NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

NANOTECHNOLOGY AND GELLED CRYOGENIC FUELS

Presentation to

Dr. Minoo Dastoor

NASA Nano / Bio Initiative

Bryan Palaszewski

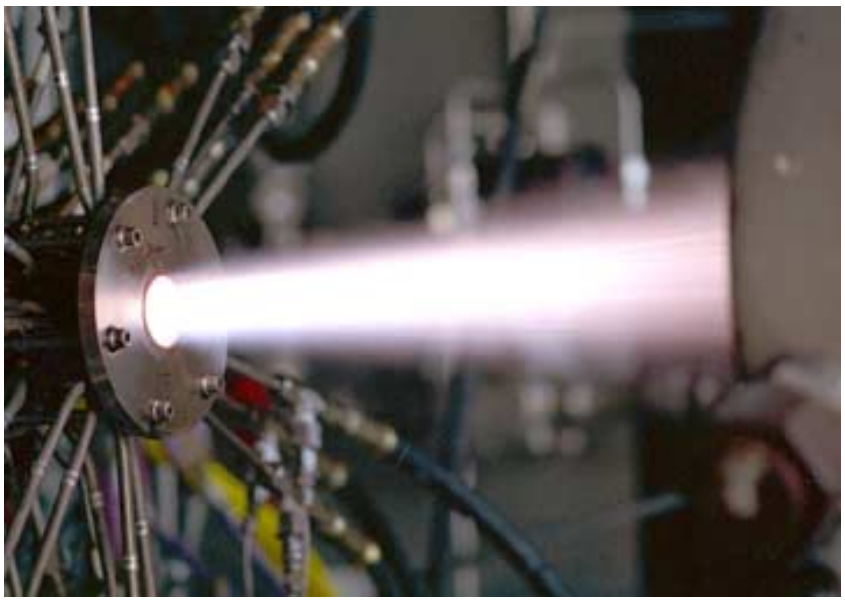
NASA John H. Glenn Research Center, Lewis Field

Cleveland, OH, 44135

May 30, 2001

Nanoparticulates for Gelled and Metallized Gelled Propellants

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division



Aerogel is a highly efficient insulator (CNN)

O2 / RP-1 /Aluminum combustion – Aerogel and nanoparticulate metals can gel the fuel, making it denser, more energetic, and safer

http://www.cnn.com/TECH/9705/13/aerogel/index.html

The Benefits of Nanogellant Gelled Cryogenic Propellants and Nanoparticulates

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- ***Nanogellant Gelled Propellants***
  - **Increased safety**
  - **Increased fuel density**
  - **Reduced leakage**
  - **Reduced slosh**
  - **Reduced cryogenic boiloff**
  - **Potential reduction in specific fuel consumption**
  - **Potential increases in engine thrust**
- ***Nanoparticulate Metallized Gelled Propellants***
  - **All of the above and**
  - **Large increases in fuel density**
  - **Larger potential reductions in specific fuel consumption**
  - **Larger potential increases in engine thrust**

Nanogellant and Nanoparticulates

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- *What are nanogellant and nanoparticulate fuels?*
  - **Nanogellants are gellants that have a nanometer scale structure, which have enormously high surface area per gram**
    - **Gelled fuel reduce leakage and increase safety**
  - **Nanoparticulates are metal particles that are 20 nanometers in diameter, much smaller than traditional 7 micron particles used for metal additives**
    - **Smaller particles allow for more efficient combustion and lower specific fuel consumption**

Nanogellants and Nanoparticulates

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

Why are Gelled Cryogenic Fuels revolutionary?

- **Gelled cryogenic fuels reduce leakage and increase safety**
- **Gelled cryogenic fuels are critical for increasing operability of cryogens for aerospace vehicles**
- **Nanogellant for gelled cryogens has a surface area of nearly 1000 m^2 /g, leading to cryogenic fuels gelled with 1-7 weight % gellant, 25 to 50% less mass than traditional gellant material**

- ***Synergy***
  - **Gelled and metallized gelled propellants have been an area of considerable interest in the rocket propulsion and explosives**

Propellant Technologies: Teams

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- *National team*
  - NASA MSFC (large scale rocket engine testing)
  - NASA GRC (gelled and metallized gelled propellants, small scale engine tests)
- *NASA partners and contacts*
  - U.S. Army Picatinny Arsenal (potential collaboration in nanoparticles)
  - USAF Research Laboratory (hydrocarbons)
  - U.S. Army Aviation and Missile Command (metallized gelled propellants)
  - U.S. Naval Surface Warfare Center, Indian Head (nanoparticle aluminum, explosives)
  - Technanogy (nanometer aluminum particles)
  - Small Business Innovation Research (Argonide, Orbitec, etc.)
  - Many other industry, Government, and university partners

Metallized Gelled Propulsion

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

Oxidizer	Fuel	Metal
O_2	H_2	Al
O_2	Hydrocarbon	Al
NTO	MMH	Al

- **Metal additives are suspended in gelled fuel and they undergo combustion with oxidizer**

Metallized Gelled Propellants: Increasing Rocket Specific Impulse for Mars Missions

