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AFRL/PRS

5 Pollux Drive

Edwards AFB CA 93524-7048

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Air Force Research Laboratory (AFMC)

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9 items enclosed

3) Paper Rec'd After 30-day Deadline = Past Due = No rush issued
reluctant

FILE

MEMORANDUM FOR PRS (In-House/Contractor Publication)

FROM: PROI (STINFO)

29 August 2002

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-VG-2002-209**
Tom Hawkins (PRSP), "Green Propulsion - A USAF Perspective" (viewgraphs)

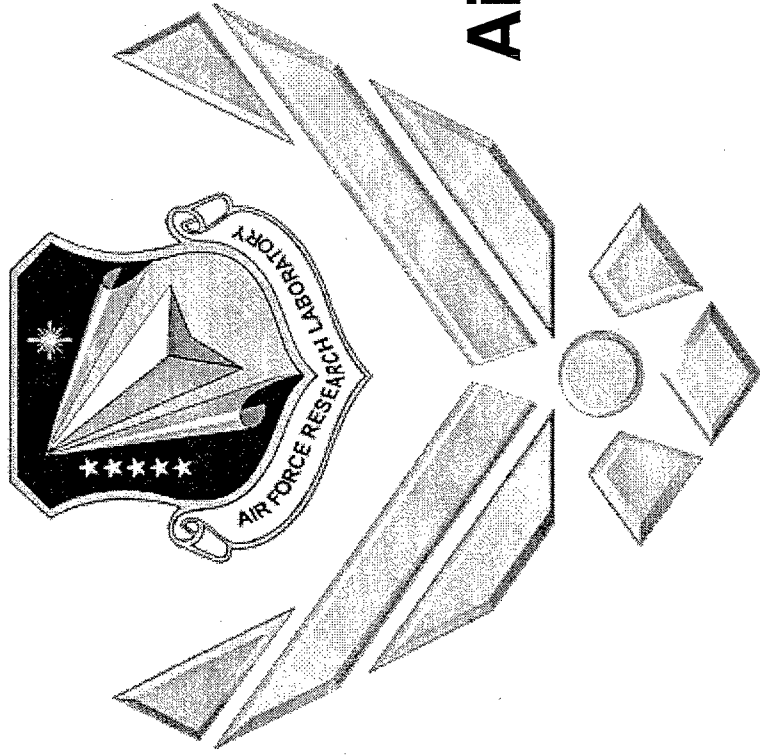
55449

5th Int'l Hydrogen Peroxide Propulsion Conference
(Lafayette, IN, 15-19 September 2002) (Deadline: 12 Jun 01 = Past due)

(Statement A)

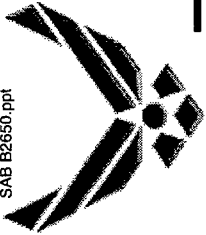
GREEN PROPULSION- A USAF OVERVIEW

September 2002

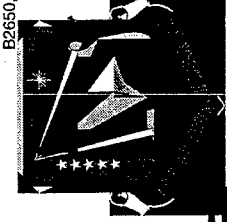


Dr. Tom Hawkins
Air Force Research Laboratory

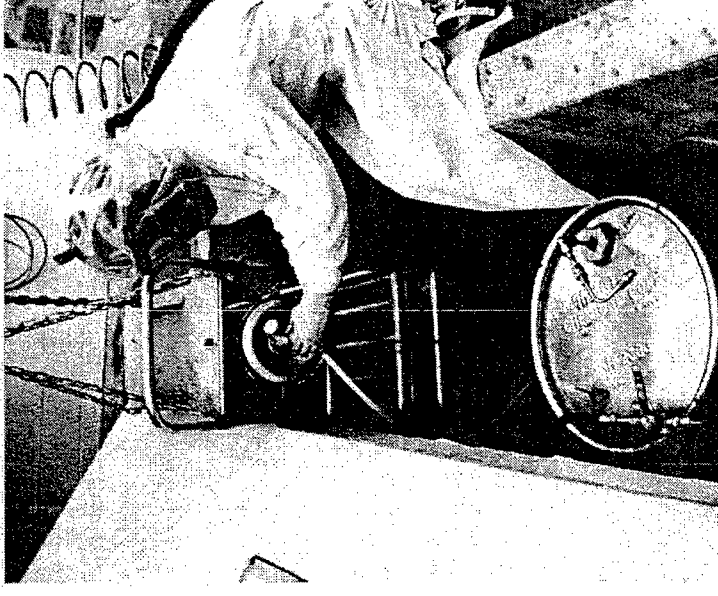
Distribution authorized for public release



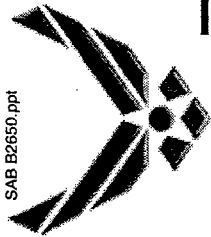
Issues and Drivers



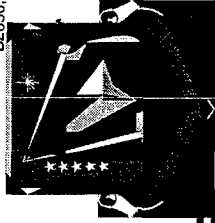
- Increased Testing and Operations Costs:
 - System Handling/Fueling
 - Monitoring System in Field
 - Delays in Launch for Corridor
 - Hazardous/Carcinogenic Vapor (Respiratory Route)
 - Dermal Toxicity
- Performance of SOTA Propellant
 - Desire Improved Isp and D*Isp
 - Improved Capabilities (Payload and Range)



