CRYOGEN SYSTEMS HARDWARE TECHNOLOGY REVIEW FOR THE SPACE SHUTTLE

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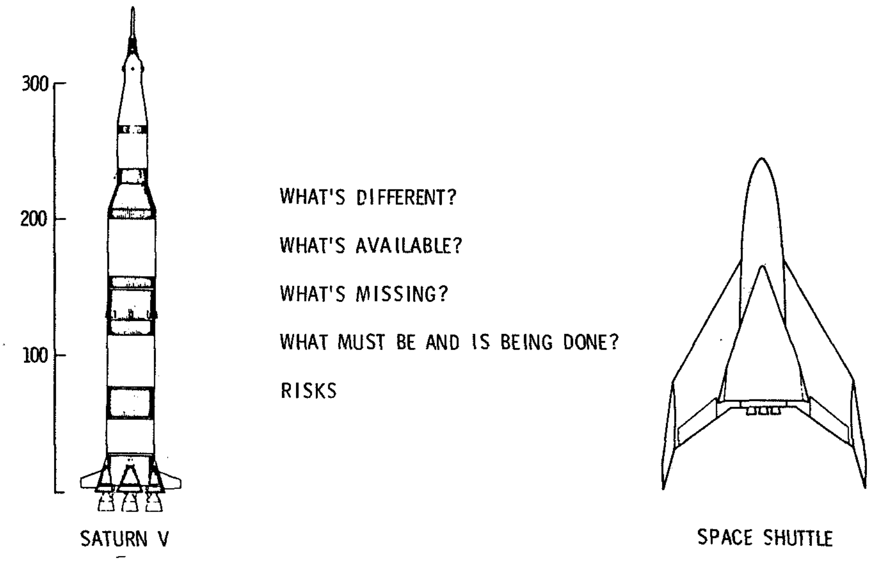
INTRODUCTION

The technical portions of the space shuttle Phase B studies presently being conducted by several major contractors, as well as on-going or proposed related systems studies, concern themselves with vehicle preliminary designs, conceptual studies, tradeoffs and optimizations, with emphasis on the systems and their technologies. Little effort can, and is, currently being devoted to a systematic appraisal of the availability, state of the art, and required technologies for specific pieces of hardware in these various systems. This evaluation concerns itself with the hardware required for shuttle cryogenic systems. It will be postulated that certain of the current - mainly Saturn V - designs and design concepts appear to be basically suitable to fill some of the needs, while for others potentially serious technology voids may exist. To remedy the latter, effective utilization of available lead time is urged, and recommendations are presented.

During the contacts with a number of Saturn cryogenic hardware suppliers and users, opinions about the scope of technology deficiencies varied widely. However, rather uniform agreement was noted with the conclusion that diligence and ideas, rather than breakthroughs, will be required for successful design and development of reliable shuttle hardware.

Mainly as the result of a consensus of expert opinion than of a systematic study, it is expected that the more serious technology voids will be with the cryogenic hardware required for the main propulsion systems, because of problems caused by their size, in combination with substantially more demanding performance requirements. Emphasis, therefore, will be placed on these components, within the confines of space and time allotted. However, reference will be made as needed to the other propulsion systems. The bulk of the discussion concerns itself with feed system valves and ducting, and with tank pressure regulation and vent components. Peripheral cryogenic hardware will be touched upon, or at least identified for future attention.

To reliably identify cryogenic hardware technology voids, an understanding is needed of the differences between the conditions to which components that were successfully used on current launch systems are qualified, and those conditions that components needed for the shuttle will have to meet. This must be the first step. Unfortunately, the information currently available is incomplete, and opinions vary over a wide range. The assumptions made for this survey, therefore, must be considered best guesses, based on currently available information. With this reservation, they do provide a guide to create a feeling for what is available, or may be available, and what is missing and which, therefore, requires action. Whatever these identified actions are, they entail risks that must be taken into account through alternate contingency plans.



DEFINITION OF CRYOGENIC SYSTEMS HARDWARE

To establish a boundary for this discussion, the tabulation identifies those cryogenic components that are expected to be required regardless of which overall design for shuttle orbiter and booster is chosen. It further underscores the fact that almost exclusively, these are functional types that have been used extensively on current cryogenic systems. Within the time and space available, a preliminary assessment will be attempted for some of the foremost currently used (Saturn) components listed.