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- **Mars missions using metallized gelled O2 /H2 /Al have an Isp of 475 to 480 seconds.**
- **O2/H2 without gellants or metal particles has an Isp of 470 seconds**
- **Rocket specific impulse (Isp) increased for several reasons:**
  - **Adding metal shifts O/F ratio from 6.0 to 1.6 (with 60 wt% Al), reducing the molecular weight of the rocket exhaust**
  - **Reducing the molecular weight increases engine Isp**
  - **Adding metal actually decreases the combustion temperature by 500 K**
  - **The added metal weight percent (wt%) is 60 to 70 % of the total H2/Aluminum fuel mass**
  - **Adding 60 wt% Aluminum increases engine Isp by 5 seconds**
  - **Adding 70 wt% Aluminum increases engine Isp by 10 seconds**
  - **O/F change increases Mars vehicle volume by only 1.1 % over the O2/H2 case**
  - **References:**
    - **Palaszewski, B., "Metallized Propellants for the Human Exploration of Mars ," NASA-Lewis Research Center, NASA TP-3062, presented at the Case For Mars IV Conference, Boulder, CO, June 4-8 1990. Also in the AIAA Journal of Propulsion and Power, Vol. 8, No. 6, Nov.-Dec. 1992, pp. 1192-1199.**
    - **Palaszewski, B. and Rapp, D., "Design Issues for Propulsion Systems Using Metallized Propellants," NASA-Lewis Research Center, AIAA 91-3484, NASA TM-105190, presented at the AIAA/NASA/OAI Conference On Advanced SEI Technologies, Cleveland, OH , September 4-6, 1991.**

Metallized Gelled Propellants: How Gellants Work

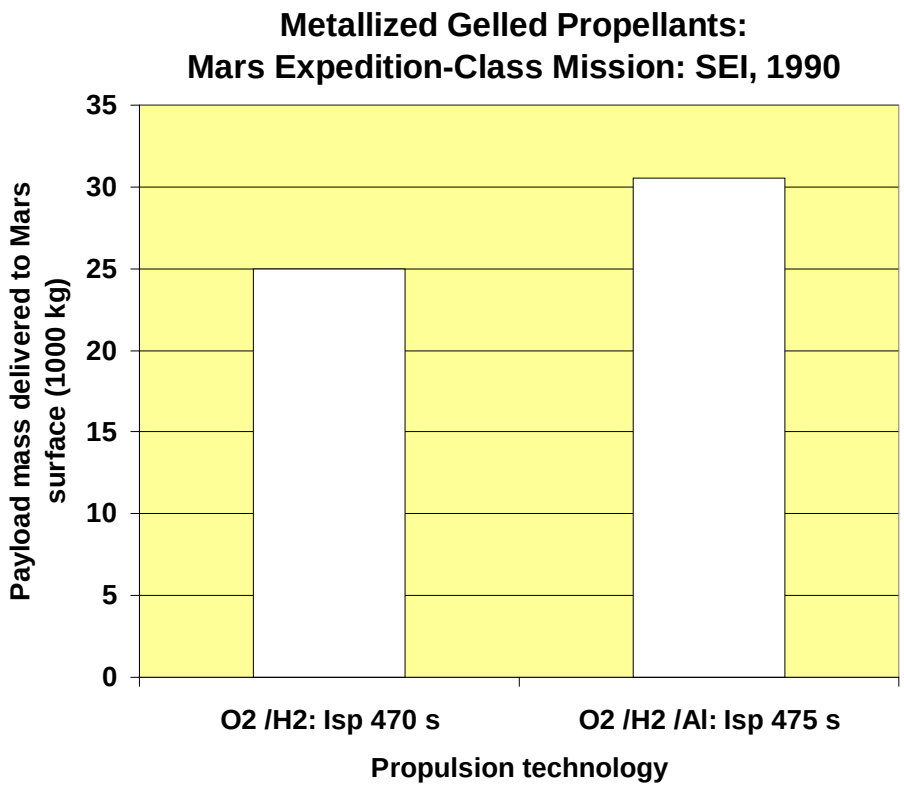
NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- Gellants create a cross-linked structure in the liquid fuel, much like a long chain polymer
- The gelled ljquid fuel is gelled with a small amount of gellant
  - RP-1: 0.9 wt% nanogellant
  - Liquid hydrogen: 7 to 8 wt% nanogellant
- The resulting gelled liquid is thixotropic (shear thinning), and its viscosity is 5 to 10 times that of the liquid alone
- The viscosity drops to the liquid viscosity when the fuel flows
- Metal particles, if small enough (nanometer sized), can act as a self gellant, reducing or eliminating the need for a separate gellant

Mars Missions: Space Exploration Initiative (SEI) and Metallized Gelled Propellants