System Handling/Fueling



Propulsion Systems



- Solid Boost Propulsion
 - Perchlorate-Based Propellants

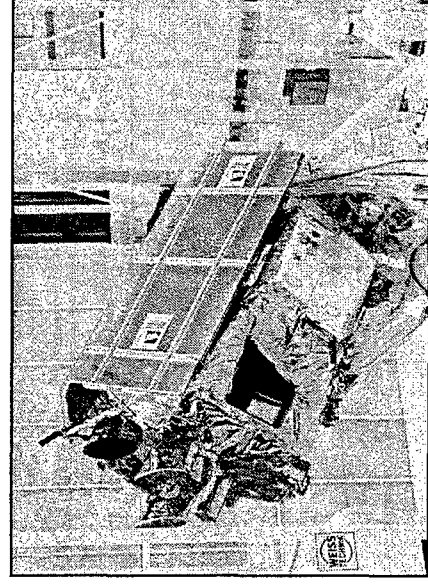
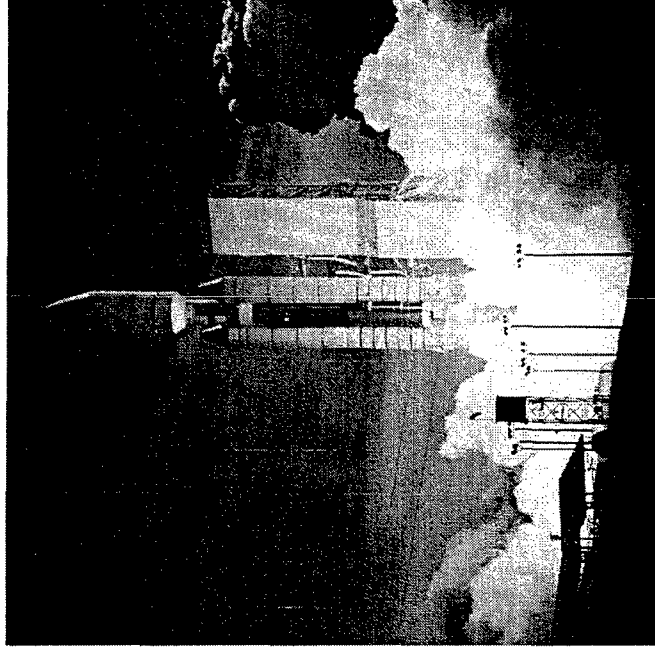
<u>System</u>	<u>Mission</u>
Titan IV	Satellite/Payload Delivery

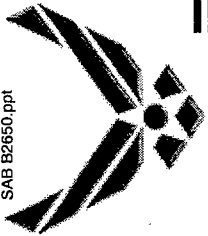
- Liquid Propulsion
 - NTO/MMH Bipropellant

<u>System</u>	<u>Mission</u>
Delta IV	Satellite/Payload Delivery

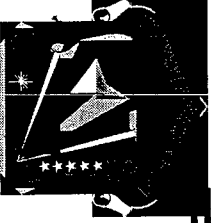
- Spacecraft Propulsion and EPU Power
 - NTO/MMH Bipropellant
 - Hydrazine Monopropellant

<u>System</u>	<u>Mission</u>
FltSatCom	Communications



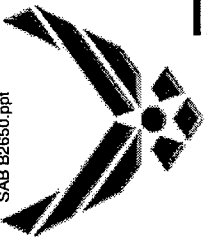


AFRL “Green” Propellant Development

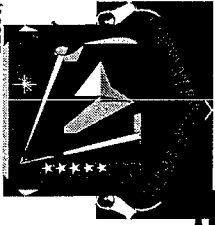


Background

- Performing “Clean” Solid Propellant R&D Since the mid 1980s
- Led Programs in Developing “Clean” Propellants and Manufacturing Processes
- 1997 White House Closing-the-Circle Award for Innovative Environmental Technology Development
- Developing Energetic, ‘Green’ Liquid Oxidizers Since 1993
- Initiated work in ‘Green’ Monopropellants in 1995