- ENCOMPASSES PROPELLANT FEED AND VEHICLE TANK LOADING AND PRESSURIZATION HARDWARE
- INCLUDES:

  VENT VALVES
  SHUTOFF VALVES (SUCH AS PREVALVES)
  FILL & DRAIN VALVES
  REGULATORS
  DISCONNECTS
  VACUUM JACKETED LINES
  CHECK VALVES
  SEALED JOINTS

- MAY INCLUDE:

  AUXILIARY GAS GENERATORS
  AUXILIARY TURBOPUMPS
  AUXILIARY HEAT EXCHANGERS
  PROPELLANT MANAGEMENT SYSTEM COMPONENTS
  PROPELLANT ACQUISITION AND THERMODYN. VENTING SYSTEM COMPONENTS
  SOLENOID VALVES, PRESSURE SWITCHES
  PROPELLANT RECIRCULATION SYSTEM COMPONENTS
  INSTRUMENTATION COMPONENTS

CRYOGENIC HARDWARE PERFORMANCE COMPARISON

Information on required cryogenic hardware cycle life, allowable leakage, and resistance to vibration effects is meager to unavailable. Estimates, where made, differ over a wide margin. The figures presented for expected average shuttle operational life are the author's best guesses. Where challenged, they are usually considered too low. The allowable shuttle component leak rates are dictated predominantly by orbiter needs to maintain internal tank pressure during stay in orbit. However, because of expected emphasis on common hardware use, several booster components would be similarly affected. The values quoted (assumed to be for nonvibrational environment) are more than an order of magnitude smaller than those specified for the Saturn S-II stage, as an example. These low rates, coupled with larger nominal component sizes, in several instances represent a major area of concern. Nothing reliable is known, nor will be known for some time, about the flight vibration characteristics to which the cryogenic hardware will be exposed. Even if it is assumed that these are not worse than those encountered on the Saturn stages, it leaves an awesome factor of two orders of magnitude for cumulative flight duration. This is another area of major concern.

The vibration durations listed for Saturn Component Qualification represent the total of sinusoidal sweep and dwell, and of random vibrations, in all axes. For the shuttle, the figures represent accumulated flight time only. How difficult the task will be will depend on the philosophies applied to shuttle component qualification testing.

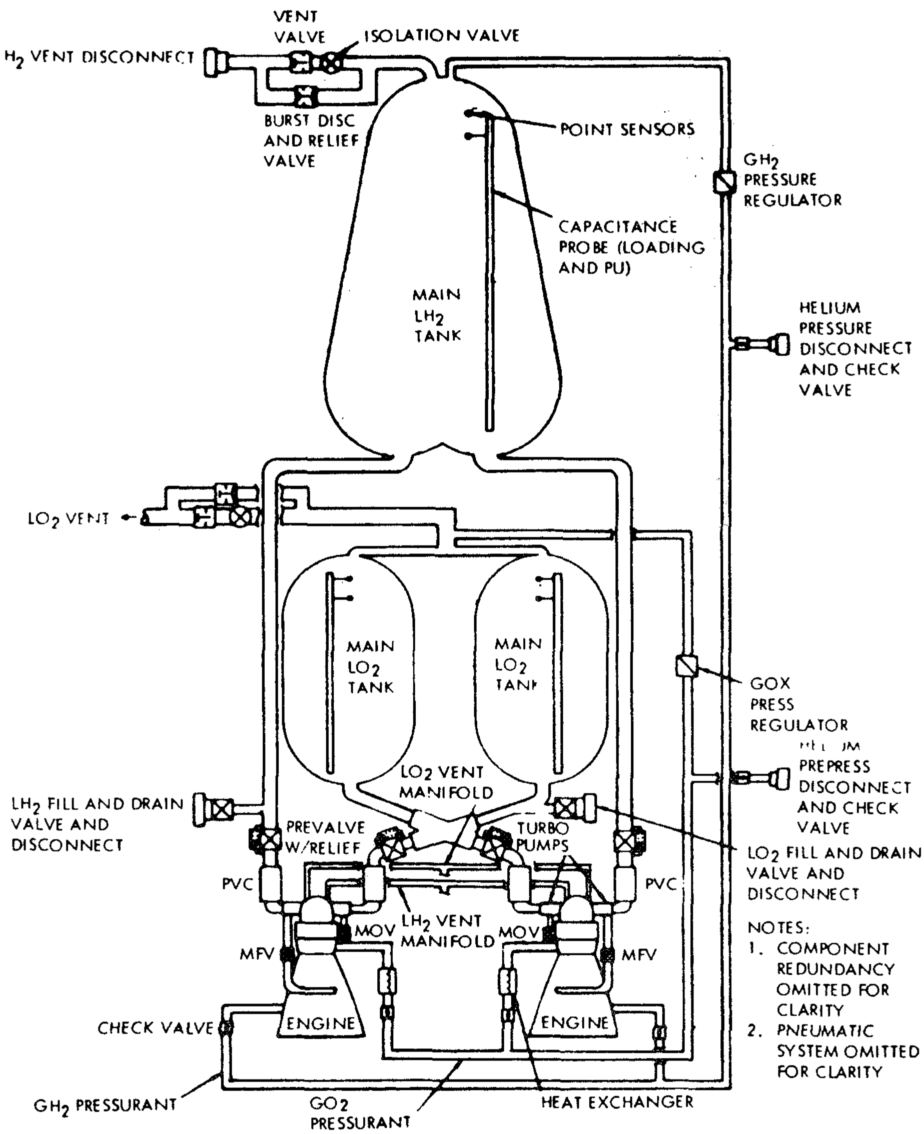
NOTES: 1 S-II powered flight time is six minutes
2 Leak rates not fully defined (gas type, pressure, temperature, vibration)