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

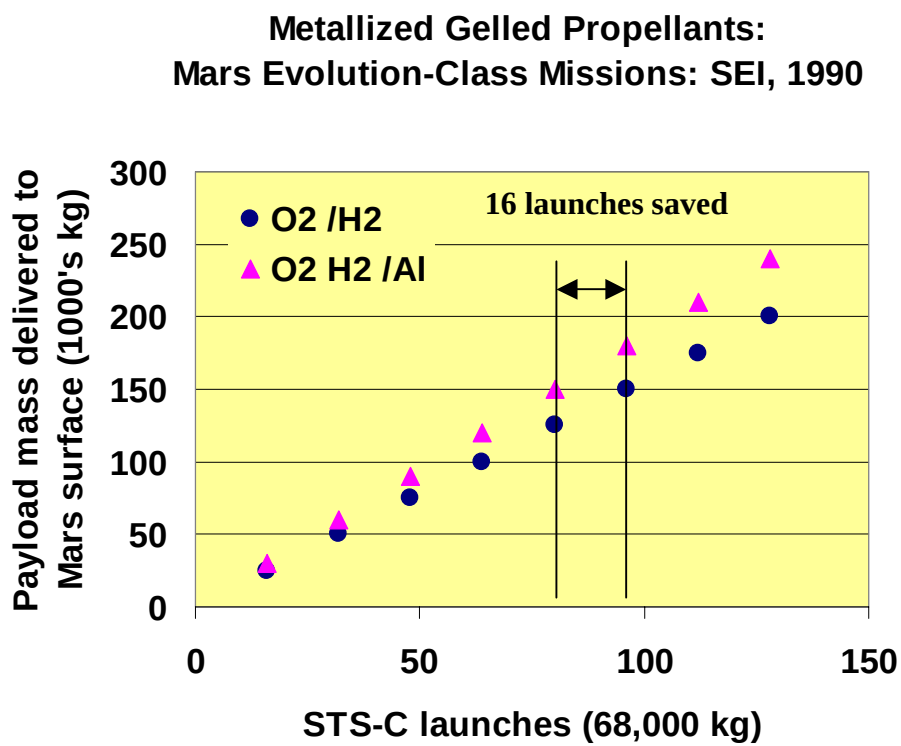
- **Mars missions using**
  - **O2 /H2**
  - **Metallized gelled propellants: O2 /H2 /Al**
- **20 to 33% higher payload to Mars surface for each flight**



Mars Missions: Space Exploration Initiative (SEI) and Metallized Gelled Propellants

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

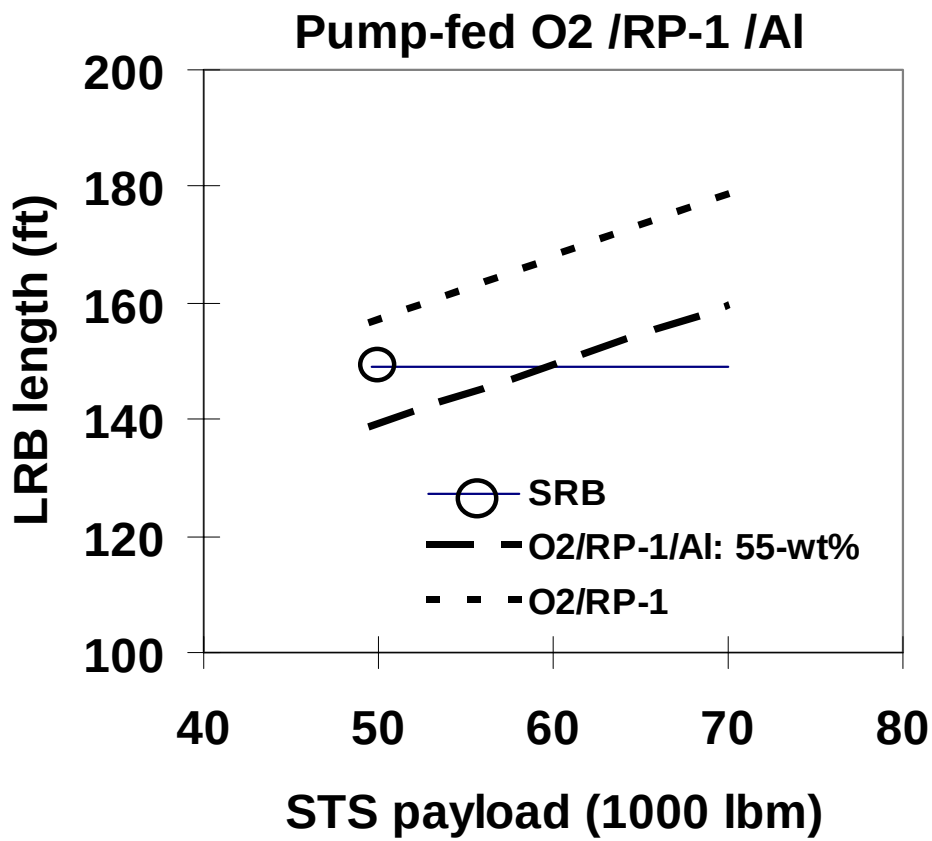
- Mars missions using
  - O2 /H2
  - Metallized gelled propellants: O2 /H2 /Al
- 20% more payload to Mars surface for each flight, with metallized gelled H2 /Aluminum
- Significant launch vehicle savings with O2/H2/Al propellants
- 16 STS-C launches saved over 5 Mars missions
- Faster payload delivery schedule, and billions saved



O_2/RP-1/Aluminum Liquid Rocket Booster for Space Shuttle (Future STS)

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- Payload increases of 14% possible with 55-wt% RP-1/Al (56,600 lbm)
- Small 1-ft diameter increase lifts payload to 70,000 lbm
- O2/RP-1: 324 s Isp
  O/F = 2.7
- O2/RP-1/Al: 317 s Isp
  O/F = 1.1



