“Back in the Day…”

Musings of a Graybeard –

Selected Events in Early Monopropellant Hydrazine Thruster Development

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Background

- New paradigm of missions was on the horizon
  - Outer planets were aligning to optimize in late 1970's
  - TOPS Advanced System Technology Project implemented as precursor study
- My part in these events
  - Initial acceptance of monopropellant hydrazine thrusters for attitude propulsion
  - Adaptation of Shell 405 catalyst to small monopropellant thrusters
  - Propellant compatibility issues

Thermoelectric Outer Planet Spacecraft (TOPS) Project

- Advanced system technology project initiated circa 1970 provided an “umbrella” for the purpose
  - To develop and demonstrate capability to perform missions to the outer planets
  - To develop understanding of necessary system capabilities for this class of mission
  - To provide design, development, and test experience in several new technologies critical to this type of mission
  - To develop an understanding of the required subsystems and their interactions so that realistic performance, reliability, schedule, and cost estimates could be made

TOPS Enabled System-Technology Studies

- "Strawman" TOPS spacecraft came into being to provide a design testbed to evaluate technologies for new components and subsystems

- Evolved into Voyager Program
  - First launch (Voyager 2) on August 20, 1977

Evolution of Monopropellant Attitude Propulsion for TOPS

- Classical attitude "torquing" system initially baselined for TOPS was gaseous nitrogen (e.g., Mariner implementation)
  - Low performance, low thrust required long lever arms (~10 ft)
    - Threaded through other subsystems, deployed with booms
    - Needed deployment flexures and thermal control
  - High-pressure gas (~3000 psia)
  - Omnipresent possibility of gas leakage from thruster valves
  - Limited growth potential for 10-year mission
- Candidate trajectory correction propulsion was monopropellant hydrazine
  - Why not tap this common propellant source to provide attitude torquing? Many advantages!
    - Store low-pressure liquid vs. high-pressure gas
    - Nearly "infinite" fuel supply for attitude propulsion needs
    - Tremendous volume savings with liquid
    - Thruster valves seal liquid vs. gas, resulting in lower leakage
    - Higher performance enables shorter moment arms (2 ft vs. 10 ft)

But there were problems!

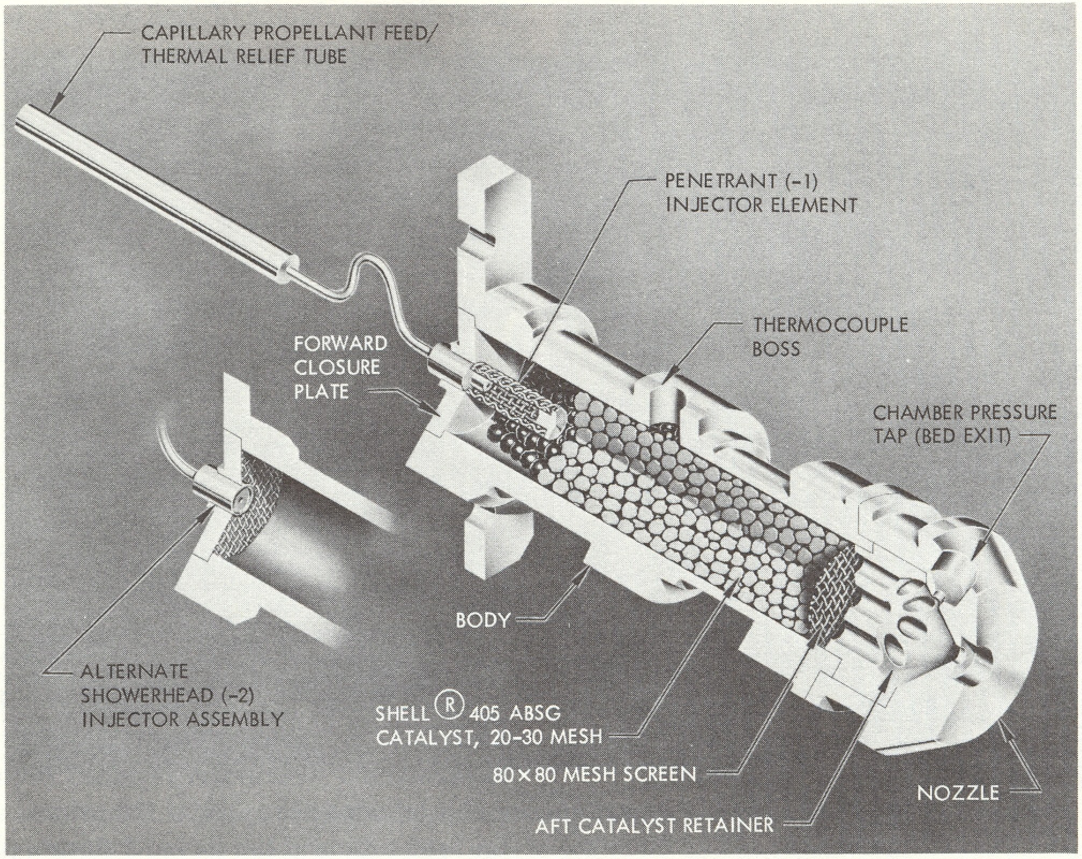
And Not All Problems Facing Us Were Technical …

