SPACE SHUTTLE AUXILIARY PROPULSION TECHNOLOGY REQUIREMENTS

Keith D. Coates

NASA Marshall Space Flight Center
Huntsville, Alabama

The presentation will cover a definition of two basic terms used in this presentation, a discussion of characteristics of typical system candidates, a comparison of propulsion systems utilizing oxygen and hydrogen as propellants with the Space Shuttle Auxiliary Propulsion System (APS) requirements, a discussion of the areas of greatest technological concern, and a summary.

INTRODUCTION

In order for everyone to more properly understand the objective of this paper, a definition of two major terms is required. "Technology" is a term which enjoys wide usage but implies different things to different people. This presentation will use the term as "systematic knowledge" in a review of several areas of a Space Shuttle APS. The term "auxiliary propulsion" is used at the Marshall Space Flight Center to include propulsion systems other than the vehicle primary (main engine) propulsion system. However, technology requirements for air-breathing engines will not be covered since it will be discussed in another part of the session.

Two types of O_2/H_2 propulsion systems have been proposed for the shuttle application. Basically, the candidates are systems that utilize either high chamber pressure ($>$100 psia) engines or low chamber pressure ($<$100 psia) engines. Each type of system has several alternatives that must be evaluated against the necessary criteria before a meaningful system choice can be made. Likewise each type system has its advantages and disadvantages. No attempt will be made to choose one type system over the other but an effort will be made to note those areas of each which seem to be most critical insofar as the requirement for more "systematic knowledge" is concerned.

INTRODUCTION

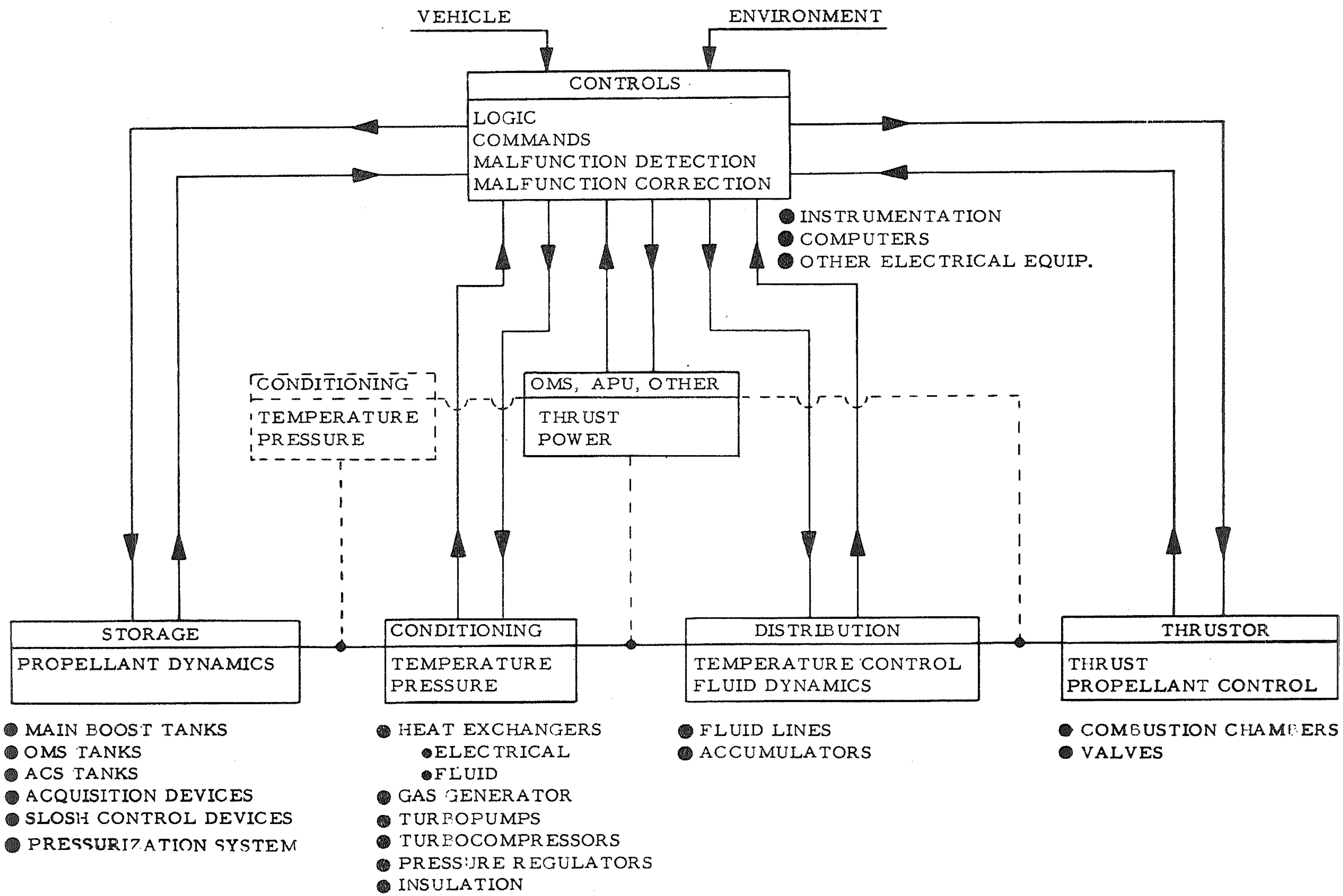
- DEFINITIONS
  - TECHNOLOGY - (1) INDUSTRIAL SCIENCE; SYSTEMATIC KNOWLEDGE OF THE INDUSTRIAL ARTS.
    (2) TERMINOLOGY USED IN ARTS, SCIENCES OR THE LIKE.
    (3) APPLIED SCIENCE.
  - AUXILIARY PROPULSION - PROPULSION SYSTEMS OTHER THAN PRIMARY. (DOES NOT INCLUDE AIR BREATHING ENGINE FOR THIS PRESENTATION)