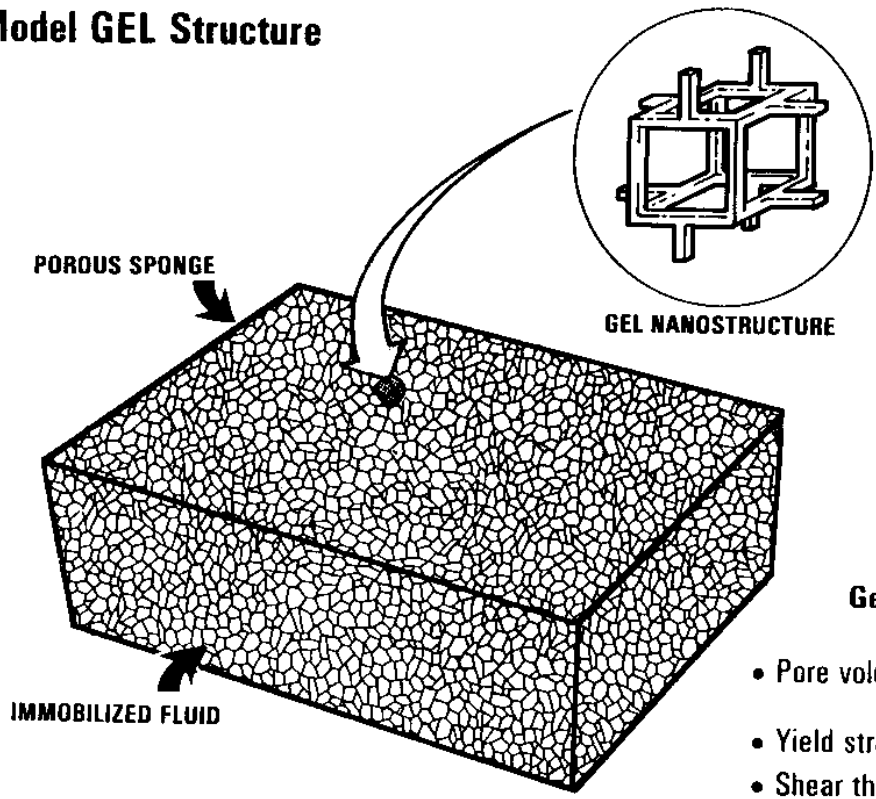
Nanogellant Gelled Propellants: Past Work

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- Worked with TRW (1989-1996) developing nanoparticulate gellants
- Nanogellants are hydrocarbon alkoxide materials, created with a supercritical processing method
  - Nanogellant for gelled cryogens has a surface area of nearly 1000 m^2 /g, leading to cryogenic fuels gelled with 0.9 to 7to 8 weight % gellant,
  - 25 to 50% less mass than traditional gellant material
- Liquid hexane, RP-1, propane (cryogenic), etc. gelled with less that 0.9 wt% of nanogellant
- Liquid hydrogen gelled with 7 to 8 weight % nanogellant (NAS3-25793, 1994 and NAS3-26714, 1996)
- Extensive data base on gelled propellants at NASA Glenn
- Joint NASA /TRW work in nanogellants being reinvigorated