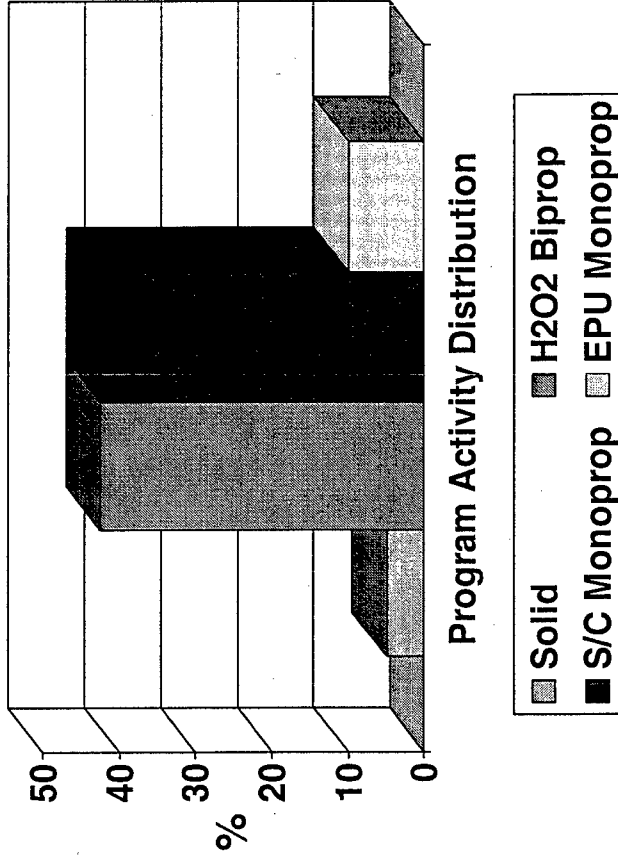


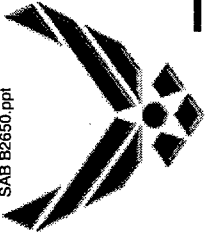
USAF Green Propellant Efforts



Over Last Year:

- USAF Liquid Propulsion
 - Evaluating Peroxide-Based Bipropulsion
 - Developing Green Spacecraft Monopropellant
 - Developing Alternative Monopropellant for APUs
- USAF Solid Propulsion
 - Completed SERDP Program Developing Greener Propellant





SERDP Green Missile Propellant

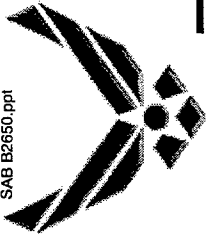


Objective

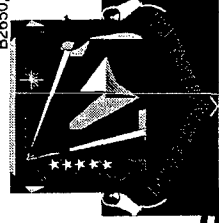
- Try to Achieve Performance Levels of Commercial Space Launch, Solid Propellant
- Determine the Potential of Nanofuels to Improve Properties (Performance, Mechanical Properties, Hazards, etc.) of Cleaner Combusting Solid Propellant for Space Launch Boosters

WFZ Baseline Propellant:

Developed as a Chloride-Free, Space Launch Booster Propellant Under USAF Contract by Alliant Technologies and Demonstrated in 800 lb. Motor