- SYSTEM CANDIDATES
  - HIGH PRESSURE - ACS, OMS, OTHER
  - LOW PRESSURE - ACS, OTHER (OMS?)

SYSTEM CANDIDATES

Both the high and low pressure systems perform essentially the same functions, i.e. store propellant, condition it to the proper state, distribute it to the thrustor inlets while maintaining the proper state, and accelerate the fluids by the combustion process through the thrustors. The means by which these functions can be accomplished determine the best system to meet the mission requirements. Thus the hardware required to fulfill the functions is the problem at hand. The uniqueness of the Space Shuttle Vehicle (i.e. reusability, long life, reliability, low cost) imposes a different type of APS hardware requirements than those associated with rocket propulsion of the past. Active use of system conditioning measurements (i.e. temperature, pressure) for closed loop control of the subsystems is an example of an area which has not been fully addressed by rocket propulsion personnel in the past. Controls will cause a much larger impact in future auxiliary propulsion systems design. Integration of the functions of the OWS, APS, APU, and other potential O_2/H_2 users offers the potential of significant advantages in overall vehicle reliability, weight, cost (common components), and development testing.

SYSTEM CANDIDATES



O_2/H_2 PROPULSION EXPERIENCE

A summary of some general characteristics of propulsion systems that are state of art and other experience that has some applicability is shown in the Chart. It is noted that all flight propulsion systems have utilized liquid cryogenic propellant pumped to a high pressure before being burned in the thrust chamber. Space Shuttle requirements which are apparently significantly different from past requirements are: (1) the number of starts, (2) operational run life, (3) state of the propellant (gas/liquid) at the thrustor inlet, and (4) maintainability. Even though the experience gained by the NASA and aerospace industry in cryogenic propulsion systems is extensive for the flight systems, the items of difference represent design requirements which are very difficult to fulfill in many instances. It should be noted that the operating pressure column gives the end to end pressure for the system (i.e. storage tank/thrust chamber pressure).

