The Choice of NH3 to Fuel the X-15 Rocket Plane

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Sept 19-20, 2011
Portland, OR

Robert W. Seaman and George Huson
Reaction Motors Inc. (Retired)

The Query

- Why/how was NH3 chosen to power the X-15?
- Who made the decision?

Beginning the Search

- Paul Curto – NASA Retired
- Roger Launius – Senior Curator, Div Space History, Smithsonian
- Christian Gelzer – Historian, NASA Dryden
- Dennis Jenkins – Author of X-15: Expanding the Frontiers of Flight

Jenkins recollection

"Reaction Motors had already decided to use ammonia on the *Viking* engine (XLR10) that the XLR99 derived from. The Air Force and Reaction Motors spent a lot of time deciding if that was the right answer (versus some hydrocarbon like JP4). I don't remember any specifics on an individual leading the charge on either side ... "

Mario Luperi

"Denville company's employees still get together nearly 40 years after its demise" – NJ.com, Aug 17, 2010

- Luperi strongly suggested chasing down Bob Seaman, the XLR-99 project leader

Bob Seaman and Wife with Interviewer Laurenz Schmidt

Robert W. Seaman
LR-99 Project Leader

…The R&D department chief Dr. Paul F. Winternitz wanted the rocket motor to run on NH_3/LOX.

"I have worked with quite a few propellant systems and found NH_3/LOX to be among the easier ones to work with. We did encounter a few challenges along the way, but none were related to the fuel itself."

Bob Seaman (center), ~1960

Why was NH_3 chosen as fuel

- The directive to use NH_3 came from Dr. Paul F. Winternitz, a propellant scientist from Austria.
- Dr. Winternitz had to find a fuel that would be stable, would be easy to keep, show a good volumetric energy density, work in the temp range and allow conclusions for a later H2 fuel system.
- NH_3/LOX fit the bill and it worked!
- Later, when gravimetric energy density was more important than volumetric energy density (for the Shuttle) H_2 was preferred

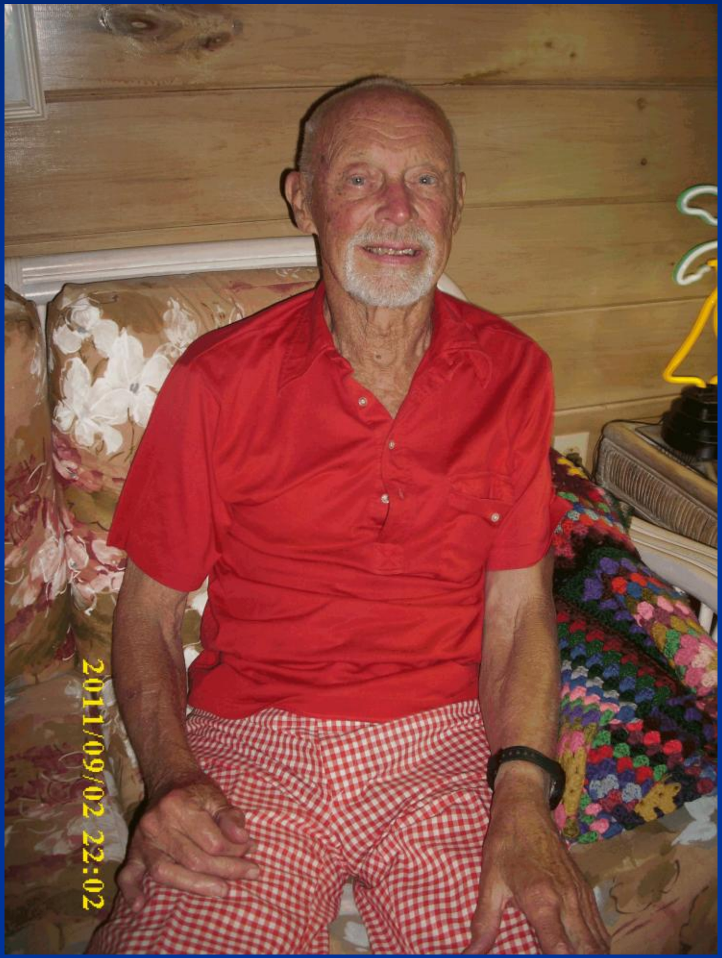
Problem was…

- It was pretty clear that Dr. Winternitz was no longer with us
- And, no one knew precisely what Dr. W's rationale was for using NH_3 in the X-15