	"ORDER OF MAGNITUDE" ESTIMATED SHUTTLE REQUIREMENT				S-II ACTUALS		
COMPONENT	NOM SIZES (EST INCHES)	AVERAGE OPERATIONAL LIFE CYCLES (100 MISSIONS)	RECOMMENDED DESIGN LIFE CYCLES	MAX ALLOWABLE LEAK RATES (SCIM)	NOM SIZE (INCHES)	DESIGN LIFE CYCL	MAX ALLOWABLE LEAK RATES (SCIM)
VENT VALVES	7 (0) 10 (B)	5000	15000	10	7	600	500
PREVALVES	14	3000	10000	20	8	750	450
FILL & DRAIN VALVES	8 (0) 10 (B)	1000	3000	10	8	1000	1500
REGULATORS	2 TO 3	5000	15000	-	2.3	1500	-
DISCONNECTS (VENT; F&D; PRE-PRESS. ETC.)	1 TO 10	500	1500	-	1, 7, 8	-	APPROX 20 SCIM ACTUALS 1 IN. SIZE
CHECK VALVES	1/2 TO 2	1000	3000	5	1/4 to 1-1/2	1500	100
FEED LINES	14 TO 16		100 MISSIONS		8	1 MISSION	

VIBRATION REQUIREMENTS: UNDEFINED (COMPARATIVE CUMULATIVE SHUTTLE COMPONENT FLIGHT EXPOSURES OF 10 HOURS, VS 6 MINUTES ON SATURN V, MUST BE EXPECTED)

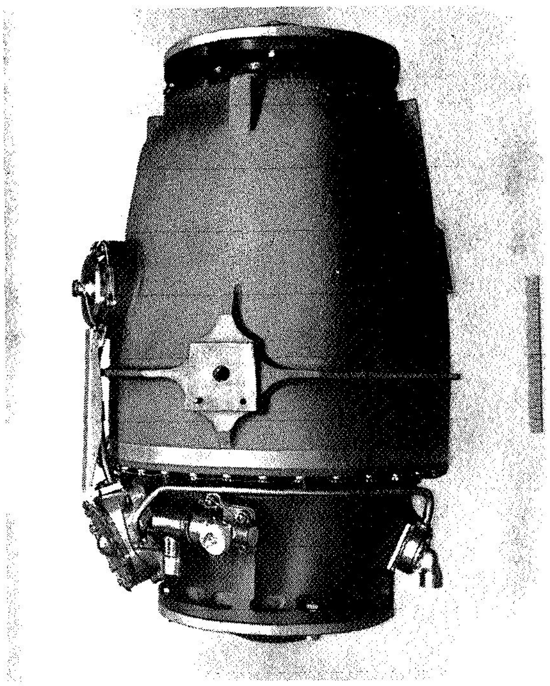
TYPICAL PROPOSED SHUTTLE MAIN PROPULSION SYSTEM SCHEMATIC

The schematic shown may be considered typical for both, orbiter and booster, except that the two would differ as to the number of engines and, depending upon which specific concept is being considered, the subdivision of propellant tankage and the required duct and line manifolding. In many respects, this functional diagram is also representative of the other (auxiliary) shuttle propulsion systems (booster and/or orbiter), except that the latter may include systems concepts such as are required for propellant storage and acquisition, ability to operate vertically and horizontally (air breathing system), and zero-g venting. These are not shown here. It is expected, however, that the success of these subsystems and concepts will depend more on systems technology than on the state-of-the-art of the hardware of which they will be composed.