The S-IVB Helium Heater is actually a heat exchanger/gas generator pressurization device and not a propulsion system. However, the experience gained in areas such as ignition, cooling, and heat transfer should be useful. The Cryogenic Auxiliary Propulsion System (CAPS) experience at Rocketdyne and TRW represents the extent of NASA contracted gas/gas thrustor work. Industry has performed several studies and conducted some tests during the past five years in an attempt to define an O_2/H_2 APS. However, the efforts have been too small to provide any significant advancements.

O_2/H_2 PROPULSION SYSTEM EXPERIENCE

SYSTEM		PROPELLANT CONDITION	OPERATION RUN LIFE	INFLIGHT STARTS	OPERATING PRESS (PSIA)	TURBOPUMP	IMPULSE/ MISSION (#-SEC)	THRUST/ ENGINE (LB_f)	MAIN-TAINABLE
CENTAUR		LIQUID	HOURS	2	15/300	YES	10^7	15,000	NO
S-IV		LIQUID	MINUTES	1	15/300	YES	4.5×10^7	15,000	NO
S-IVB	STAGE	LIQUID	HOURS	2	27/780	YES	10^8	200,000	NO
	He HTR	LIQUID	HOURS	4,000(QUAL)	25	NO	—	25	NO
S-II		LIQUID	MINUTES	1	27/780	YES	4×10^8	200,000	NO
CAPS	NAR	GAS	—	MULTIPLE	10	—	—	20	NO
	TRW	GAS	—	MULTIPLE	10	—	—	20	NO
INDUSTRY		MATERIALS, INSULATION, ENGINES, PROPELLANT CONTROL, ETC.							
STUDIES		CENTAUR APS, S-IVB APS, ETC.							
SHUTTLE APS		GAS	MONTHS	10^6	15/1000	NO/YES	1.5×10^7	500/5,000	YES

IDENTIFICATION OF CRITICAL TECHNOLOGIES

After reviewing "what is the job?" and "what has been done previously?", areas which require that more "systematic knowledge" be made available can be identified. The object of any hardware is to provide a required function. To select hardware, certain criteria must be assessed in terms of relative importance. Some criteria will govern the design of one component more than another. The ultimate criteria which seems to always be the hardest to define is cost and cannot be disassociated from any of the other criteria.

After assessing the importance of the criteria, one must determine the alternatives to meeting those requirements. Long life may be met by redundant components, replaceable or repairable components. If weight or other criteria does not allow this, a new development program may be required. The state of the Space Shuttle APS presently is such that the criteria and alternative have not been thoroughly defined nor evaluated. Preliminary requirements indicate some areas that are deficient in their capability to meet the Space Shuttle objectives.

IDENTIFICATION OF CRITICAL TECHNOLOGIES

- CRITERIA
  - OPERATIONAL RUN LIFE
  - ENVIRONMENT
  - NO. OF STARTS
  - SUB-SYSTEM INTEGRATION
  - VEHICLE INTERFACE - STRUCTURAL, THERMAL, ELECTRICAL
  - WEIGHT (PERFORMANCE)
  - GROUND OPERATIONS
  - DEVELOPMENT STATUS

- ALTERNATIVES
  - SYSTEM DESIGN - ASSIGN FUNCTION TO OTHER COMPONENT
  - MULTIPLE COMPONENTS
  - REPLACEABLE COMPONENTS
  - REPAIRABLE COMPONENTS
  - NEW DEVELOPMENT

IDENTIFICATION OF CRITICAL TECHNOLOGIES (CONT'D)

The Space Shuttle Vehicle may require up to 30 engines or more to meet basic mission needs. Requirements for many starts and low leakage dictate that new valves must be developed. O_2/H_2 engines capable of providing low impulse bits ($\approx$50 lb-sec) require fast response from the large gaseous propellant valves.

Reliable ignition of gaseous O_2/H_2 many times causes concern. An item such as a spark plug igniter might be an excellent candidate for periodic replacement such as practiced in automobiles.

High performance and low weight are almost synonymous with high combustion temperatures. The temperatures in conjunction with quick response creates a cooling problem which must be evaluated.