what Dr. W's rationale was for using NH_3 in the X-15

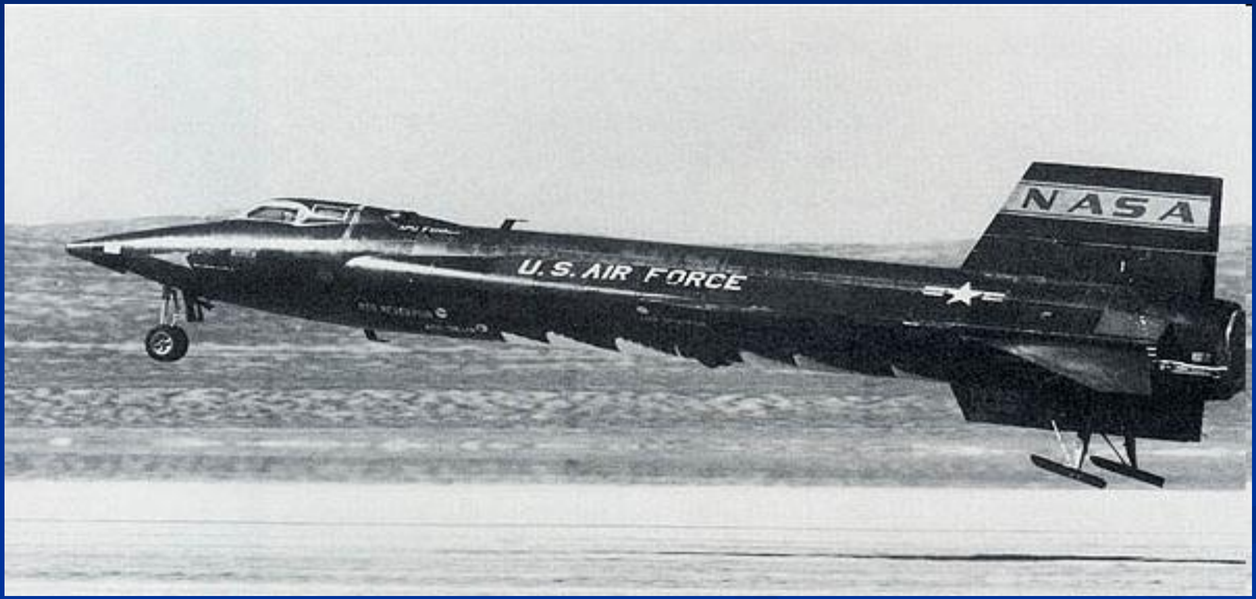
- Back to Mario Luperi who suggested trying Rita Dudak Dwyer, another RMI retiree
- Rita suggested George Huson as possibly "the man" and got us in contact

George Huson, Project Engineer



- George was a bright young engineer who joined RMI in 1955
- Worked for a well respected rocket engineer named Robertson Youngquist
- Youngquist had earlier patented a rocket motor cooling system in 1946
- In looking at fuels that would have excellent cooling properties, he came up with NH3
- He and his boss went to the NASA project manager, and had their suggestion approved

