

History and Use of LH2 Cryogenic Storage and Transfer Systems at KSC

DOE/NASA Cryogenic Storage Workshop
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Agenda

- The Early Years – Mercury and Gemini
- The Apollo Program – the Dawn of Large Cryogenics Systems
 - Storage Systems
 - Vacuum Jacketed Transfer Systems
- The Space Shuttle Program – 30 years of Cryogenic Operations
 - Operations Overview



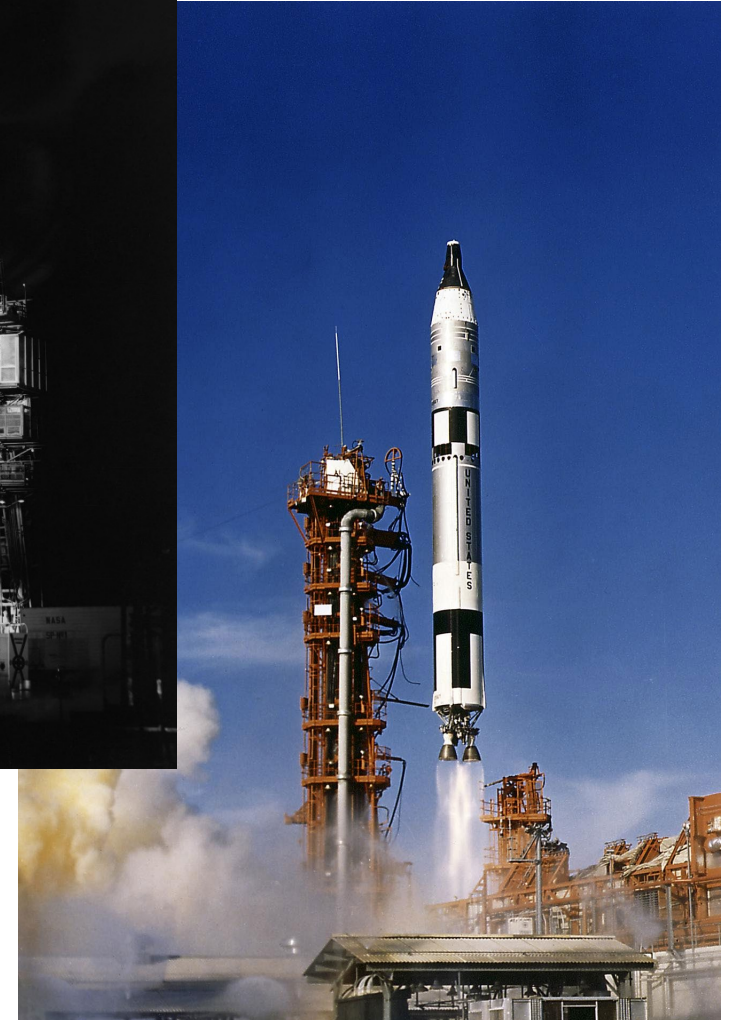
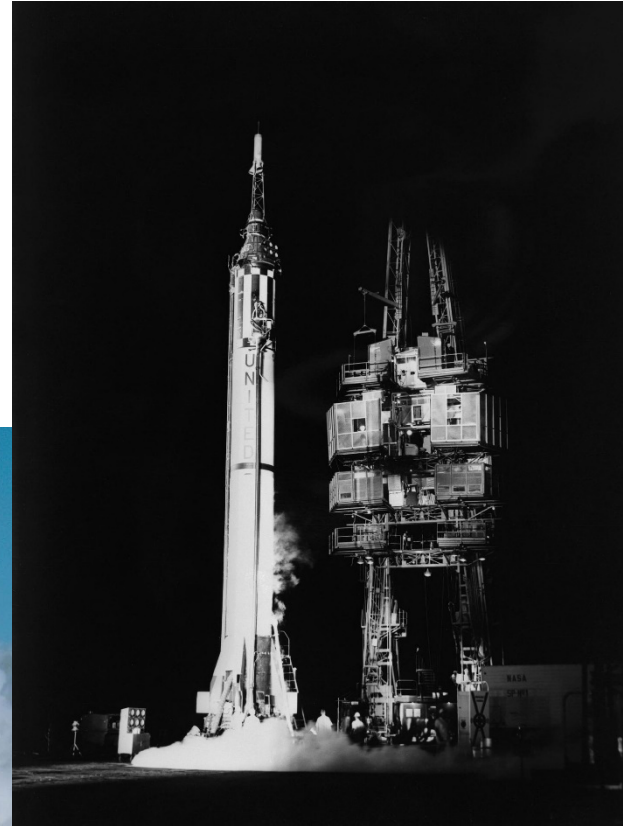
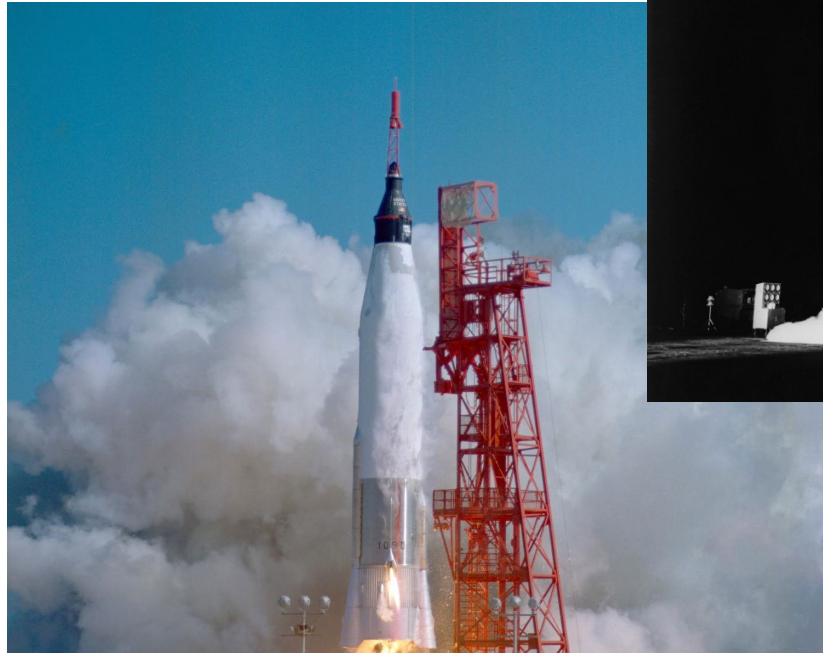
Mercury and Gemini

