INTRODUCTION: THE CHALLENGE OF OPTIMUM INTEGRATION OF PROPULSION SYSTEMS AND LARGE SPACE STRUCTURES

Richard F. Carlisle
NASA Headquarters

The integration of propulsion systems and large space structures systems will result in an optimum spacecraft system design that will provide an improved facility and resources to an on-board payload designed to meet mission requirements. Characteristics of each system will be discussed and technology challenges will be identified.

Introduction

The Spacecraft Systems Office's goal, Figure 1, is to define and implement new technology tasks that will provide cost effective operational spacecraft for the 1990's that meet new challenging mission performance requirements at an affordable reduced cost. The office addresses three classes of spacecraft: large space systems at Low Earth Orbit (LEO); advanced spacecraft at Geostationary Earth Orbit (GEO); and advanced planetary spacecraft. This paper discusses the integration of propulsion system and structure systems primarily at LEO and GEO and the transfer task from LEO to GEO.

The purpose of this meeting is to provide a technology exchange of the state-of-the-art and system characteristics of the two systems in question, that is propulsion and structures. It is envisioned that when we each have a better understanding of the design characteristic constraints and sensitivities of each other's technology, we will be able to offer ideas and suggestions of trade-offs that will benefit in an optimized integrated design, Figure 2.

This meeting will be successful if we can surface technology questions and/or concerns that result in challenges and action items for future consideration. Your attendence here today represents the experts in the industry in these two disciplines.

I charge each of you to be attentive and give it your best for two days and make this technology exchange a practical contribution that will result in better, lower cost spacecraft to meet the requirements of future challenging missions at affordable cost.

Integrated Propulsion and Structures Sub-System Functional Matrix (Figure 3)

The most significant external disturbance of a large space system in low earth orbit is aerodynamic drag that must be compensated for by some type of mass expulsion actuator. Aerodynamic drag predominates at altitudes below approximately 140-160 miles depending on the size and spacecraft configuration. The Shuttle has difficulty in carrying large spacecraft into high orbits. If it is desired to operate at say 200-240 miles a popular technique is to deploy the structure at a more convenient lower orbit and provide enough propulsion on board the spacecraft so that the spacecraft engines can put the spacecraft into a higher orbit.

The above scenario says if a spacecraft is of a given configuration and size it must have propulsion on board. This propulsion is required to provide multi burn, low thrust performance over many starts and stops for a long operational life. A major question then is, if this propulsion is on board as part of the spacecraft design what other requirements should be imposed on this system? If the spacecraft can provide for its own orbit maintenance and/or maneuvers, it can eliminate the need of the support of a costly transportation vehicle.

Figure 3 shows a functional matrix of possible propulsion system characteristics for a spacecraft for deployable and assembled spacecraft structures. The matrix shows that either electric propulsion or low thrust chemical propulsion systems could provide the propulsion required. The figure shows the trade-off considerations of a single propulsion engine or multi-engines. The figure illustrates that a single point engine is bounded by some upper limit of thrust for assembled spacecraft. The matrix also shows several additional functions that can be provided to the spacecraft if a propulsion system is an integral part of the spacecraft. For example, one may not include a propulsion system to a spacecraft design for momentum dump, however, if there is a propulsion system on board for stationkeeping or orbital maintenance it may well be used also for momentum dump. A careful review of all of the functions that can be provided for a spacecraft by an integral propulsion system may result in the inclusion of the propulsion for several functions even if no single function were mandatory.

The next figure (Figure 4) shows propulsion interface issues for each combination of engines discussed in the previous chart (function matrix Figure 3). A single engine has a single loading point into the structure that requires load carrying members into the structure from a hard point mechanical interface. Low thrust engines may excite structural dynamics that result in negative forces at the engine. This interaction represents an engine design constraint derived from the structural dynamics. In turn the propulsion dynamics must be compatible with structural dynamics or the engine may excite structural transients during engine starting and stopping.

Multiple engines introduce additional interface issue specifically relative to the sensing tolerance of the multiple engine dynamics. If engine starts are out of sync unpredicted structural response between engines could occur.

The next figure (Figure 5) illustrates advantages of each alternate propulsion configuration.