The X-15 with the LR-99 motor

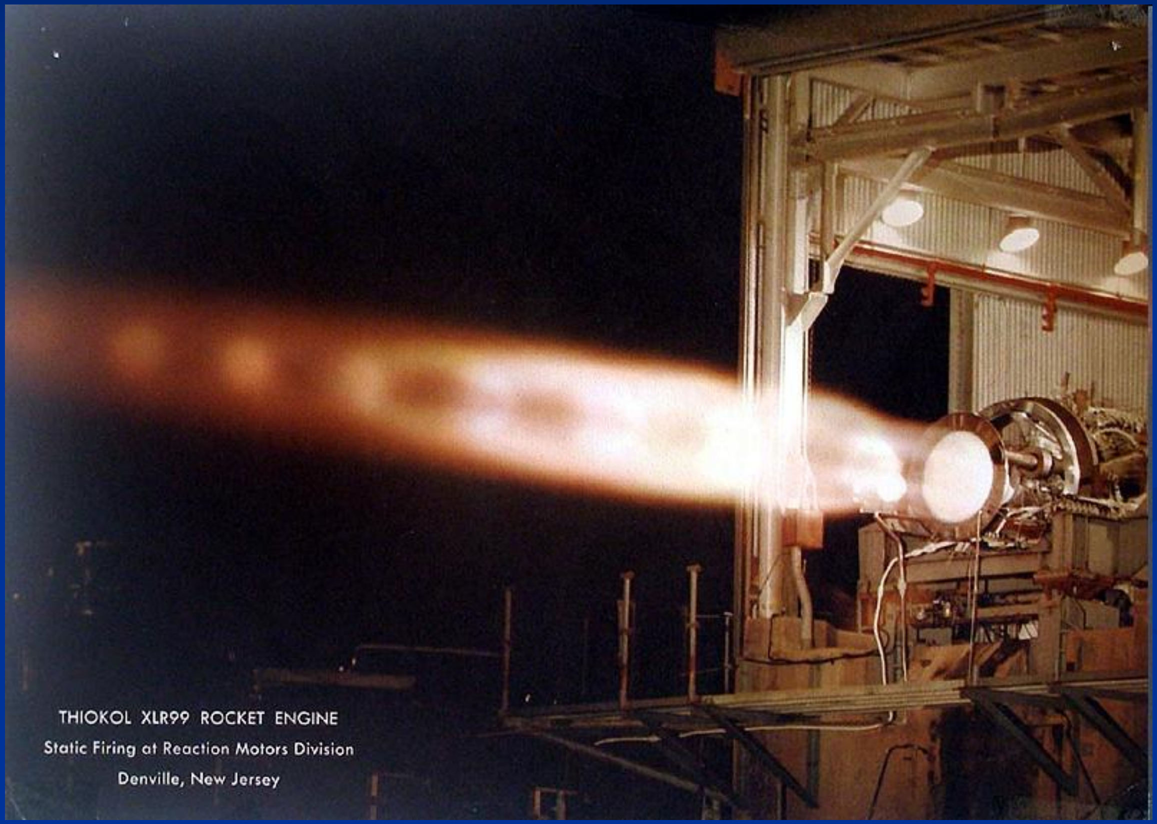


The X-15 is perhaps the most ambitious aircraft ever created. It was built to push the limits of flight and explore the possibilities of space travel. During its research program the aircraft set unofficial world speed and altitude records of 4,520 mph (Mach 6.7 on Oct. 3, 1967, with Air Force pilot Pete Knight at the controls) and 354,200 ft (on Aug. 22, 1963, with NASA pilot Joseph Walker in the cockpit).

Photo of LR-99

The LR-99 was the first large, "man rated," throttleable, restartable liquid propellant rocket engine. The throttle setting could be varied from about 30 percent to 100 percent of thrust, and the restart capability allowed it to be shut down in flight with the assurance that power would again be available later, if needed. The range between 30% -50% throttle was almost never used as it tended to result in unstable operations of the engine. The LR-99 was one of the rocket engines used in the X-15 manned research aircraft which was capable of propelling man to the fringes of space.

Stationary Test of XLR-99 Denville NJ



The "pulsations" are supersonic shock waves from pressure adjustments that go on in the exhaust.