Model GEL Structure

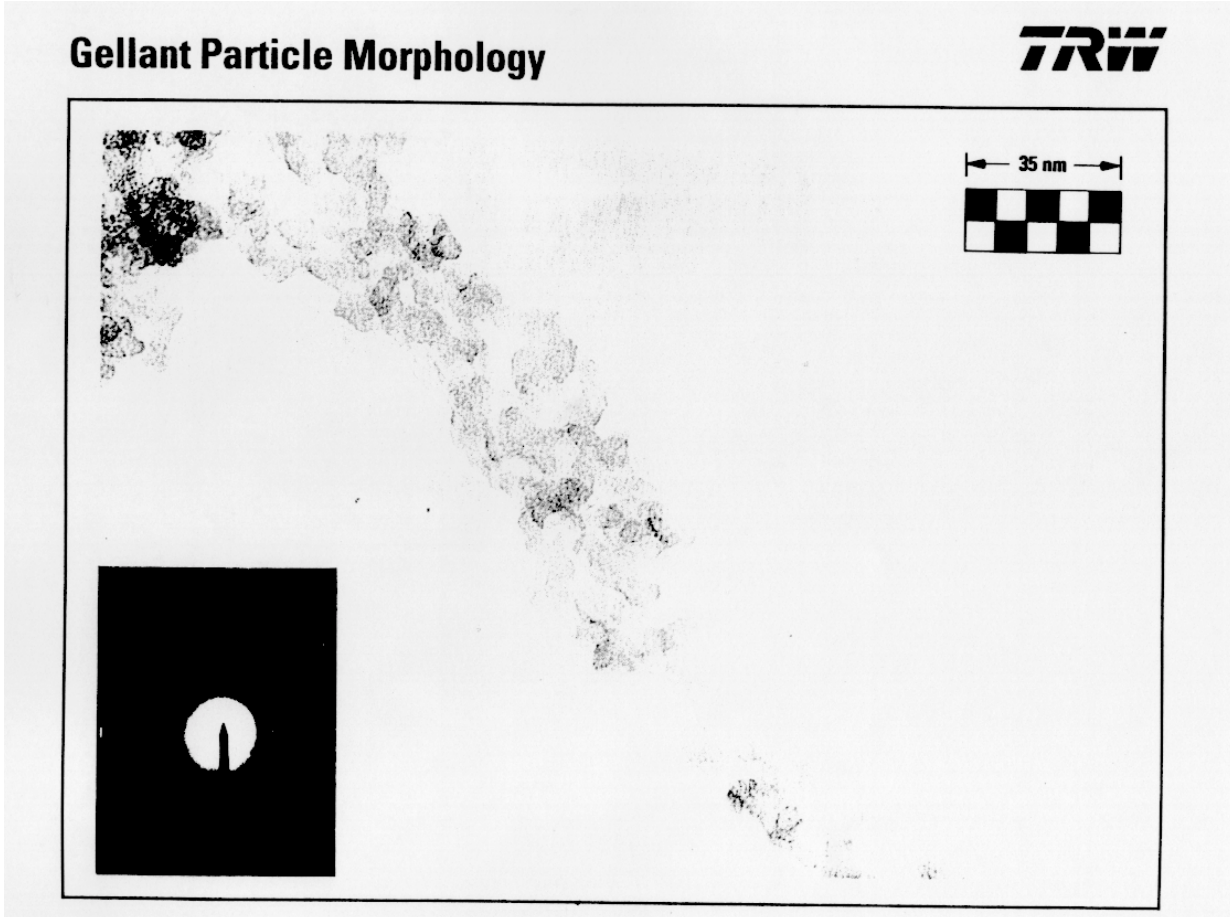
TRW



Gel Merit Figures

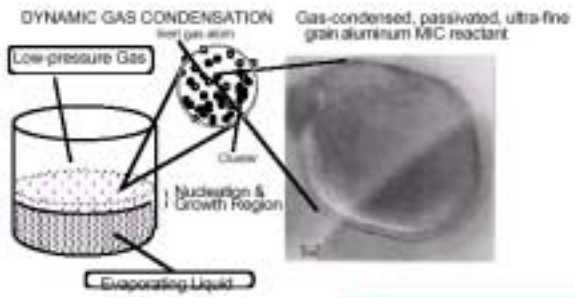
- Pore volume = $\frac{V_{GEL} - V_{SKEL}}{W_{SKEL}}$
- Yield strength
- Shear thinning
- Energy density

Transmission Electron Microscopy (TEM) photo of nanogellant



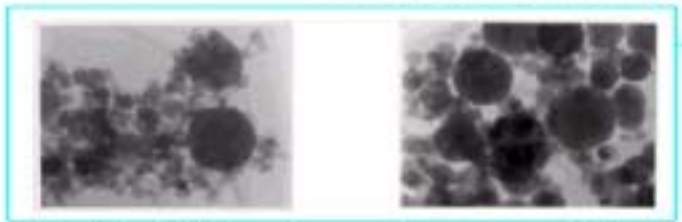
TRW aerogel type nanogellant, Circa 1990

Dynamic Gas Condensation Is Used At LANL To Fabricate MIC Reactants



- Ultra fine particles (~20 nm)
- Uniform size distribution
- Size easily controlled
- Amenable to continuous production (currently ~25g/hr)
- Process self-purifies source metal

LANL Al Powder

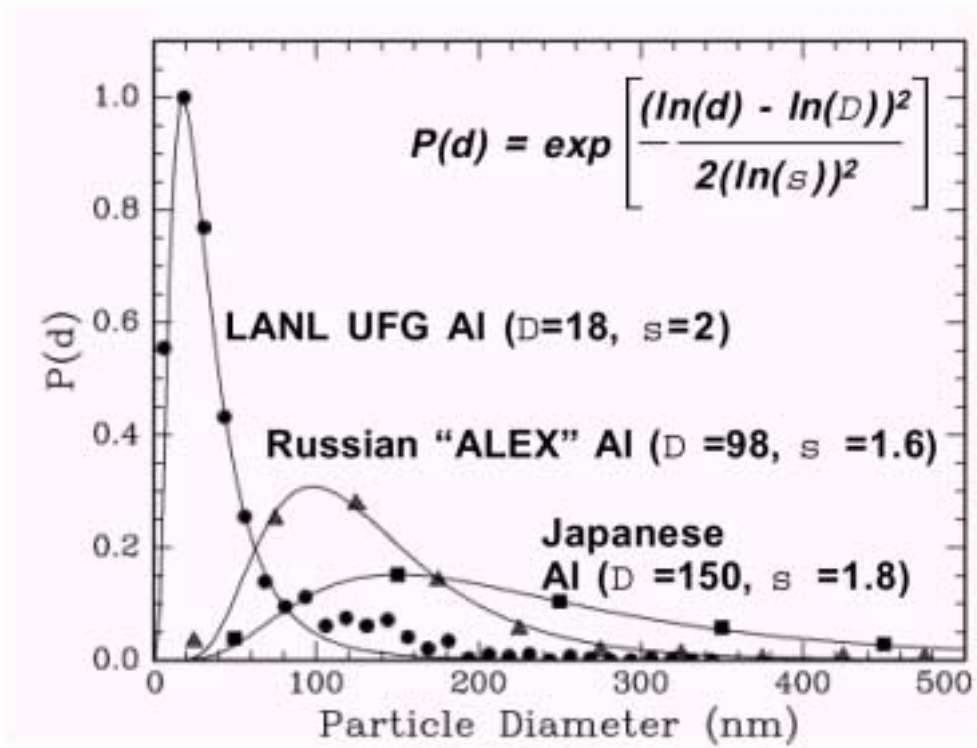


Russian Al Powder ("ALEX")