FIGURE 1 SPACECRAFT SYSTEMS

GOAL

- DEVELOP SUBSYSTEM TECHNOLOGIES FOR OPERATIONAL SPACECRAFT AND SPACE OPERATIONS FOR THE 1990'S

  - INCREASE CAPABILITIES
  - DECREASE COSTS

FIGURE 1 (Concluded) OAST LARGE SPACE SYSTEMS PROGRAM ELEMENTS AND RELATIONSHIP

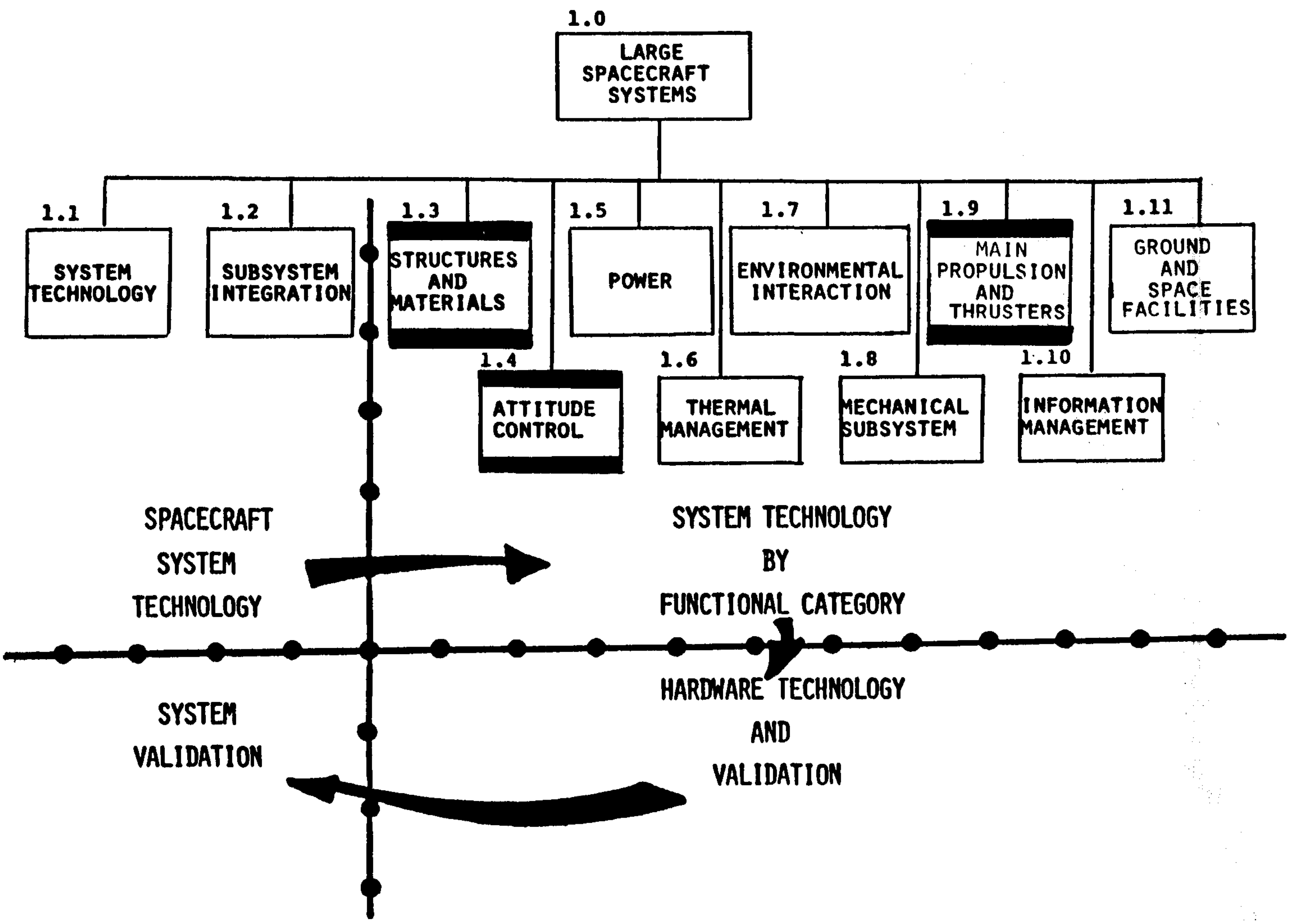