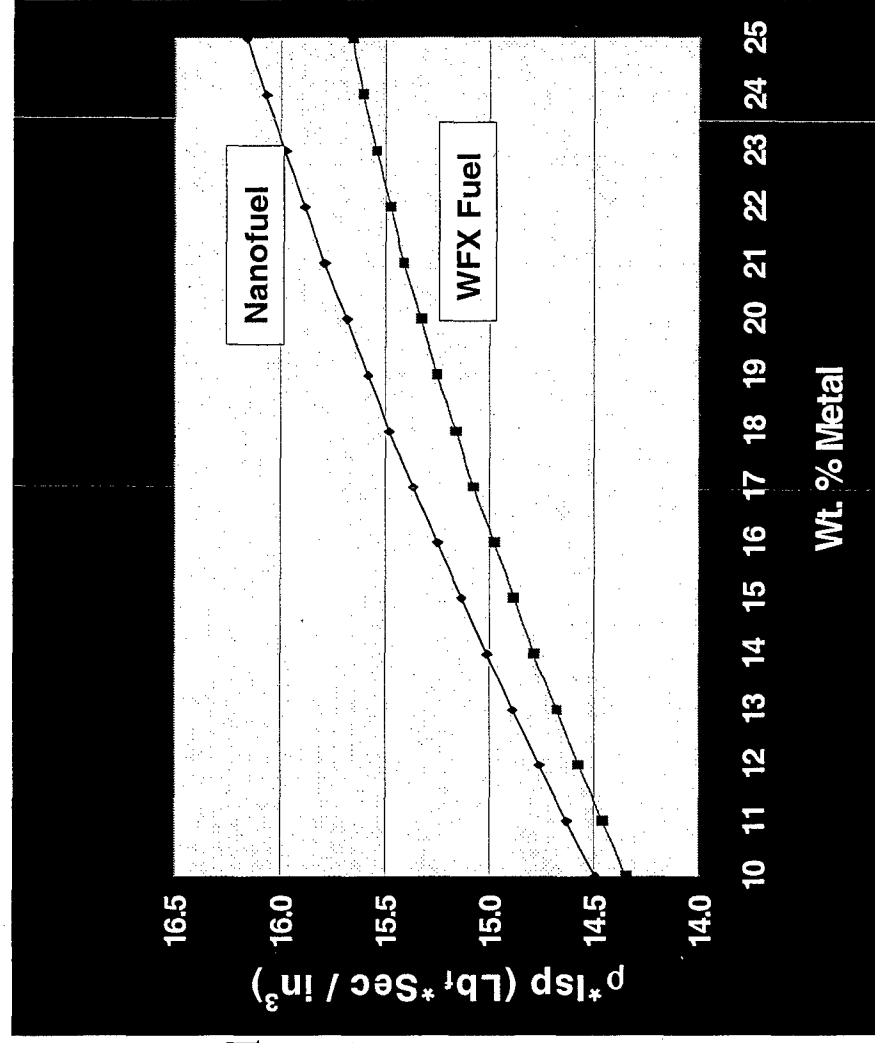


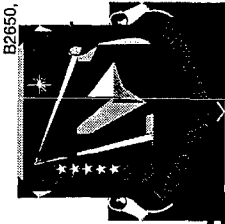
Payoff



Need: Improvement Over WFX in Density Impulse

- Effect of Nanofuel on Propellant Isp
 - Little Change in Theoretical Isp in Substituting WFX Fuel with Nanofuel
- Effect of Nanofuel on Propellant Density
 - Significant Increase in Propellant Density and Volumetric Impulse with Nanofuel

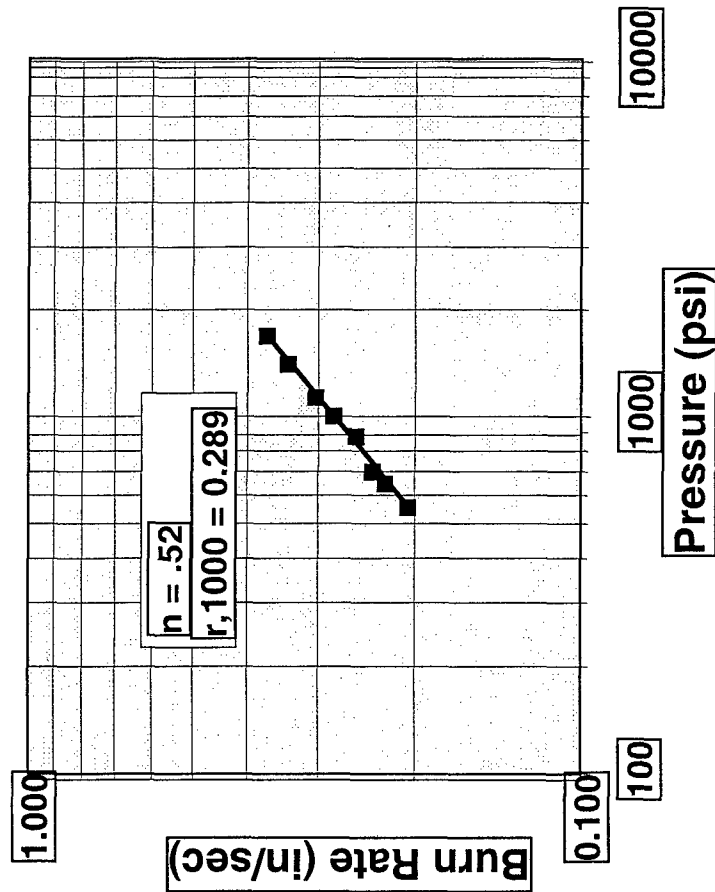




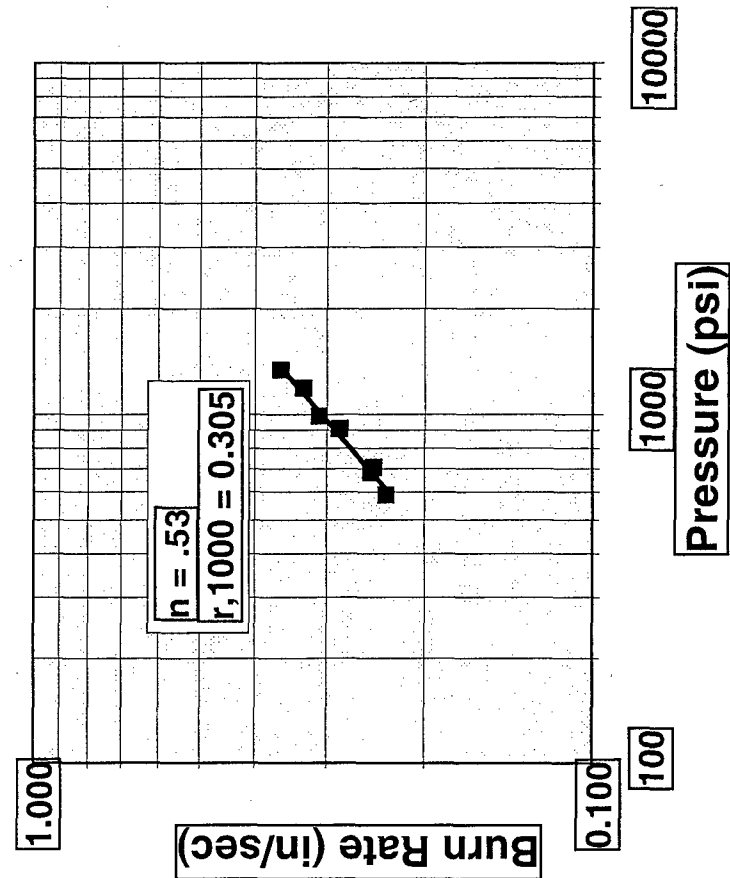
Motor Ballistics

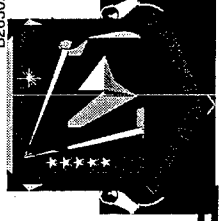
Successful Series of Small Motor Firings Using Modified Propellant