7-INCH VENT & RELIEF VALVE

Requirements for shuttle use in the areas shown are over an order of magnitude more stringent than for Saturn. S-II hardware condition following qualification is reported to have been excellent, suggesting a potential for increased life. Full achievement of shuttle requirements without modifications and verification appears doubtful. Leak requirements may be unachievable and indicate the potential need for alternate systems solutions (such as in-orbit isolation valves). Improvements to achieve narrower vent bands and improved position indicators will require special attention.



DESIGN & PRODUCTION: AMETEK/CALMEC

USE: SATURN S-II, LH_2 & LOX

TYPE: POPPET

PRINCIPAL REQUIREMENTS:

PARAMETER	SATURN COMPONENT QUALIFICATION	ESTIMATED REQUIRED SHUTTLE DESIGN POINTS (0)
CYCLES	600 MINIMUM	15000
VIBRATION	5-1/2 HOURS	>10 HOURS
LEAKAGE	500 SCIM He	10 SCIM

STATUS: QUALIFIED FOR SATURN S-II

TECHNOLOGY ASSESSMENT:

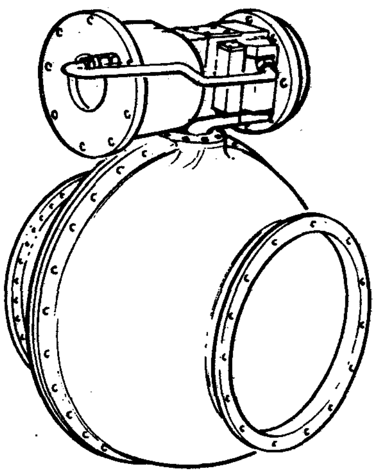
POTENTIAL CANDIDATE FOR SHUTTLE ORBITER

SCOPE OF ADDITIONAL DEVELOPMENT UNCERTAIN

(ENDURANCE LIMITS NOT EXPLORED)

10-INCH VENT & RELIEF VALVE

A better definition of booster in-flight (vibration) maximum allowable leak rates is required for a better assessment of the basic suitability of this valve for Space Shuttle use. It appears that cycle-life limits have not been explored.



DESIGN AND PRODUCTION: WHITTAKER

USE: SATURN S-IC

TYPE: VISOR

PRINCIPAL REQUIREMENTS:

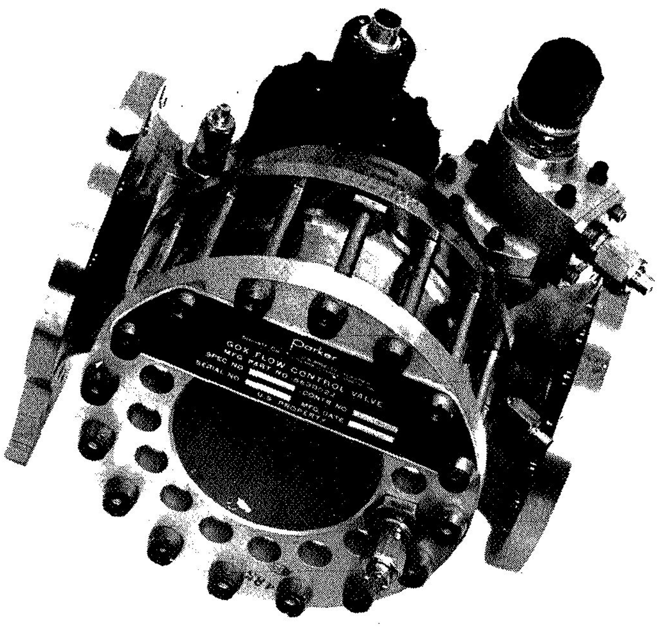
PARAMETER	SATURN COMPONENT QUALIFICATION	ESTIMATED REQUIRED SHUTTLE DESIGN POINTS (B)
CYCLES	1000	15000
VIBRATION	1.2 HOURS	10 HOURS
LEAKAGE	750 SCIM He	$\leqq$ 750 SCIM GH_2

STATUS: QUALIFIED FOR S-IC

TECHNOLOGY ASSESSMENT: POSSIBLE CONCEPT FOR PREVALVE BUT PROBABLY NOT FOR VENT VALVE

2.8-INCH REGULATOR

The regulator embodies a principle that has been successfully demonstrated in operational use. Those familiar with its performance believe that it is a strong candidate for booster use, subject to exploratory tests, modifications, and demonstration.