FIGURE 2 SPACECRAFT SYSTEMS OFFICE/LARGE SPACE SYSTEMS

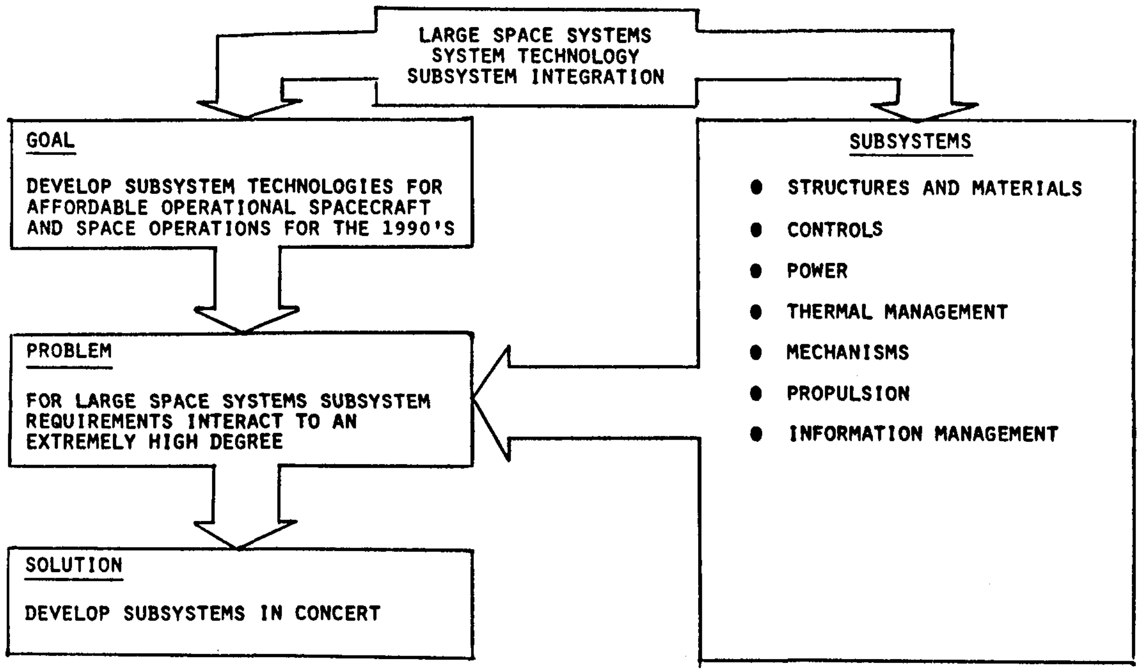

FIGURE 2 (Concluded) SPACECRAFT SYSTEMS OFFICE/LARGE SPACE SYSTEMS

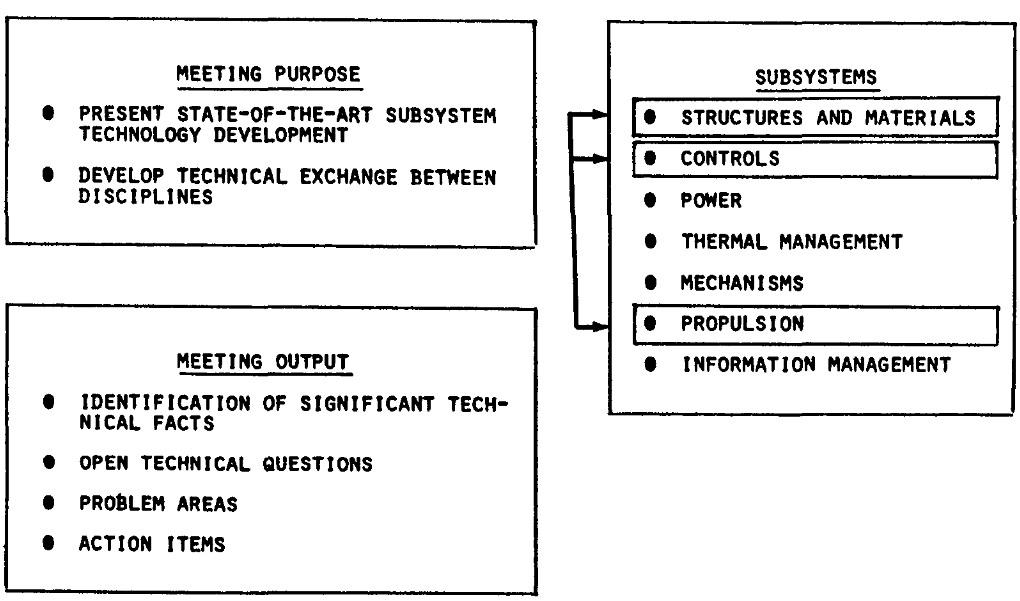

FIGURE 3 INTEGRATED PROPULSION AND STRUCTURES SUBSYSTEM FUNCTIONAL MATRIX*

STRUCTURES SUBSYSTEM

(INCREASING SIZE →)