WFZ Baseline

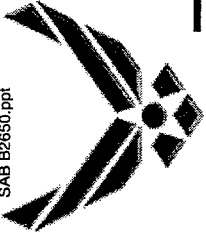


Modified Propellant-18% Nanofuel

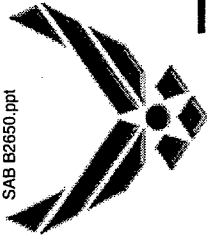




Program Summary



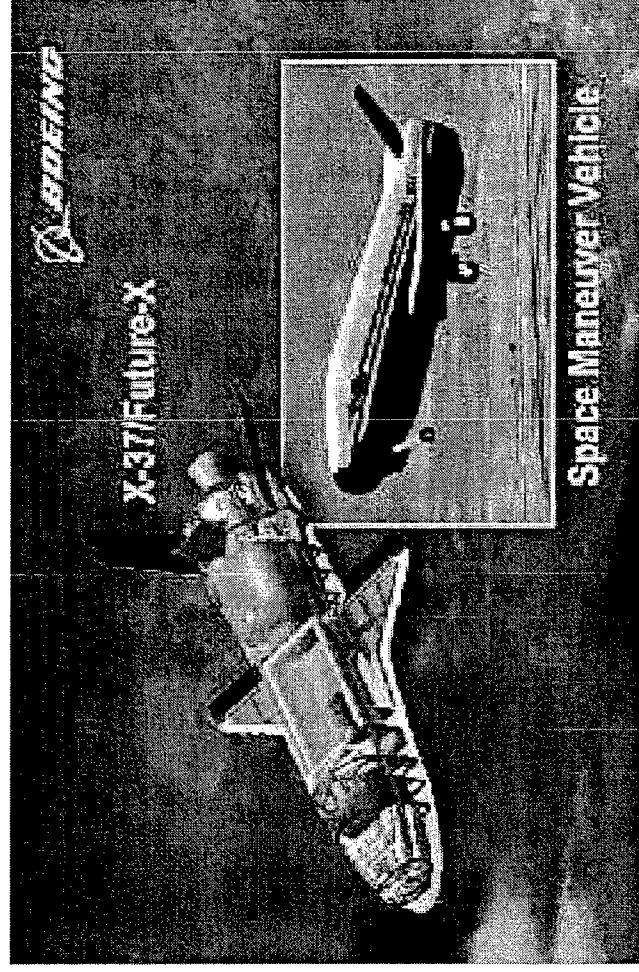
- Nanofuel Addition Did Not Adversely Affect Propellant Processability (End-Of-Mix Viscosity Remained <3KP)
- Hazards
 - Modified Propellant Maintained “Zero” Card (NOL Card-Gap Test)
 - Increased Propellant Impact Sensitivity (160 Kg*cm) and Friction Sensitivity (265 N), But Still Within an Acceptable Range
- Significant Increase in $\rho \cdot I_{sp}$ from 15.5 to 16 lbf*sec/in³ with Little Change in I_{sp}
 - Equates to > 500 lb Increase in Payload (GSO) Compared to Motor with WFZ Clean Propellant
- SERDP Program Completed- USAF Continuing Research in Nanofuels

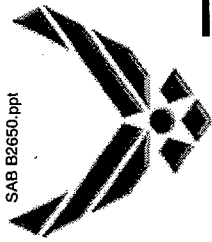


Peroxide-Based Bipropellant

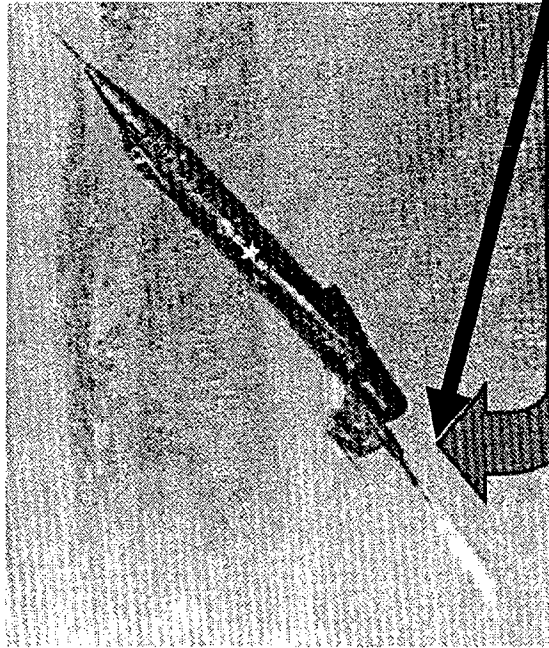


- Boeing X-37 technology carried on Air Force Long Range Plan as SMV vehicle technology demonstrator
- Proposed X-37 main engine, AR2-3, meets reusability objectives, but did not meet current storable bipropellant performance objectives
 - AR2-3 Isp 246s vs. 320s
 - AR2-3 developed 1950's
- Technology short fall prompted Congress to fund AFRL SMV Tech Demo