- Sociological
  - The spacecraft culture was not ready to switch from cold-gas nitrogen to a liquid for attitude propulsion
    - Use of liquid propellants for this application was a paradigm shift
    - Motivated a first look at a “pulsed plenum” concept
      - Hydrazine was decomposed by a gas generator and stored in a plenum
      - Gas then pulsed out through small nozzles as needed
      - System “looked” like a conventional cold-gas system

… But There Were Technical Problems

- Catalyst beds were coming apart by catalyst breaking up during operation
  - Mechanical failure from thermal and propellant-decomposition stresses
- Hydrazine was forming a gelatinous compound “scum”
  - Clogging lines and filters
- What was apparently good enough for “larger” monopropellant engines was unacceptable for an attitude propulsion system (APS)
  - APS required many starts with long in-between cold soak
  - Low nominal thrust level of 0.1 lbf (0.44 N) meant small passages, hence high susceptibility to contamination
- These problems are addressed in this talk

Fabricated a "Testbed" Small Thruster



Adapted the Catalyst to Small Monopropellant Thrusters

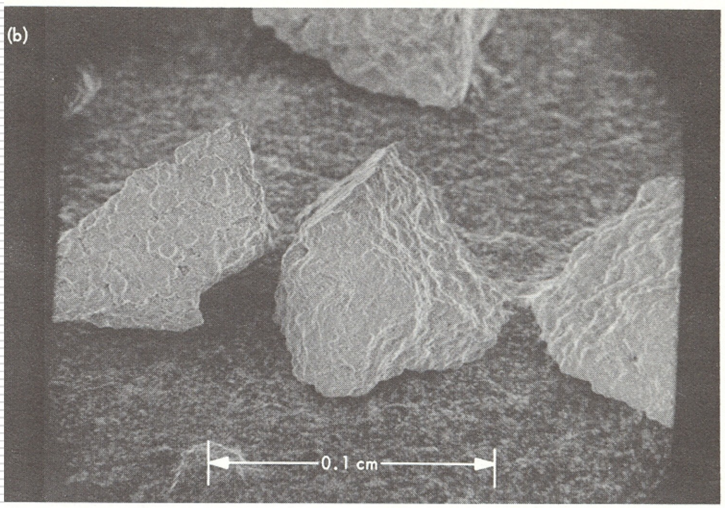
- Preferred catalyst was Shell 405, produced by Shell Development Company, Emeryville, CA
  - Initial development undertaken in 1962, eight years before initiation of TOPS monopropellant APS needs
  - Iridium impregnated into alumina substrate
  - Delivered typically as nominal ¼-in x ¼-in cylindrical pellets or as prescreened fractured pieces
  - Colorful development history a subject for a separate talk

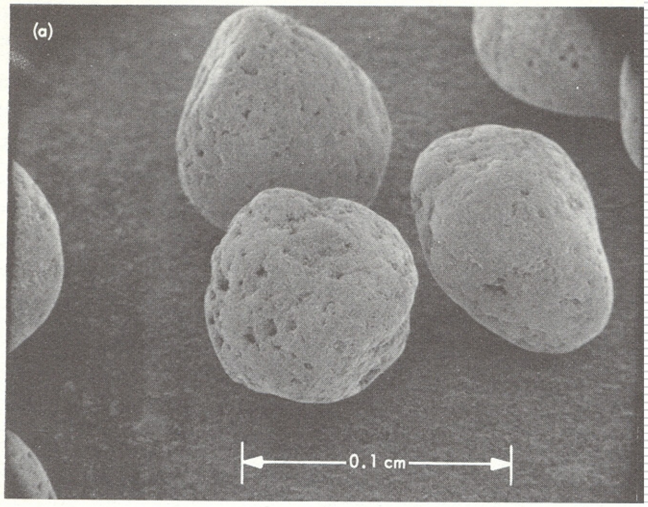
- Major technology-development effort to adapt catalyst for mechanical survivability
  - Catalyst crushed easily
  - Fines would flow out of catalyst bed, creating voids, causing “washout”
    - Washout – increased flowrate, decreased performance
    - Problem experienced with larger (nominal 25 - 50 lbf) trajectory-correction thrusters