MAIN PROPULSION AND THRUSTER SUBSYSTEM (INCREASING THRUST LEVEL ↓)

		DEPLOYABLE	ASSEMBLED	
ELECTRIC PROPULSION	SINGLE POINT	• ORBIT TRANSFER LEO TO HEO, AND LEO TO GEO IN PACKAGED OR DEPLOYED STATE • STATIONKEEPING AT LEO HEO, AND GEO	SAME ASSEMBLED	←SIZE/THRUST LIMIT
LOW THRUST CHEMICAL	MULTI-POINT	• ORBIT TRANSFER LEO TO HEO AND LEO TO GEO IN DEPLOYED STATE	SAME IN ASSEMBLED STATE	
		• STATIONKEEPING • ATTITUDE CONTROL, STABILITY AND POINTING • FIGURE CONTROL • MOMENTUM DUMP • END OF LIFE DISPOSAL	SAME	
IUS SUSS A/D	SINGLE POINT	• ORBIT TRANSFER LEO TO HEO AND LEO TO GEO IN PACKAGED STATE		

* TELEOPERATOR RENDEZVOUS FUNCTIONS OMITTED

FIGURE 4 INTEGRATED PROPULSION AND STRUCTURES SUBSYSTEM INTERFACE ISSUE MATRIX

STRUCTURES SUBSYSTEM

(INCREASING SIZE →)

MAIN PROPULSION AND THRUSTER SUBSYSTEMS (INCREASING THRUST LEVEL ↓)

		DEPLOYABLE	ASSEMBLED	
ELECTRIC PROPULSION	SINGLE POINT	• SINGLE LOAD PATH INTO DEPLOYED STRUCTURE • NEGATIVE ACCELERATION INTO PROPULSION SYSTEMS THROUGH LOW FREQUENCY STRUCTURAL VIBRATION • EXCITATION OF LOW FREQUENCY STRUCTURES	SAME ASSEMBLED	←SIZE/THRUST LIMIT
LOW THRUST CHEMICAL	MULTI-POINT	• INTEGRATION OF PROPULSION SUBSYSTEM ELEMENTS WITH STRUCTURES E.G., EITHER WITH COMMON ELEMENTS SUCH AS A PROPELLANT FUEL TANK OR AS COMPLETELY SEPARATE MODULAR ENGINE OR BOTH		
		• CONTROL AND RELIABILITY OF PROPULSION SYSTEM DURING LEO TO HEO AND LEO TO GEO ORBIT TRANSFER • PROPULSION UNITS UNDER VARYING NON UNIFORM ACCELERATION FROM LOW FREQUENCY STRUCTURAL VIBRATION • EXCITATION OF STRUCTURAL NATURAL FREQUENCIES	SAME	
SUSS A/D IUS	SINGLE POINT	• REMOTE DEPLOYMENT RELIABILITY		

FIGURE 5 INTEGRATED PROPULSION AND STRUCTURES SUBSYSTEM INTERFACE ADVANTAGE MATRIX

STRUCTURAL SUBSYSTEM

(INCREASING SIZE ⟶)

MAIN PROPULSION AND THRUSTER SUBSYSTEMS (INCREASING THRUST LEVEL ↓)

		DEPLOYABLE	ASSEMBLED
ELECTRIC PROPULSION	SINGLE POINT	• SIMPLIER PROPULSION AND STRUCTURES SUBSYSTEM INTEGRATION AND ANALYSIS	SAME; ← SIZE/THRUST LIMIT
LOW THRUST CHEMICAL	MULTI-POINT	• MULTIPLE LOAD CARRYING PATHS INTO DEPLOYED STRUCTURE • PERFORM MULTIPLE FUNCTIONS, E.G., ORBIT TRANSFER AND ATTITUDE CONTROL, AND STABILIZATION	• INTEGRATION OF PROPULSION SUBSYSTEM WITH EITHER COMMON ELEMENTS OR COMPLETELY SEPARATE MODULES WITH STRUCTURAL SUBSYSTEM SAME ASSEMBLED
SUSS A/D IUS	SINGLE POINT	• EXISTING HARDWARE • RAPID TRANSIT TIME	