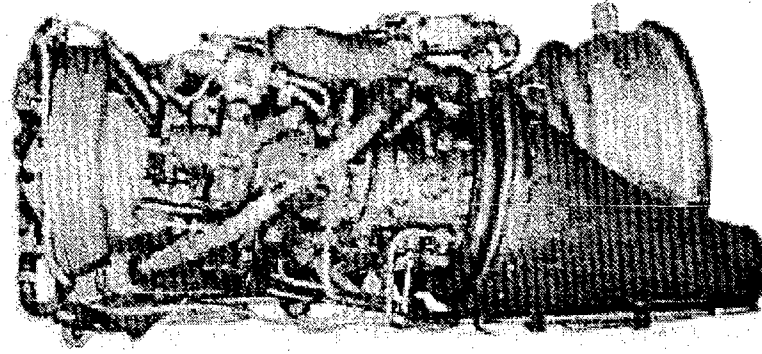




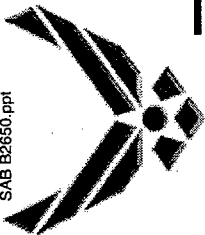
H202 Reusable State-of-the-Art



NF-104



AR2-3

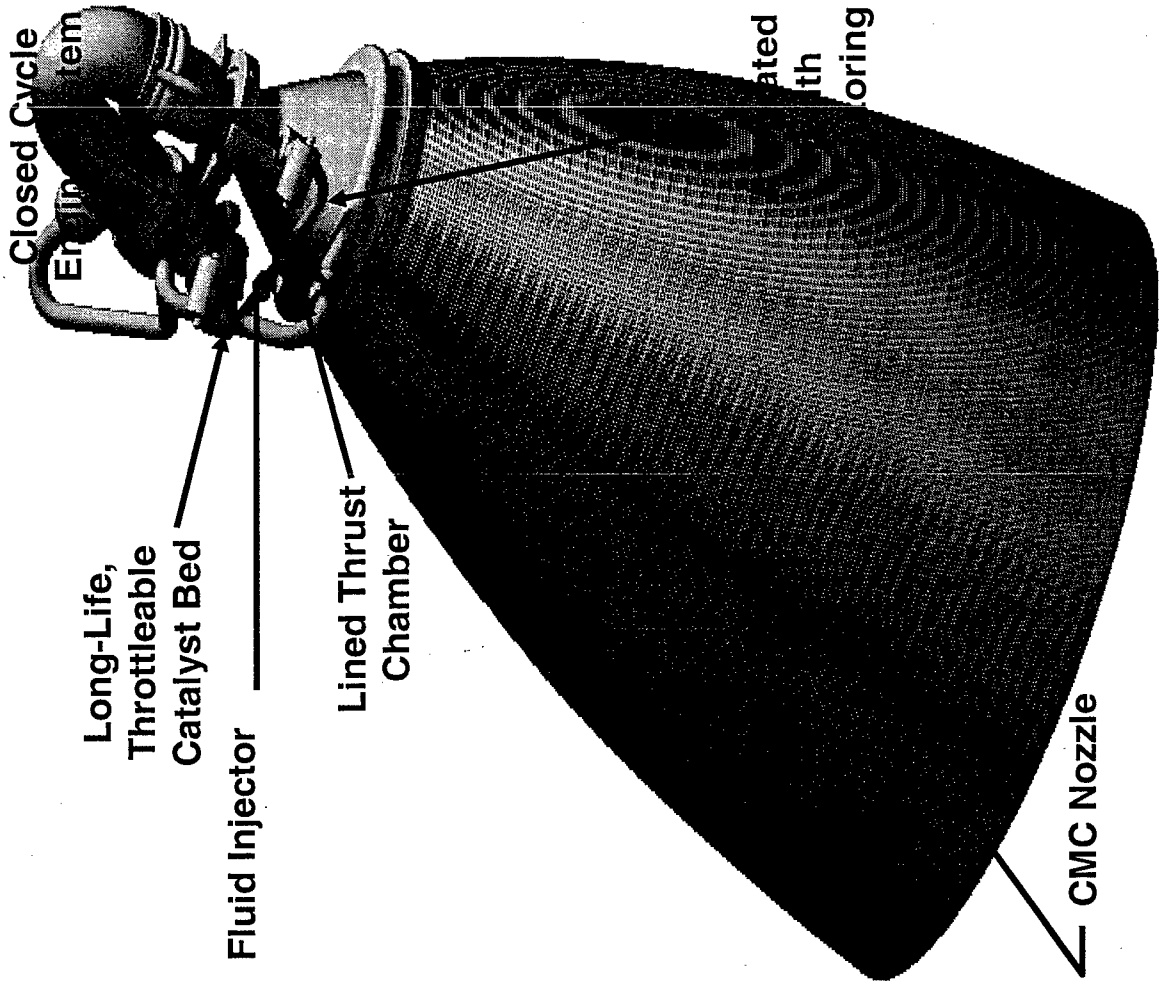


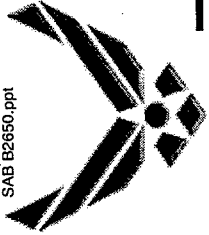
Phase II Aerojet Engine Technology

B2650.



- Aerojet's Advanced Reusable Rocket Engine (ARRE) Provides the Air Force with an Advancement in Reusable, Rocket Engine Technology for SMV Applications
 - 98% Hydrogen Peroxide Propellant Improves Vehicle Operations
 - Closed-Cycle Engine System Provides High Performance and Throttleability
 - Component Designs That Improve the Engines Life and Enable its Reusability and Operability

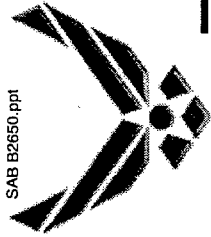