DESIGN & PRODUCTION: PARKER-HANNIFIN

USE: SATURN S-IC GOX

TYPE: BUTTERFLY/BELLOWS ACTUATOR

PRINCIPAL REQUIREMENTS:

PARAMETER	SATURN COMPONENT QUALIFICATION	ESTIMATED REQUIRED SHUTTLE DESIGN POINTS (B)
CYCLES	APPROX. 1500	15000
VIBRATION	2 HOURS	10 HOURS
LEAKAGE	NO SHUTOFF MODE	NO SHUTOFF MODE
CAPACITY LB/SEC	50 GOX	38-45 GOX; 19 GH_2 (MAX EST)

STATUS: QUALIFIED FOR SATURN S-IC

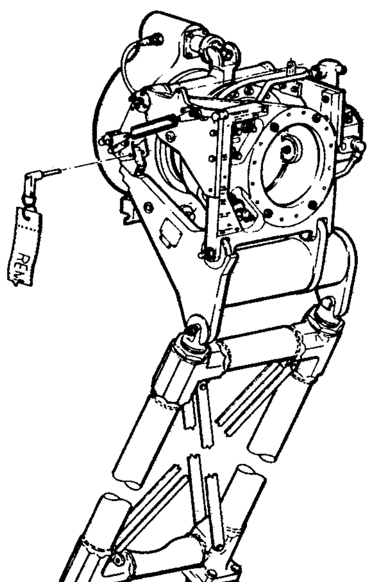
TECHNOLOGY ASSESSMENT:

PROMISING CANDIDATE FOR SHUTTLE BOOSTER, WITH LIMITED MODIFICATIONS, MAINLY FOR GH_2 USE

In the design shown, the airborne half essentially consists of the mating ring with sealing surfaces. All more complex parts of the coupling are ground-stationed. The current practice is to have the supplier refurbish the ground half, including its built-in butterfly shutoff valve, after every launch. This practice stems from the fact that it is exposed to copious amounts of launch pad cooling water, salty air and atmospheric moisture, essentially without protection downstream (outside) of the built-in valve. Also, sufficient time is available.

In the opinion of experts, the ground half would be reusable an indefinite number of times if it were adequately protected against the cited effects. Based on experience from Saturn and other launch vehicles, they believe this would be a matter of implementing such protection. This may include operational changes, angular attitude of disconnects, purges, doors. Similarly, the airborne half should be reusable as is, except that simple provisions for routine replacement of mating parts (especially the seal) may be the most economical way.

A number of smaller disconnects is in use on Saturn. These are also considered basically ready for shuttle use, if cleanliness and dryness are assured by proper means.



DESIGN & PRODUCTION: ROYAL INDUSTRIES

USE: SATURN S-II, LOX & LH_2

TYPE: BUTTERFLY (BUILT-IN GROUND VALVE)

PRINCIPAL REQUIREMENTS:

PARAMETER	SATURN COMPONENT QUALIFICATION	ESTIMATED REQUIRED SHUTTLE DESIGN POINTS
NOM SIZE	8 IN.	8 IN. (0); 10 IN. (B)
CYCLES (DISENG)	100	500
CYCLES (GR VALVE)	500	1500
VIBRATION	4 HOURS	10 HOURS
LEAKAGE (GR VALVE)	300 SCIM	300 SCIM
LEAKAGE (COUPLING)	60 SCIM	60 SCIM

STATUS: QUALIFIED FOR SATURN S-II

TECHNOLOGY ASSESSMENT:

BASICALLY READY FOR SHUTTLE USE, IF ADEQUATELY PROTECTED

PRINCIPAL AREAS OF CONCERN

In discussions with suppliers and users of current cryogenic systems hardware the principal areas of concern listed emerged. For vibration requirements, the concern was virtually unanimous. This may be attributed to the fact that a number of current cryogenic components had - sometimes substantial - difficulties in passing qualification, and that qualification specifications for the Space Shuttle may be vastly more stringent. Not much less concern is in evidence regarding leakage requirements, especially when viewed in combination with the vibration conditions, the increased life cycle requirements, and potential cumulative contamination. Lesser concern is voiced about the life-cycle numbers, the only areas in which shuttle data are cautiously predictable. It is believed that full utilization of current technology and meticulous attention to all details will solve life-cycle problems. It was noted that cryogenic components of comparable size are in successful operational use, although with less stringent requirements.

