS / ATOMIC OXYGEN • POLAR PLASMA / EMI

CHART 08
2 OF 2

NATIONAL SPACE NEEDS

- LOW COST, RELIABLE TRANSPORTATION
  - SYSTEM COST DRIVER
- ORBITAL TEST PLATFORMS
  - ENABLE NEW TECHNOLOGY
  - VALIDATE ADVANCED TECHNOLOGY
- LOW COST, LONG LIFE SPACECRAFT
  - MODULAR STANDARD INTERFACES
  - AUTONOMOUS OPERATION
  - REPAIRABLE / SERVICEABLE

CHART 09

TEST BED UTILIZATION

TECHNOLOGY ENABLING	TECHNOLOGY ENHANCING
HEAT PIPE / THERMAL STORAGE	LARGE DIAMETER N_2 O_2 DIAPHRAMS
TETHERED POWER / PROPULSION EXPERIMENTS	ELECTRIC PROPULSION DEVICES
CONTROL OF LARGE STRUCTURES	ADVANCED BATTERIES
TELEROBOTICS DEMONSTRATIONS	ADVANCED STELLAR SENSORS (< 1 ARC SEC)
CONTAMINATION STUDIES	AUTONOMOUS SYSTEM DEMOS
CRITICAL CLEANING	NUCLEAR POWER SUPPLY HANDLING
ENVIRONMENTAL INTERACTIONS	NEW SOLAR CELLS
TWO - PHASE FLUID PHENOMENA	HIGH POWER ELECTRICAL DISTRIBUTION & SWITCHING
CRYO REFRIGERATORS	

CHART 10

SPACECRAFT 2000 SYSTEM CHARACTERISTICS

- MODULAR CONSTRUCTION / STANDARD INTERFACES
  - INTERCHANGEABLE / REPAIRABLE
  - UPGRADEABLE
  - DEVELOPMENT COSTS REDUCED
- AUTONOMOUS SYSTEMS
  - REDUCED OPERATIONS COSTS
  - FAULT DETECTION / ISOLATION
  - RECONFIGURATION
  - REDUCED DATA LINK LOADS
- REPAIRABLE / SERVICEABLE SUBSYSTEMS
  - INCREASED SPACECRAFT LIFE
  - REDUCED CONSUMABLES MASS
  - RECONFIGURABLE HARDWARE

CHART 11

RECOMMENDATIONS & BENEFITS

DEVELOP SYSTEM LEVEL ANALYSIS TOOLS FOR SUBSYSTEM TECHNOLOGY ASSESSMENT

- EARLIEST IDENTIFICATION OF THE HIGHEST PERFORMANCE AND COST BENEFITS

DEVELOP A FLEXIBLE, MULTIDISCIPLINARY ORBITAL TEST BED CAPABILITY

- TECHNOLOGY RISK REDUCTION
- INSTILL NEW MOMENTUM IN TECHNOLOGY DEVELOPMENT
- ENCOURAGE COMMERICAL VIABILITY
- PROVIDE UNITED STATES SPACE TECHNOLOGY LEADERSHIP

CHART 12