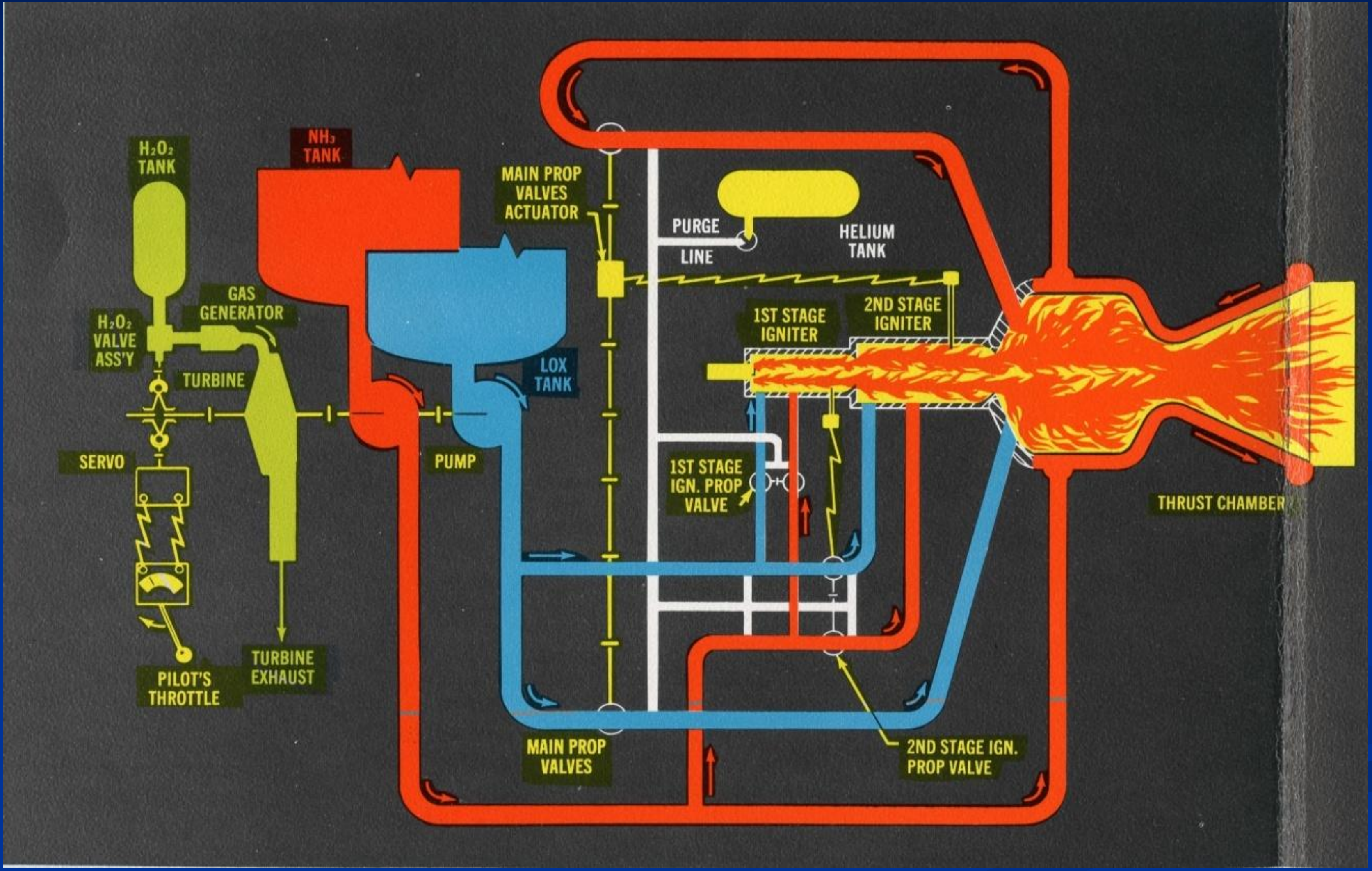
X-15/LR-99 at the Smithsonian

http://www.extension.iastate.edu/registration/events/partlists/nh3.html

RMI Precursors to LR-99

- Atlas – HC plus LOX
- Titan – Hydrazine plus nitrogen tetroxide (N2O4)
- Superperformance engine –Jet fuel & H202
- Bell X-1 "Glamorous Glennis" – Ethanol plus LOX