- VIBRATION ENVIRONMENT - MAJOR
- LOW LEAKAGE REQUIREMENTS - SERIOUS
- LIFE CYCLE REQUIREMENTS - MODERATE

EXTRAPOLATION TO OTHER SHUTTLE CRYOGENIC SYSTEMS HARDWARE

The hardware required for auxiliary shuttle propulsion systems, specifically the de-orbit, airbreathing, and attitude control systems, and as defined earlier, is expected to consist of components of smaller nominal size, compared to those for the main propulsion system. The smaller masses, smaller diameters, shorter sealing circumferences, and the smaller absolute contraction/expansion factors, among perhaps others, are expected to lessen some of the expected problems.

With this in mind, the cursory evaluation performed and the conclusions drawn here are largely applicable to this hardware. This does not include, however, technologies associated with systems concepts such as propellant storage, systems packaging (RCS), expulsion devices and the like.

Several successful operational systems (Centaur; S-IV; RL10, and J-2 Engines) should provide valuable experience for extrapolation to the Space Shuttle.

- THE GENERALLY SMALLER SIZES REQUIRED SUGGEST SMALLER PROBLEMS
- SPECIFIC AND GENERAL CONSIDERATIONS FOR MAIN PROPULSION SYSTEM CRYOGENIC COMPONENTS APPLY
- RECOMMENDATIONS AND CONCLUSIONS INCLUDE THIS HARDWARE
- REPRESENTATIVE EXPERIENCE EXISTS (CENTAUR, S-IV J-2, RL-10)

RISKS

Whatever is done or planned at this early stage, there are certain risks involved that will remain despite all careful planning and evaluating. The list shown probably is incomplete but may convey a feeling for potential risks that have actually been incurred and with which most agencies and contractors are well familiar.

- BELATED ATTENTION TO HARDWARE DETAIL -- "PANICS"
- ENVIRONMENTAL CONDITIONS SIGNIFICANTLY MORE SEVERE THAN EXPECTED
- DISCOVERY OF TECHNOLOGY DEFICIENCIES SIGNIFICANTLY LARGER THAN EXPECTED
- MAJOR LATE SYSTEMS CHANGES AFFECTING HARDWARE
- EXPERIENCED SUPPLIERS DEFUNCT OR UNWILLING TO BID
- LATE NEED TO SWITCH A SUPPLIER
- NEW PROCUREMENT PERSONNEL

RECOMMENDATIONS

In order to channel the thinking of those who will be responsible for generating the cryogenic hardware for Space Shuttle use in the right direction, to permit them to start thinking, and to open a channel for idea exchange, early, albeit conditional, definition of the most likely basic design and qualification requirements is urgently recommended.

For the optimum utilization of time and funding, early evaluation of design concepts that had been successful for past applications, notably Saturn, is advised. Similarly, experiments to uncover hidden unknowns should prove beneficial.

The availability of some of those suppliers who contributed quality hardware in the past appears to be uncertain in some instances. Since relearning and educating is known to be a costly process, early thought should be given to avoidance of problems.

Since unforeseen situations will arise as always, alternative routes to solve the most likely problems should be included in all planning efforts.

- "MAXIMUM RESULTS FOR MINIMUM $"

GENERAL

- FULL UTILIZATION OF VALUABLE TIME

SPECIFIC

- EARLY DEFINITION OF DESIGN AND QUALIFICATION PARAMETERS
- EARLY HARDWARE DESIGN STUDIES AND EXPERIMENTAL EVALUATION OF PROMISING CONCEPTS
- EXPERIMENTS TO IDENTIFY EARLY HIDDEN TECHNOLOGY DEFICIENCIES
- STEPS TO ASSURE AVAILABILITY OF EXPERIENCED AND PROVEN MANUFACTURERS
- ADEQUATE CONSIDERATION OF CONTINGENCIES