Uncontrolled slosh or any movement of propellant masses within the propellant tanks will result in usage of attitude control propellant due to the induced disturbances. The location of the propellant within the propellant tanks and the resultant heat transfer impact due to the propellant being in contact or not being in contact with the tank walls in a zero "g" environment will impose a bigger requirement on the system which depends on utilization of primary vehicle residual boost or solar heat input as a source of energy. The acquisition of liquid propellant for turbopump operation is of concern primarily if many starts are required of the turbopump. The inability to create a zero "g" environment for long periods of time causes a lack of confidence in the proving of many designs until they are flown.

IDENTIFICATION OF CRITICAL TECHNOLOGIES (CONT'D)

	LP	HP
• **POTENTIAL CRITICAL AREAS**		
• ENGINES	✓	✓
• VALVES CAPABILITY TO MEET NO. OF STARTS WITHOUT LEAKAGE OR FAILURE TO OPERATE WITH QUICK RESPONSE	X	X
• IGNITION CONCEPT FOR MANY STARTS	X	X
• COOLING TECHNIQUE FOR HIGH PERFORMANCE ENGINE CAPABLE OF QUICK RESPONSE	X	X
• PROPELLANT CONTROL	✓	✓
• SLOSH EFFECT ON VEHICLE CONTROL DYNAMICS	X	X
• LOCATION OF PROPELLANT IN TANK IN ZERO "G" (EFFECT ON HEAT TRANSFER)	X	
• ACQUISITION OF LIQUID PROPELLANT FOR TURBOPUMP OPERATION		X
• DEMONSTRATION OF ZERO "G" EFFECTS IN TEST PROGRAM	X	X

IDENTIFICATION OF CRITICAL TECHNOLOGIES (CONT'D)

Separate from the problem of being able to control heat transfer in a zero "g" environment is the problem of favorably (i.e. use environment advantageously) isolating the propulsion system. Tanks, lines, heat exchangers and other parts of the system should be capable of operating in the expected thermal and vacuum environment which requires the use of high performance insulating (HPI). Susceptibility of HPI to physical damage, moisture, and contamination warrants it to be a major concern.

The heat exchanger sizes dictated by requirements of cycle life, response, and efficiency do not exist in the O_2/H_2 stable of components. The magnitude of the requirements indicates that significant knowledge must be gained before a suitable heat exchanger will be available.

The area of turbopumps/turbocompressors is of concern especially in the system in which the pump or compressor must undergo many starts. The run life of these components is nearly the same if a high pressure OWS is assumed with a low pressure ACS. Thus the problem of bearing life, seal life, etc. would exist for either concept. The power required to operate either a turbopump or compressor represents an inefficient use of propellant and is a candidate for improvement in efficiency.

Other areas of concern are system interactions (i.e. effect of operation of one component on another), subsystems integration, (i.e. different requirements of propellant conditions, etc.) and closed loop controls.

IDENTIFICATION OF CRITICAL TECHNOLOGIES (CONT'D)

	LP	HP
• POTENTIAL CRITICAL AREAS		
• THERMAL CONTROL	✓	
• INSULATION SUSCEPTIBILITY TO PHYSICAL DAMAGE, MOISTURE, CONTAMINATION	X	
• HEAT EXCHANGER CYCLE LIFE, RESPONSE, AND EFFICIENCY	X	X
• TURBOPUMPS/TURBOCOMPRESSORS		✓
• RUN LIFE OF BEARINGS, TURBINE BLADES, ETC.	X(OMS)	X
• START TRANSIENT EFFECTS ASSOCIATED WITH MANY STARTS		X
• POWER REQUIRED FOR OPERATION		X
• OTHER	✓	✓
• SYSTEM INTERACTIONS	X	X
• SUBSYSTEMS INTEGRATION	X	X
• CONTROLS	X	X

SUMMATION

After a review of the anticipated most critical areas required for design of an APS for the Space Shuttle, the conclusion is that existing technology is not adequate. Also, it can be stated that new technology is required regardless of the choice of a high or low pressure APS. However, with the O_2/H_2 propulsion systems base existing within the NASA and industry and with the required time and funds made available, the areas of concern only represent interesting engineering problems and not impossible dreams.