LR-99 at Full Throttle



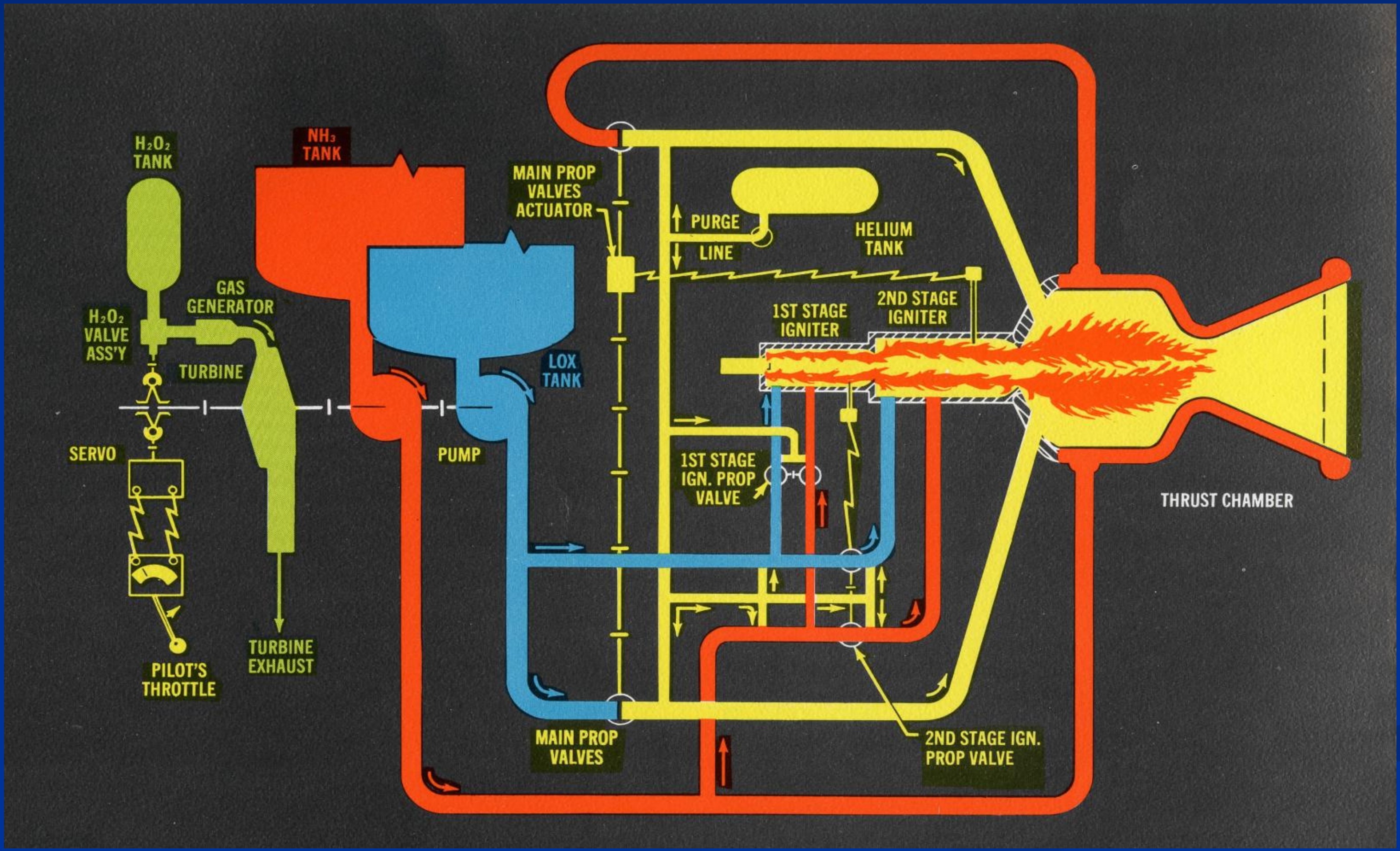
3 Stage Ignition

Specific Heat (kJ/kg-K)

- Water = 4.2
- Gasoline = 2.2
- Ammonia = 4.7

NH3 is one of the very few liquids whose specific heat is as high or higher than water.

Second Stage Burn



Why was the X-15 built?

- To explore whether it was possible to design a controllable airplane that could fly and survive hypersonic speed.
- To test if there were materials that would withstand both stress and temperature.
- To test if the airplane would be controllable outside the atmosphere (through attitude rocket motors).
- The answers to all of these is …. YES, it was possible! Up until today the X-15 hold speed and altitude records for airplanes.