Mercury (Redstone and Atlas)

- LO2 and RP-1 Systems
- Sub-orbital and Orbital Missions
 - Getting a taste of Space
- Early days, LO2 loaded from tankers straight to launch vehicle

Gemini (Titan)

- Hypergolic Propellants



Apollo Space Launch Complexes 34 & 37

Saturn 1 and 1B First Stages

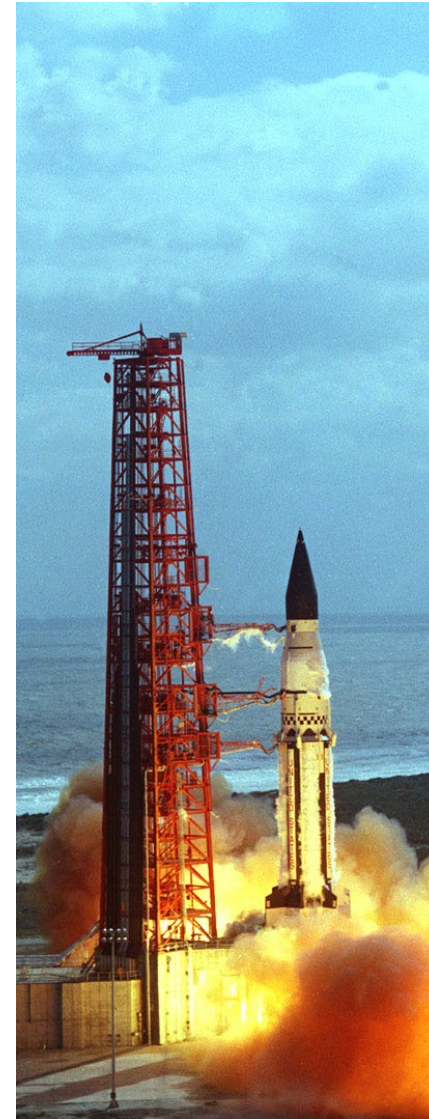
- LO2 and RP-1

Saturn IV and IVB Second Stages

- First use of LH2 on the second stage
- RL-10 Engines (Still in use today)



Image Credit: NASA Image Gallery



Apollo Launch Complex 39 Pads A & B

- Built in the early 1960's to support Saturn V rocket and the race to the Moon
 - 3 Stage Rocket (363' tall)
 - LO2/RP-1 1st Stage
 - LO2/LH2 2nd and 3rd Stages
 - 850,000 Gallon LH2 Storage
 - 10,000 GPM max flowrate
 - 900,000 Gallon LO2 Storage
 - 10,000 GPM max flowrate
- At the time, the largest Cryogenic Systems in the world.

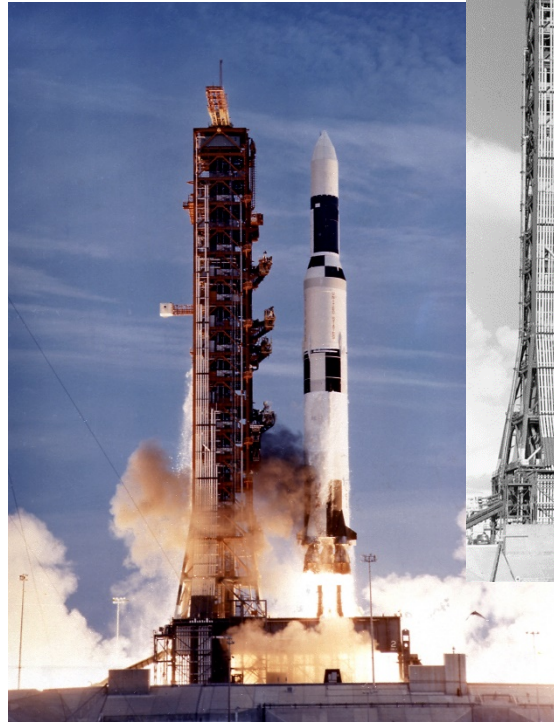


Apollo Launch Complex 39 Pads A & B

- 11 Moon Related Missions (1968-72)
 - 2 to LEO for Systems Checkout (7 & 9)
 - 3 Lunar Flybys (8, 10 and 13)
 - 6 missions to the Lunar Surface (11, 12, 14, 15, 16 & 17)
- Skylab Space Station Launch (1973)
- Three Missions to Skylab (1973-74)
- Apollo-Soyuz Test Project (1975)



