CRYOGEN TECHNOLOGY BASE FOR SPACE SHUTTLE

A. L. Worlund and T. W. Winstead

NASA Marshall Space Flight Center
Huntsville, Alabama

Introduction

The cryogen technology is multiple discipline technology with application to main propulsion, auxiliary propulsion, jet engine, life support, and auxiliary power systems of the Space Shuttle vehicle. The extensive technology base available to support cryogen utilization has been developed from ground base technology programs and the highly successful manned space flight programs. The technology base for the disciplines presented on chart 1 will be summarized and assessed to identify potential problem areas and technology deficiencies. Prelaunch and flight environments are discussed.

Discipline	Application			
	Ascent		Orbit	
	O_2	H_2	O_2	H_2
Stratification	X	X	X	X
Mixing	-	-	X	X
Thermal Conditioning				
- Geyser Suppression	X	-	-	-
- Quality Control	X	X	X	X
In-Space Venting	-	-	X	X
Pressurization	X	X	X	X
Mass Gauging	X	X	X	X
Tank Insulation	Discussed Individually			
Acquisition And Transfer				
Systems Integration				
Hardware				

Technology Status Categories

The technology status for concepts applicable to each discipline are categorized as being (1) adequate, (2) reasonable, or (3) insufficient information. Entries in the adequate category are judged to have sufficient data to support subsequent development, or to select baseline concepts for the anticipated environment. In the reasonable category, the available data is sufficient to initiate subsequent development with an acceptable risk. However, unresolved problems may exist. In the third category, insufficient information, limited or immature data preclude initiating subsequent development or consideration of baselining the concept with an acceptable risk.

Technology Status Categories

[1] Adequate	-	Available Data Are Sufficient To Support Subsequent Development, Select Baseline Concepts
[2] Reasonable	-	Available Data Are Sufficient To Initiate Subsequent Development With Acceptable Risks
[3] Insufficient Information	-	Limited Or Immature Background Data Precludes Baselining The Concept For The Anticipated Environment

Stratification and Mixing

Reliable predictions for propellant thermal stratification are essential to determine tank pressures needed to suppress boiling and to provide adequate pump net positive suction pressure. Semi-empirical analytical models based on Saturn and earlier launch vehicles are adequate to develop design criteria for the Space Shuttle ascent tanks. Additional confidence in the extrapolation of the models should result from the study presently in progress.[1]

The capability to pump saturated propellants at about 45 psia is indicated. Therefore, the primary influence of stratification in the on-orbit tanks will be the frequency of vent system cycling. Prediction methods for stratification in the on-orbit cryogen tanks are inadequate, and the available data are from small storage tanks and short duration orbital data from the S-IVB stage. However, the analytical models and limited data both indicate that tank pressure rise rates resulting from thermal stratification can be one to two orders of magnitude greater than for a "mixed" system. This characteristic can impose fundamental design penalties, since (1) the vent system component life cycles are increased, (2) a tank pressure collapse can occur when stratified propellants are mixed due to vehicle maneuvers, and (3) mass gauging techniques may be influenced.

The potential design impact of inadequate on-orbit tank stratification techniques can be minimized. Studies[2,3] have indicated that low-power mixers can preclude low-g stratification using state-of-the-art components. Axial mounted jet pumps appear to be optimum. The penalties for redundancy appear to be minimal, since the primary system cost or weight is in electrical power utilization.

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[1] Holmes, L. A., "The Development of Thermal Stratification and Destratification Scaling Concepts," Contract NAS8-24747 (In Process)

[2] Poth, L. J. et al, "A Study of Cryogenic Propellant Stratification Reduction Techniques," Final Report, Contract NAS8-20330, Nov. 1968

[3] Sterbentz, W. H., "Liquid Propellant Thermal Conditioning System," Interim Report, NAS3-7942, April 1967

Stratification And Mixing

	High Tank Heat Input		Low Tank Heat Input	
	High-G	Low-G	High-G	Low-G
Stratification	Industry [1]	Centaur S-IVB [2]	Industry [1]	Industry [3]
Mixing	-	-	-	MSFC/GDC LeRC/LMSC [1]

Key: Technology Status

[1] Adequate

[2] Reasonable

[3] Insufficient Information

Propellant Thermal Conditioning

Feedline geyser suppression and propellant quality control are two critical considerations to cryogen utilization for propulsion. A geyser results from the formation of a Taylor bubble in a line filled with boiling liquid. When the Taylor bubble fills a majority of the cross section of the line, it reduces the pressure on the fluid below, which feeds the Taylor bubble by flash boiling and "burps" fluid from the line. Geyser suppression is essential since the hydraulic forces produced during the refill of long vertical LOX lines can exceed design loads. For example, S-IC LOX feedline geysers resulted in pump inlet pressures approaching 1400 psi.