  The knowledge gained from the X-15 was vital for the design of the Gemini and the Apollo missions, but most importantly for the later Space shuttle

Challenges along the way

- In one of the pre-flight rating test, when the LR-99 was still the XLR-99 the motor disintegrated. Fuel explosion?

  No… the answer was that a small design change shifted the resonance frequency of the injectors to 1450 Hz, where the motor put out quite a lot of energy and the injectors tore apart. Insulating and detuning them solved the problem

- In a pre flight test the motor exploded. First it looked like a fuel explosion. Then they noticed the engine was compacted rather than blown apart and we could not find a piece of the H2O2 tank. The conclusion was the H2O2 explosively decomposed.

Highlights of X-15 Program

- Start in 1955, after fierce competition, the program got awarded to North America Aviation Inc. The Air Force was the contractor and NASA the sponsor.
- During 8 operational years the program cost about $ 300 million in 1969 $, each flight averaged about $ 600,000.
- There were a total of 12 test pilots flying the X-15 in 199 flights. One, Mike Adams, crashed on flight 191 and lost his life.
- Speed record : Mach 6.7 (or 4,520 Mph) Flt. 188 10-03-67
  Pilot : William J. "Pete" Knight
- Altitude record: 354,200 ft (or 108 km) Flt. 91 08-22-63
  Pilot: Joseph A. Walker

Reaction Motors Inc.

- Built XLR-10 (Viking Rocket—alcohol + O_2)
- Built XLR-11 (Bell X-1 – First aircraft to break sound barrier;) [I think I got this right]
- During the Viking and the LR-99 program RMI had approximately 1000 employees, 300 of them worked on the XLR-99, later the LR-99
- RMI worked at the same time on a 6000 lbs thrust H_2O_2 motor, that program got cancelled later

Basic Specs of the X-15

- X -15
  - Length — 50ft
  - Wingspan — 22 ft
  - Fuel capacity — 1000 gal LOX 1400 gal NH_3
  - Airweight — 33,000 lbs launch
    14,700 lbs landing
  - Material — Inconel – X
    to withstand 1200° F skin temp.

Basic Specs of the X-15

- LR-99

- Thrust throttleable from 28,500-60,000 lbs
- Weight 910 lbs
- Pressure 600 PSI (combustion chamber)
- Burn rate 30 gal LOX and 42 gal NH_3 / sec

The motor had to be rebuilt after max 2 hours of operation

BACKUP SLIDES

Topics

- The X-15 Program and Plane
- Reaction Motors Inc.
- The XLR-99 Engine
- Choice of NH3 to Fuel the X-15

- Rocket engine not stoichiometric
- NH_3 Fuel rich – reduced molecular weight
- Specific impulse – Thrust/flow rate
- $T_c/\bar{m}$ –bar
- Cooling capability = (pounds/sec) * specific heat – better than HC
- 10 Btu/sec-in^2 – throat of rocket
- Pencil and paper – simultaneous equations

- High flame temperature
- Presence of NOx and N2O parasitic
- Needed to calculate performance

Zero-Emission Combustion

- Only hydrogen and ammonia burn without emitting greenhouse gases (contain no carbon)
- Also, no CO, SO_x, or NO_x
- Hydrogen combustion--