What We Did

- Pre-selected catalyst size
  - “Standardized” on nominal 20 - 30 mesh pieces
- “Tumbled” catalyst to produce nearly spherical pellets
  - Tumbling broke down sharp points/edges, typical source of fines
- Vibration-tamped catalyst bed during bed loading
  - Induced maximum settling and compaction
- Preloaded catalyst bed upon final assembly
  - Needed to maintain a compression on the bed
  - Set preload to 150 - 200 psi, nominal 180 psi
  - Preload prevented relative motion – hence grinding – within the catalyst bed during operations
- Suggested application of sustained catalyst-bed preheating
- Process became standard procedure

Catalyst in Various Stages

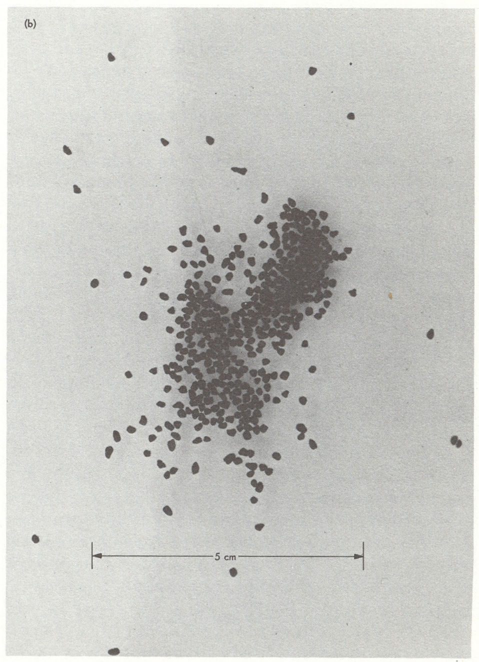




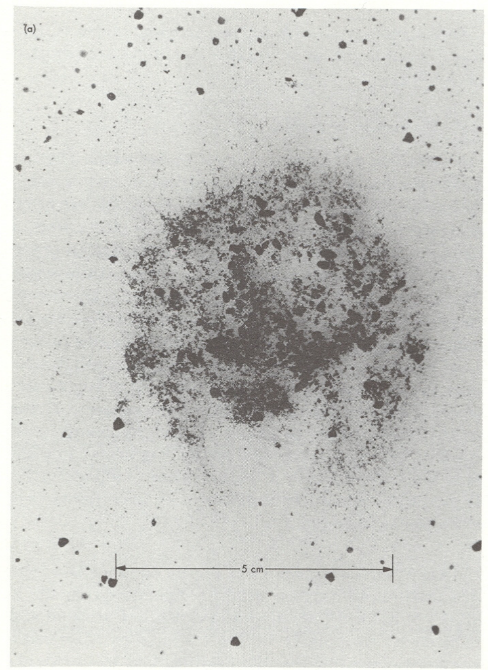
Appearance before "tumbling" to break edges and corners

Smoothed, more spherical form after tumbling

Catalyst “Fines”



“Normal” pellets after processing



Pellet “fines” generated from tumbling to break corners

Catalyst Future

- Rumor – Shell no longer to produce Shell 405
  - Complete specifications to be given to new producer
- Caution!
  - Be prepared for future problems with catalyst – all over again!
    - Processes are never completely replicated

And There Were Problems with Propellant Compatibility

- Three problems were faced
  - Hydrazine auto-decomposition occurs when in contact with numerous materials
  - Contamination
  - Formation of gelatinous films