Image Credit: NASA Image Gallery



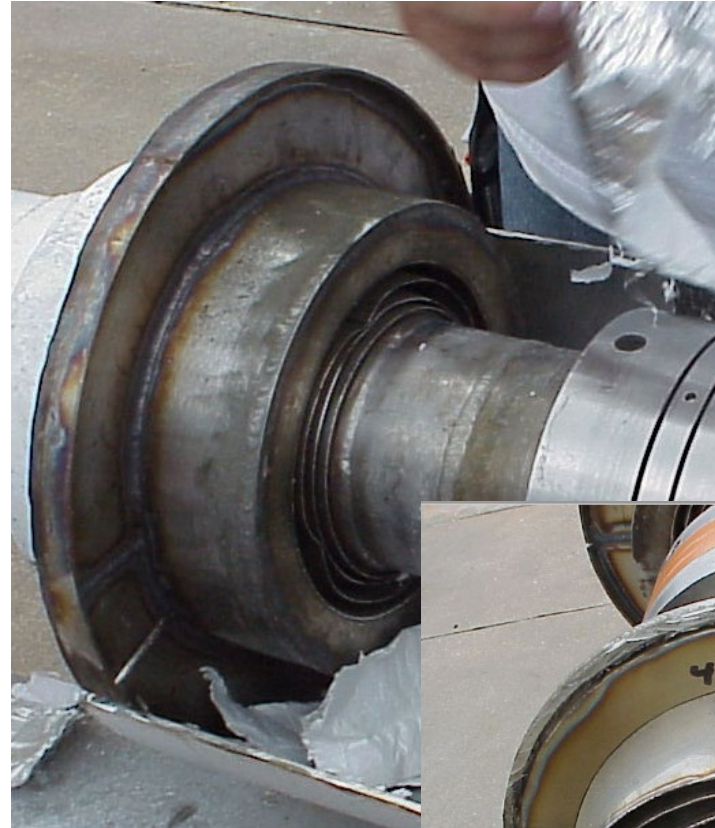
Apollo Cryogenic Innovations

Cryogenic Piping Systems

- 36% Ni alloy (N-Var) to reduce thermal contraction of cryogenic piping
 - No expansion loops in 1200' piping runs
- One of the first attempts at large diameter VJ piping
 - Many vacuum leaks due to seam welds on pipe section end caps
 - After several in place modifications, piping is still in use today

Large Cryogenic Components/Systems

- 10,000 gpm LO2 Pumps – based on sewage pumps
 - Caused a 'Brown out' in Titusville the first time they tried to use them (2500 HP motor)



Shuttle Program – Reused Apollo Ground Systems

LO2

- Abandoned 10,000 gpm pumps and 14" uninsulated transfer line
- Kept the 1000 gpm pump and 6" VJ transfer line
- Reused second stage vehicle valve control skid



LH2

- Kept everything
- Reused second stage vehicle valve control skid



LH2 Storage Tank Specifics

- Manufacturer (1965) - Chicago Bridge and Iron
- Inner tank diameter is 61.5 ft
- Outer tank diameter is 70 ft
- The annular vacuum space between inner & outer tanks is filled with perlite insulation
 - 25 microns when in service
- Geometric volume of the tank is 911 kgal
- Rated LH2 capacity is 850 kgal
 - 7% calculated ullage space
- 10" x 12" VJ transfer line
- MAWP or design pressure = 90 psig with full vacuum in annular space



The Shuttle Program (1981-2011)

LH2 Propellant Operations

- Storage Tank topped off in the weeks before Launch countdown.
- Vehicle rolled to the pad about 30 days before launch
- Ground and flight cryogenic systems verified purity ($>99.9\%$ GHe) and Dewpoint ($< -40\text{F}$) in piping systems and flight tanks the week before launch operations
- Three hours to load propellant starting at L-8 hours
 - LH2 Maximum flow rate ~ 8500 gpm – Pressure fed system
- LO2 and LH2 propellants loaded at the same time
- Once tanks were full, maintained fill level during 'replenish' operations (~ 100 gpm)
 - Quietest and most thermally stable time of the loading process
 - Astronauts put on board during this timeframe



The Shuttle Program (1981-2011)

Program Highlights

- 135 Missions
- > 240 Propellant Loading Operations
- First on orbit satellite repair (Solar Max)
- LDEF (Long Duration Exposure Facility)
- Space Lab (multiple missions)
- Magellan to Venus
- Galileo to Jupiter
- Ulysses to the Sun
- Hubble Space Telescope
 - Initial Launch 1990
 - Repair and Service Missions in '93, '97, '99, '02, '09
- 20+ missions to assemble the International Space Station



Questions?