Preliminary design criteria for prelaunch conditioning of propellant feedlines has been established.[4] This geyser-nongeyser region correlation, developed for vertical feedlines, may require re-evaluation to establish utility for line configurations with significant horizontal runs or multiple branches.

Orbiter main-engine start requirements for propellant thermal conditioning are primarily to prevent vapor from forming in feed systems. The loss of acceleration head pressure at booster cutoff will cause propellant "flashing" if the feed system propellants are superheated at tank pressure. Vapors would then have to be ingested by the engine pumps during the engine start.

Propellant thermal conditioning systems used to suppress feedline geysers and control propellant quality are summarized on chart 4. These approaches may be applicable to the Shuttle vehicle. However, complex sequence schemes and single-point failure modes must be avoided. The natural recirculation system is the preferred concept for ascent propulsion. It results in minimum vehicle-facility interfaces, does not require active auxiliary components, and is relatively insensitive to stage configuration.

[4] Murphy, D. W., "Mechanics of Geysering of Cryogenics," Final Report, NAS8-5418, June 1964.

Propellant Thermal Conditioning

Concept	Geyser Suppression	Quality Control		Remarks
		Ascent	Restart	
Subcool Replenish	-	Atlas	-	Facility Constraints
Evaporative Cooling	-	S-IB S-IV	-	Limited Capability
Overboard Dump	-	S-IV Centaur	Centaur S-IVB (Contingency)	Payload Impact Complex Sequencing
Recirculation - Natural	S-IC	S-II (O_2) Atlas	-	Preferred Ascent Concept
- Forced	-	S-IVB S-II (H_2) Centaur	S-IVB Centaur	Auxiliary Systems Required

In-Space Venting

A vent system that exhausts only vapor is essential for propellant management of the tanks for on-orbit maneuvers. The S-IVB and Centaur stages employ positive acceleration to maintain settled propellants and to prevent liquid entrainment. Vent system designs that do not have to rely on vehicle acceleration enhance mission flexibility. The technology status of the primary methods investigated to ensure vapor venting from cryogen containers under in-space conditions are summarized in chart 5.

The heat exchanger/mixer is a preferred concept, based on demonstrated feasibility, system simplicity, performance in 100 percent liquid, weight, and a favorable system failure rate analysis. Prototype hydrogen systems have been successfully tested[5,6] in a 1-g environment, and the technology is readily adaptable to long term storage. An optimum system for in-space venting of LOX containers has not been defined. However, the heat exchanger/mixer concept appears to be applicable. Baseline consideration of this concept for LOX tank venting appears to be a reasonable development risk.

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[5] Stark, J. A., and Blatt, M. H., "Cryogenic Zero-Gravity Prototype Vent System," Final Report, Phase 2, Contract NAS8-20146, Oct. 1967

[6] Sterbentz, W. H., "Liquid Propellant Thermal Conditioning System," Final Report, NAS3-7942, August 1968

In-Space Venting

Concept	Feasibility Studies	Process Investigation	Subsystem Tests	Orbital Experiments	Operation Systems	Remarks
Vehicle Acceleration	Industry 1	Industry 1	Industry 1	AS-203 1	Saturn Centaur 1	Heavy
Hx/Mixer	Industry 1	MSFC/GDC LeRC/LMSC 2	MSFC/GDC LeRC/LMSC 2	None 2	None	Preferred Concept
Wall Hx	Industry 1	Industry 2	AF/MMC MSC 2	AS-203 2	None	Design Problems
Mechanical Separators	Industry 1	Industry 2	GDC 2	None	None	Inadequate
Dielectrophoresis	Industry 1	Industry 2	Industry 2	None	None	Design Problems

Key: Technology Status

1 Adequate
2 Reasonable
3 Insufficient Information

Tank Pressurization

Tank pressurization is required to suppress bulk boiling of propellants, to satisfy pump net positive suction pressure requirements, and to stabilize tank structure. The technology background within the industry is adequate for autogenous or helium pressurization, employing diffused gas techniques.[7,8] The thermal management studies of the on-orbit propellant systems are expected to indicate that saturated or low temperature pressurant is desired. This will be a unique application of pressurization technology, and may present some development problems. The available data on sub-surface pressurization techniques are limited to small tanks at one-g. This technology is immature for low-g applications.