- Contamination and gelatinous formation were related

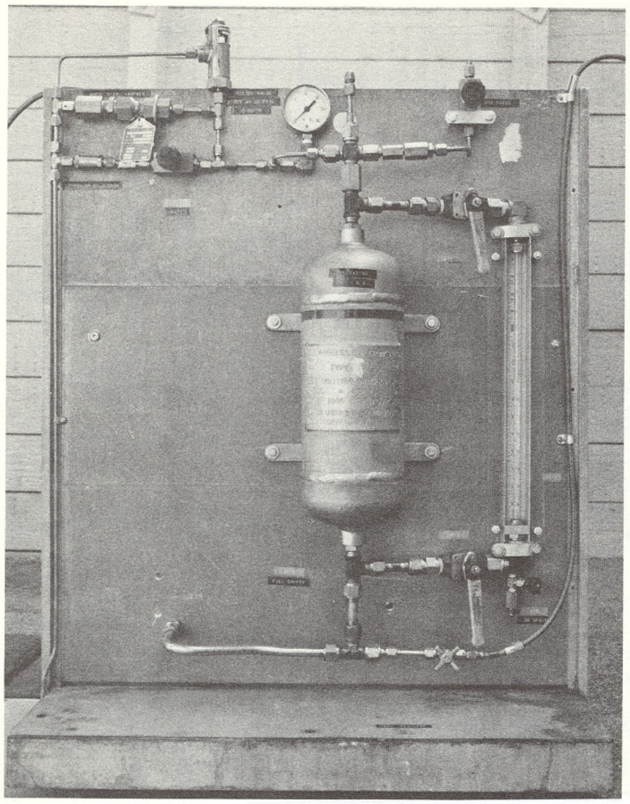
What We Did

- To prevent auto-decomposition
  - Selected materials known to be compatible
    - Principally 300-series stainless steel
  - Supercleaned and passivated all contact surfaces
    - Exposed contact surfaces to small amounts of hydrazine until decomposition stopped
- But…
  - Some low-level propellant decomposition still occurred due to contamination
- And…
  - Hydrazine has a natural affinity to absorb CO_2 from the atmosphere and form a gelatinous compound!

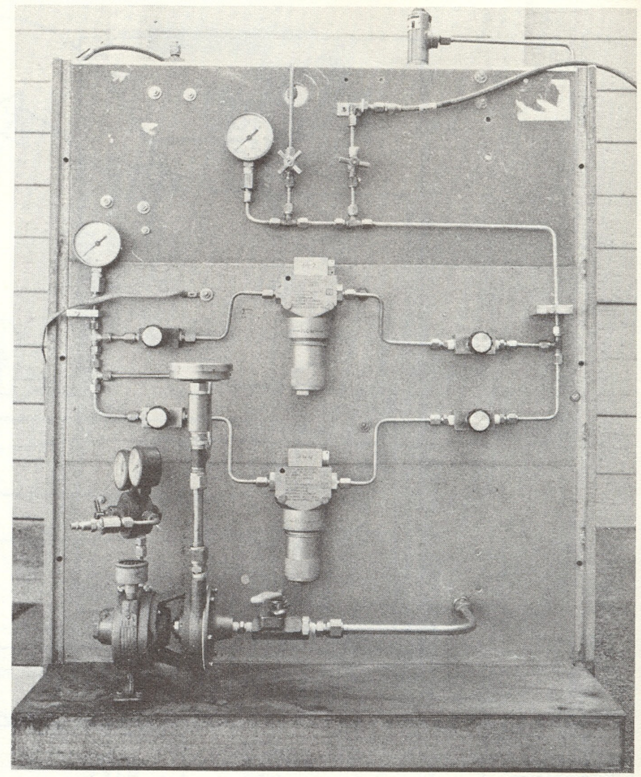
Attacked the Contamination Problem!

- First – Initiated a policy to store all hydrazine to be used in propulsion systems under a cap of gaseous dry nitrogen
  - Produced a specification to this effect
- Next – Designed and built a hydrazine recycling system for the purpose of producing ultraclean propellant
  - Cycled it through two parallel 10-micron absolute filters continuously for several hours to "scrub" propellant
  - Pump-discharge pressure of 30 psi held maximum temperature below 120 °F to prevent thermal decomposition
  - Propellant periodically sampled for cleanliness
  - Considered propellant sufficiently clean when sample showed fewer than 2 particles/cc
    - "Good enough" was established by trial and error
- Result – Problem of gelatinous compound never recurred
- Recycling system used thereafter for propellant cleaning and transfer
- Thus began the precedent for ultraclean propellant

Hydrazine Recycle System



Propellant tank with sight gage



Recycle system with air-driven pump

The Culture Now

- Nearly exclusive use of ultra-pure hydrazine for propulsion applications
- All hydrazine used for space propulsion now stored under dry nitrogen cap
- Careful catalyst selection with proper bed compaction applied to thruster designs to maintain stability and prevent formation of fines during operation

Parting Thoughts

- "Those who cannot learn from history are doomed to repeat it." – George Santayana
- "Ignorance of history is its own revenge." – Phil Moynihan

References:

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2. Moynihan, P. I., "Performance Characterization Tests of Three 0.44-N (0.1-lbf) Hydrazine Catalytic Thrusters," Technical Report 32-1584, Jet Propulsion Laboratory, Pasadena, CA, September 1, 1973
3. Long, H. R., Bjorklund, R. A., "Trajectory Correction Propulsion for TOPS," Technical Report 32-1571, Jet Propulsion Laboratory, Pasadena, CA, November 15, 1972