Program Status



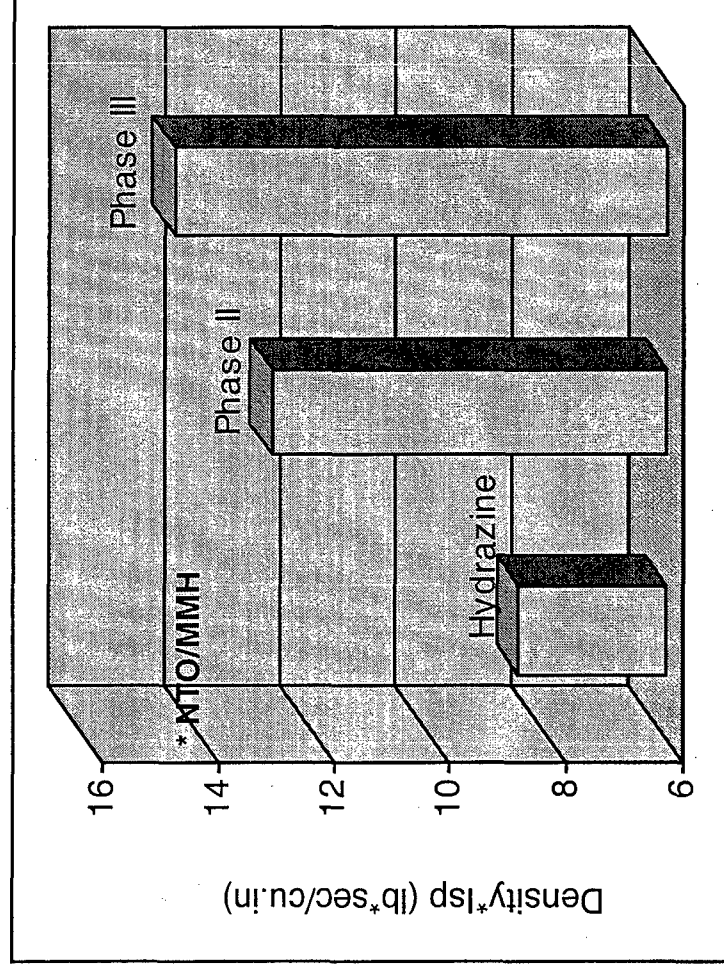
- System preliminary design review complete
- Thrust chamber (injector & chamber) fabrication/assembly underway
- Injector test scheduled for 1QFY03
- Injector test with regeneratively cooled chamber scheduled for 2QFY03



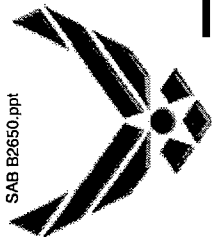
Advanced Spacecraft Monopropellant Performance Objectives



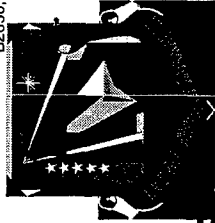
- Increase Density Isp of New Monopropellants for IHPRPT Demonstration:
 - 50% by 2005
 - >70% by 2010
- New Monopropellants to Have Reduced Toxicity- Allowing Operations w/o SCAPE-suited Crews



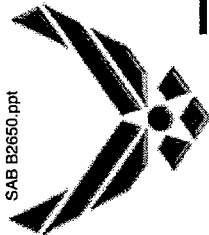
USAF is Lead for IHPRPT Monopropellant Development