$$H_2 + O_2 \rightarrow H_2O$$

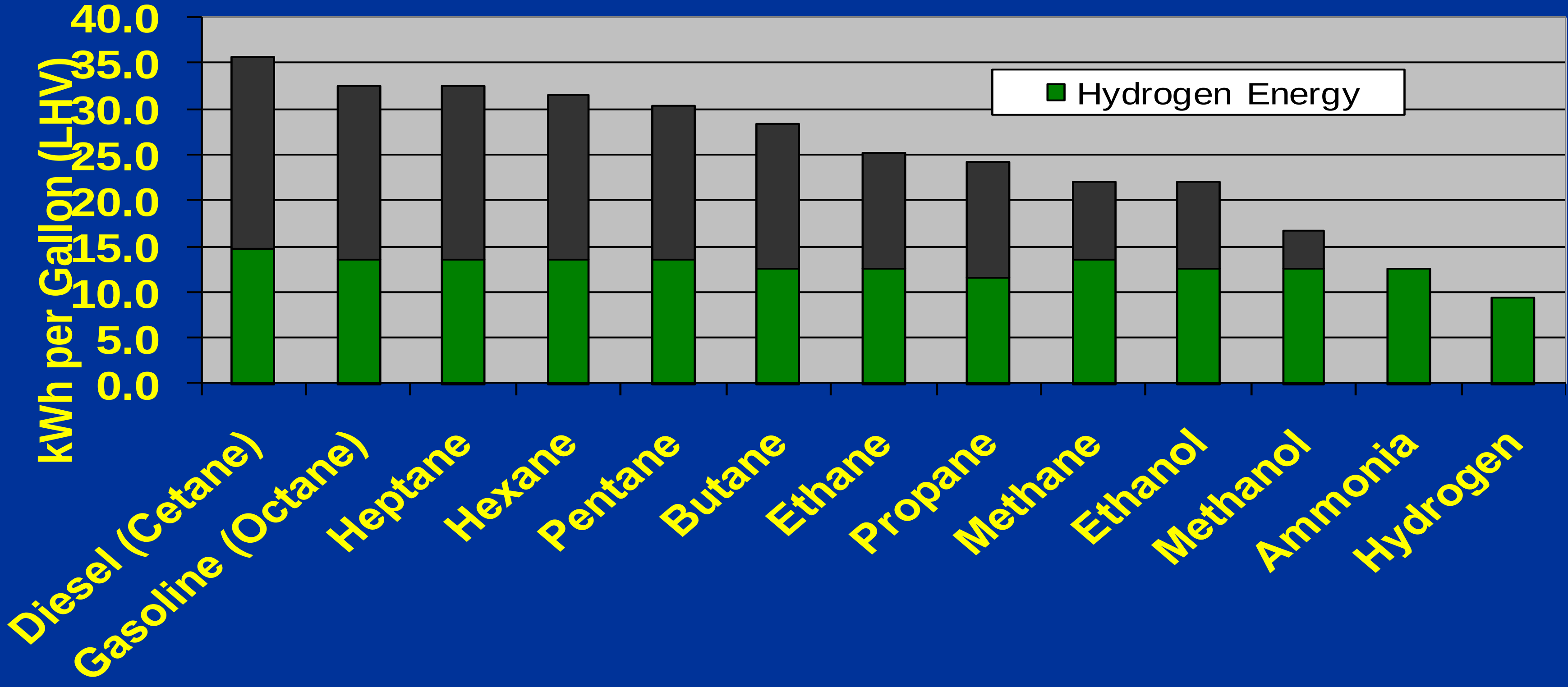
(water only combustion product)