Japanese Al Powder

Materials Science and Technology

LANL Al Powders Have A Smaller Mean Size And A Narrower Size Distribution Than Commercial Powders

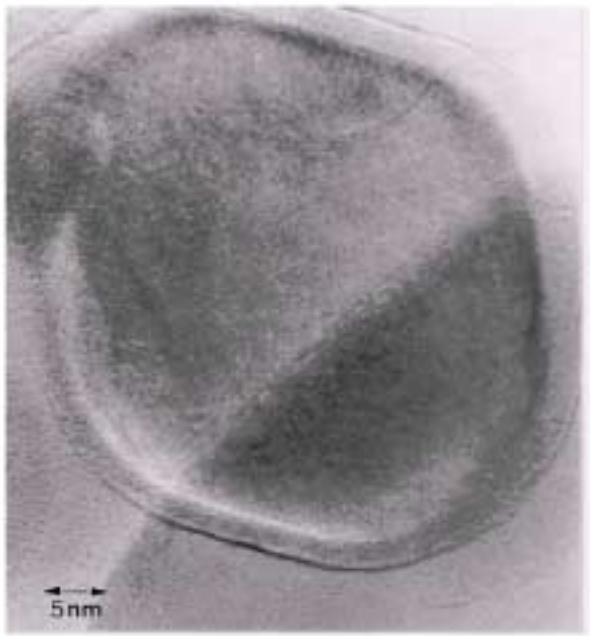


- log-normal distribution function fits measured data well
- D = peak position
- s fixes distribution width

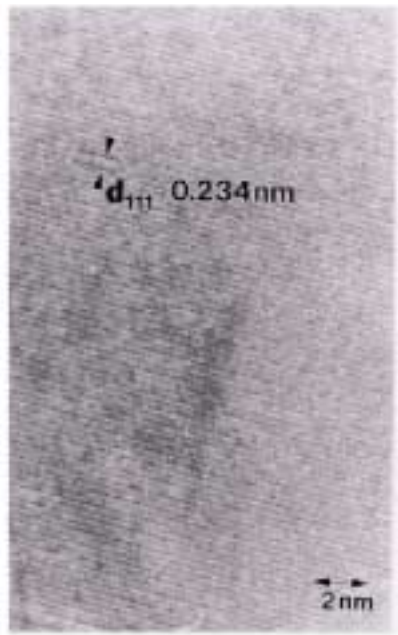
Materials Science and Technology

LANL UFG ALUMINUM PARTICLES ARE SINGLE CRYSTALS WITH NEGLIGIBLE STRUCTURAL DEFECT DENSITY

GAS-CONDENSED Al PARTICLE



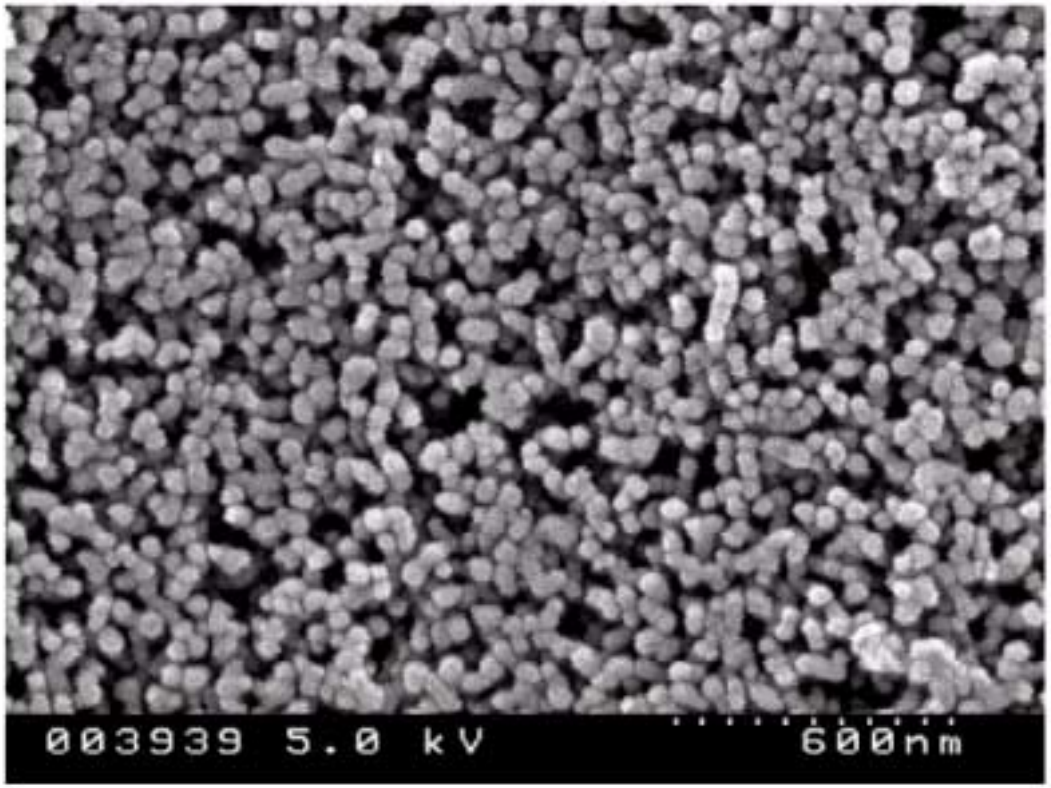
Al (III) LATTICE FRINGES



- interior aluminum is crystalline
- no structural defects apparent
- 2.5 nm thick Al_2O_3 passivation layer