Historically, extensive heat exchanger development has been required to assure performance and stability.[9] The theory developed for instability in cryogenic heat exchangers has emphasized supercritical fluids, and defined generalized corrective solutions. The generalized solutions are applicable as guidelines to new heat exchanger development programs.

The major considerations for pressurization of the Space Shuttle cryogen tanks will be to determine the most economical compromises between performance, flexibility, and maintainability. Studies to assess improvements in cost effectiveness of tank passivation are in process (NAS10-7258).

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[7]Nein, M. E., and Thompson, J. F., "Experimental and Analytical Studies of Cryogenic Propellant Tank Pressurant Requirements," NASA TN D-3177, February 1966

[8]Epstein, M., and Anderson, R. E., "An Equation for the Prediction of Cryogenic Pressurant Requirements for Axisymmetric Propellant Tanks," Cryogenic Engineering Conference, August 1967

[9]Friedly, J. C., Manganaro, J. L., and Kroeger, P. G., "Investigation of Thermally Induced Flow Oscillations in Cryogenic Heat Exchangers," General Electric Company, Final Report, NAS8-21045, October 1967

Tank Pressurization

Concept		High Tank Heat Input		Low Tank Heat Input	
		High-G	Low-G	High-G	Low-G
Diffused Gas	Small Tank	Industry [1]		Industry [1]	MSFC/MDAC [2]
	Large Tank	Titan Atlas Thor Centaur Saturn [1]	Centaur Saturn [1]	AF LeRC [1]	[2]
Sub-Surface (Bubbled)	Small Tank	-	-	LeRC AF MDAC [2]	[3]
	Large Tank	-	-	[2]	[3]

Key: Technology Status

[1] Adequate [2] Reasonable [3] Insufficient Information

Low-G Mass Gauging

The mass gauging of propellants in a zero-g environment is essential to provide operational flexibility. The technology base is inadequate to support baselining any of the primary candidate concepts summarized on chart 7. The potential advantages of the Radio Frequency and the Point Phase Detector systems are low weight and power input, and presents no hazards to personnel. However, these systems are immature. Capacitance concepts that require a wire matrix within the tanks are complex and may be limited to small tank applications. Nucleonic systems applicable to cryogens may require complex electrical networks and shielding. Also, studies indicate that system accuracy may be sensitive to orientation. The acoustical system is not applicable since it has been developed for non-cryogens and positive expulsion bladders.

The technology base is adequate for mass gauging systems required for loading and propellant utilization under one-g applications. However, improvements in maintenance and reliability are indicated.

Concept	Feasibility Studies	Development Test	Orbital Experiments	Operational Systems	Remarks
Radio Frequency	MSFC/Bendix [2]	Gov't/Bendix [3]	None	None	Immature; Low Weight And Power
Capacitance	MSFC/Tran-Sonic Simmonds [1]	MSFC/Tran-Sonic Simmonds [2]	AS-203 [2]	None	Complex Limited Application
Nucleonic	Industry [1]	Industry [2]	None	None	Complex; Sensitive To Orientation
Point Phase Detectors	MSFC [1]	MSFC/MPI MSFC [3]	None	None	Immature; Potential Mapping Technique
Acoustical	Industry [1]	AF/Acoustica [1]	Mol-HSQ (Non-Cryogen) [2]	None	Applicable To Positive Expulsion

Key: Technology Status [1] Adequate [2] Reasonable [3] Insufficient Information

Summary

The cryogen technology available to the Space Shuttle is more mature and comprehensive than that on which previous launch vehicles were designed and developed. The disciplines and flight application are summarized on chart 8. The data is sufficient to select baseline concepts with the following exceptions:

<u>Orbit Stratification</u> - Technology is inadequate due to wide range of analytical results and limited applicable data. Inadequate technology has no significant impact on Shuttle concepts since mixer implementation can negate requirement.

<u>Orbit Mass Gauging</u> - The concept evaluations in progress are immature. Additional technology development is required to provide the operational flexibility desired for the Space Shuttle.

Discipline	Application			
	Ascent		Orbit	
	O_2	H_2	O_2	H_2
Stratification	Adequate	Adequate	Inadequate	Inadequate
Mixing	-	-	Reasonable	Reasonable
Thermal Conditioning				
- Geyser Suppression	Adequate	-	-	-
- Quality Control	Adequate	Reasonable	Adequate	Adequate
In-Space Venting	-	-	Reasonable	Adequate
Pressurization	Adequate	Adequate	Adequate	Adequate
Mass Gauging	Adequate	Adequate	Inadequate	Inadequate