- Ammonia combustion--

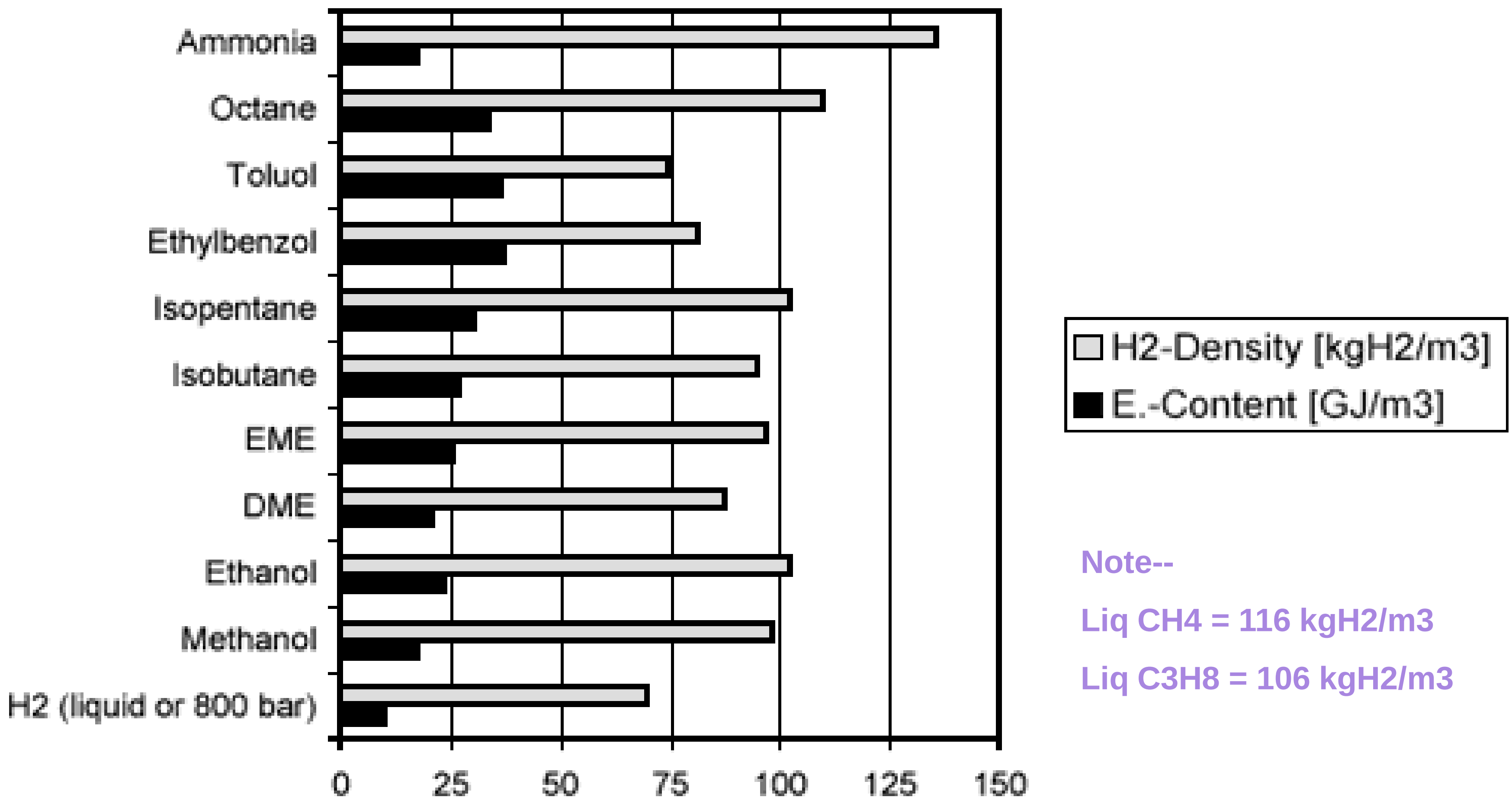
$$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$$

(nitrogen and water only combustion products)

Volumetric Energy Density



H_2 and Energy Density for Various Fuels



Note--

Liq CH_4 = 116 kgH2/m3

Liq C_3H_8 = 106 kgH2/m3

Hydrogen density and HHV energy content of ammonia and selected synthetic liquid hydrocarbon fuels

Bossel et al., *The Future of the Hydrogen Economy: Bright or Bleak?,* Oct 28, 2004
http://www.oilcrash.com/articles/h2_eco.htm

Ammonia Fuel History

- 1930s Norsk Hydro
- 1940s Belgium—Ammonia Buses
- 1960s U.S. "Energy Depot" (Vito)
- 1960s X-15 Rocket Plane
- 1974 Univ Tennessee Ammonia AMC Gremlin
- 1981 "Hydrofuel" (Vezina)
- 1994 & 1996 Avery and Steele "Ammonia Economy" papers
- 2004 1st AFN Conf
- 2007 Hydrogen Engine Center—Ammonia Generator

Ammonia Safety

- Inhalation hazard, so must be handled with respect
- Millions of tons are stored, transported, and handled every year with an excellent safety record
- Not corrosive
- Not explosive nor highly flammable
- Can be stored at moderate pressures
- Safer than gasoline or propane
- Lighter than air
- Trapped by water
- Not a greenhouse gas