Materials Science and Technology

SEM of LANL UFG ALUMINUM PARTICLES



Materials Science and Technology

Nanoparticle and Nanogellant Fuels: Small Business Innovation Research (SBIR)

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- *Argonide (Sanford, FL)*
  - Title: Metastable electroexploded nanophase aluminum based gels as a component of propulsion fuels
  - SBIR Phase II completed - 2001
  - Alex and other metals produced by the electroexplosion of metal wire are metastable, producing additional energy and burning rate
  - Discovered reduction of ignition delay with gelled Oxygen /RP-1/ Aluminum fuels
- *Orbitec (Madison, WI)*
  - Title: Gelled LH2 /UFAL /LOX propellant system
  - SBIR Phase I underway -2001
  - Uses ultra-fine aluminum powder (UFAL) to develop a gelled LH2 fuel and LOX propellant system.
  - This innovation will increase the performance, density, and combustion efficiency of LH2/Al/LOX for use in rockets and combined-cycle vehicles

Propellant Technologies – Applications and Fuels

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- *Nanogelled Cryogenic Propellants with Nanoparticulate Additives*
  - **Revolutionary Aeropropulsion vehicles**
  - **Next generation aerospace vehicles**
  - **Many others**
- *Planned fuels:*
  - **Liquid methane**
  - **Liquid propane**
  - **Liquid nitrogen**
  - **RP-1**
  - **Jet A**
  - **JP-8**
  - **Liquid hydrogen (last to be addressed in testing)**

Approach

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- *First year goals:*
  - Determine the location for Nanogellant Production
    - Produce nanogellant
    - Characterize the nanogellant production uniformity
    - Determine the effects of storage (shelf life) of the nanogellant
  - Determine the location for Nanoparticulate Production
    - Produce nanoparticles
    - Characterize the particle size and uniformity
  - Determine the location for the multi-fuel test area
  - Ambient temperature check out
    - Produce gelled aviation fuel (high H/C ratio fuel)
    - Produce an aviation fuel doped with nanoparticulates
    - Produce a gelled aviation fuel doped with nanoparticulates
    - Determine the characteristics of the gelled-doped aviation fuel

Approach

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- ***Second year and third year goals***
  - **Liquid nitrogen (LN2) check out**
    - **Produce gelled LN2 using nanogellants**
    - **Produce a mixture of LN2 and nanoparticles**
    - **Produce doped-gelled LN2**
    - **Determine characteristics of the doped-gelled LN2**
  - **Determine cryogenic fuels of interest (potential fuel include but are not limited to liquid propane, liquid methane, and liquid hydrogen)**
  - **Fuel 1 to N testing**
    - **Produce gelled Fuel 1 to N using nanogellants**
    - **Produce a mixture of Fuel 1 to N and nanoparticles**
    - **Produce doped-gelled Fuel 1 to N**
    - **Determine characteristics of the doped-gelled Fuel 1 to N**
    - **Optimize production process if necessary to obtain desired results**

Approach

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- *Fourth and fifth year goals*
  - Build up combustion test area
  - Produce sufficient quantities of gelled-doped fuel in production area to support combustion tests
  - Develop diagnostic techniques
    - Measure uniformity of nanogellant/nanoparticulate dispersion in fuel
    - Effect of nanoparticulates on rotating machinery
    - Combustion process
    - Emissions
  - Perform initial combustion tests
  - Optimize fuel formulation and repeat combustion tests

Gelled and Metallized Gelled Propellants

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

Contact:
Bryan Palaszewski
NASA John H. Glenn Research Center
Lewis Field
MS 5-10
Cleveland, OH 44135
(216) 977-7493 Voice
(216) 433-5802 FAX
bryan.a.palaszewski@grc.nasa.gov

Fuels and Space Propellants Web Site
http://www.grc.nasa.gov/WWW/TU/launch/foctopsb.htm

Gelled Hydrogen Propellants

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

Past Results

- First gelled cryogen (nitrogen) was formulated circa 1960
- Evaporation (boiloff) of gelled hydrogen
  - reduced by factor of 2 to 3 (NAS3-4186, 1966)
  - reduced by factor 25 to 50 % (NAS3-2568, 1964)
    - variations due to tank geometries, heat leaks
  - both used silica gellants, at high weight percentages (36 weight %)
- Work with Lockheed (LMSC) and MSFC, with frozen ethane (NAS8-20342, 1968)
- Later work used frozen ethane or methane gellant, at 4 to 10 weight % (Aerojet, SNP-1, 1970)
- Work with TRW using nanoparticulate gellants, at 7 to 8 weight % (NAS3-25793, 1994 and NAS3-26714, 1996)
- Extensive data base on gelled propellants at NASA Lewis

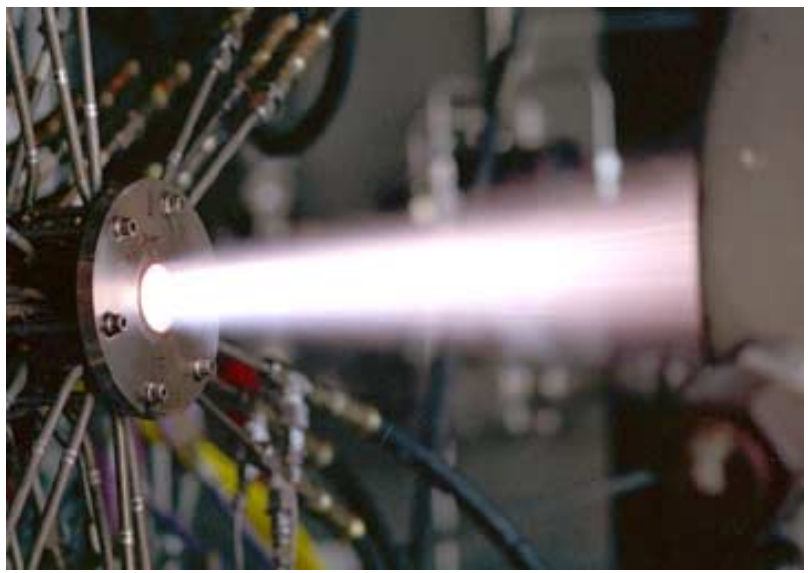
Metallized Gelled Propellants

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

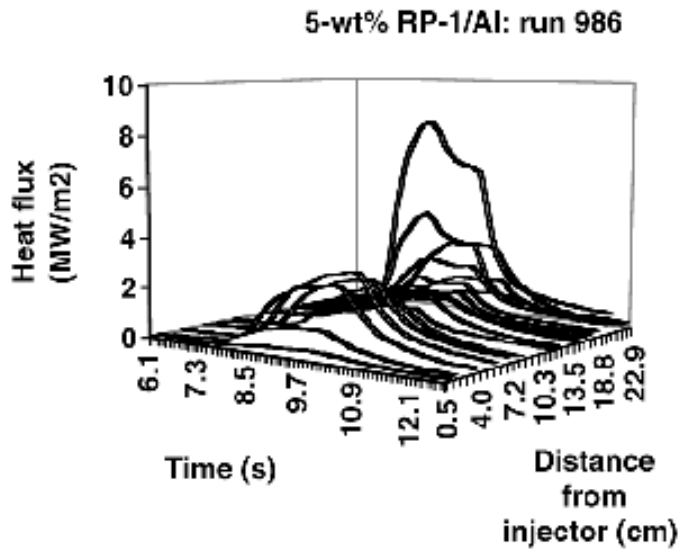
- **Goal**
  - **Determine combustion and heat transfer characteristics of metallized gelled RP-1 /Al propellants in a rocket engine**
  - **Evaluate fuels including traditional RP-1 and metallized gelled RP-1 /Al with 0-, 5-, and 55-wt % loadings of aluminum, with gaseous oxygen as the oxidizer**
- **Hardware**
  - **Experiments conducted with a 40-lbf thrust engine composed of a modular injector, igniter, chamber, and nozzle**
  - **31 cooling channels for chamber calorimeter measurements, with temperature and pressure sensors**
- **Results**
  - **Gelled fuel coating, composed of unburned gelled fuel and partially combusted RP-1, formed in the 0-, 5- and 55-wt % engines**
  - **Coating caused a decrease in calorimeter engine heat flux in the last half of the chamber for 0- and 5-wt % RP-1 /Al propellants**

Metallized Gelled Propellants

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division



5 wt% RP1-Al rocket engine test firing at the GRC.



Three-dimensional roller-coaster plot of metallized gelled propellant heat flux: 5-wt % RP-1/Al.

The Benefits of Gelled and Metallized Gelled Propellants

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- **Gelled propellants**
  - **Increased safety**
  - **Increased fuel density**
  - **Reduced leakage**
  - **Reduced slosh**
  - **Reduced cryogenic boiloff**
  - **Increases in engine specific impulse (in some cases)**
- **Metallized Gelled Propellants**
  - **All of the above and**
  - **Large increases in fuel density**
  - **Large increases in engine specific impulse (in some cases)**

Propellant Technologies: Nanotechnology

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- **Nanotechnology is applied to rocket and aerospace propellants**
  - **Gellants**
    - **for hydrocarbons**
    - **for liquid cryogenic fuels (hydrogen, methane, propane)**
    - **Nanoparticulate materials used for gellants (hydrocarbon alkoxides)**
    - **Gellants increase fuel safety, density, and energy**
    - **Gellants reduce fuel slosh, and reduce the vehicle dry mass with higher fuel density**
  - **Nanophase aluminum particles added to rocket and aerospace fuels**
    - **Metallized gelled propellants**
      - **RP-1 /Aluminum**
      - **Hydrogen / Aluminum**
      - **Others (MMH / Aluminum, etc.)**
    - **Adding metal particles can increase engine exhaust velocity and fuel density**

The Benefits of Gelled and Metallized Gelled Propellants

NASA John H. Glenn Research Center, Lewis Field
Turbomachinery and Propulsion Systems Division

- **Gelled Propellants**
  - **Increased safety**
  - **Increased fuel density**
  - **Reduced leakage**
  - **Reduced slosh**
  - **Reduced cryogenic boiloff**
  - **Reduction in engine specific fuel consumption (in some cases)**
  - **Increases in engine specific impulse (in some cases)**
- **Metallized Gelled Propellants**
  - **All of the above and**
  - **Larger increases in fuel density**
  - **Larger reductions in engine specific fuel consumption (in some cases)**
  - **Larger increases in engine specific impulse (in some cases)**