Desirable Monopropellant Properties



Characteristic	Objective
Density Isp [2.07 MPa- vac, exp=50] Vapor Toxicity Carbon Content Melting Point Detonability [NOL Card Gap] Impact Sensitivity [Drop Weight] Adiabatic Compression [U-Tube Test] Thermal Stability Critical Diameter	>50 % (Over SOTA) Does Not Require SCBA No Solid Carbon Forms in Theoretical Exhaust < 2°C Class 1.3; (Prefer 24 Cards Maximum (E ₅₀)) 20 kg-cm Minimum (E ₅₀) No Explosive Decomposition (Pressure Ratio of 35) < 2% by wt. Decomposition for 48 hrs at 75 °C No Propagation in Lines of < 1.91 cm Diameter



Advanced Propellant Characteristics



Properties	AFN1	Hydrazine
Isp , sec; (a)	261	233
Density , g/cc	1.46	1.01
Chamber Temp. (Theoretical) , K	2083	883
Carbon Content of Exhaust; (b)	none	none
Impact Sensitivity* , kg-cm (5 negatives)	60	>200
Friction Sensitivity, N (5 negatives)	300	>371
NOL Card Gap (at 69 Cards)	negative	negative
Thermal Stability, % wt loss/48hr, 75°C	1.96	(< 0.1)
Melt Point, C	<-22	1

a: Theoretical, calculated with 2.07 MPa chamber pressure, exhaust to vacuum, 50/1 expansion

b: as soot or solid carbon (by theoretical computation)

c: by DSC; melt transition was broad, melt peak reported

*: For reference, n-propyl nitrate had an impact sensitivity of 8 kg-cm

Propellant Displays Acceptable

Safety/Sensitivity Properties For Continued Development



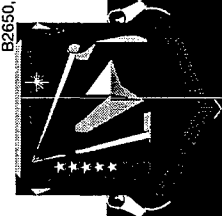
Toxicology

Results

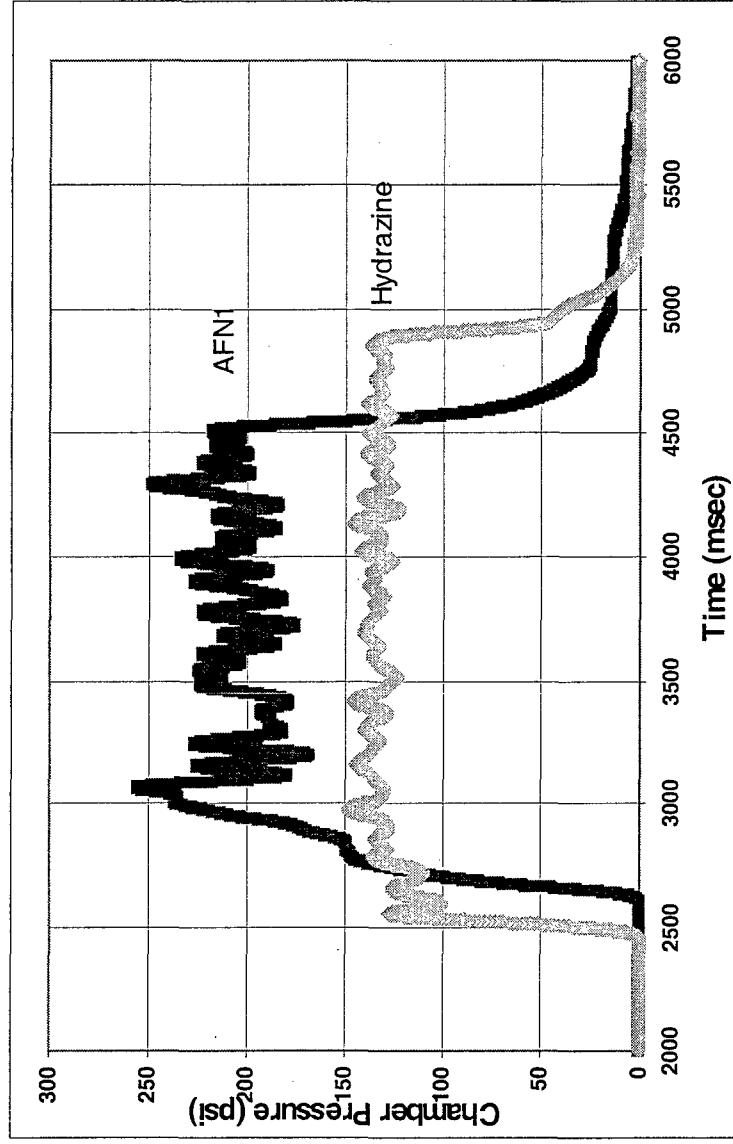
PROPERTY	AFN1	HYDRAZINE
LD50 (rat), mg/kg	325-367	60
Dermal Irritation	Slight-Moderate	Corrosive
Genotoxicity (Ames)	3 Negative/ 2 Positive	Positive

Evaluation:

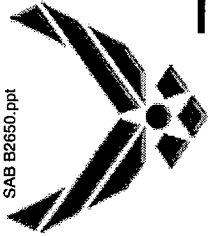
- 6X Less Oral Toxicity Than Hydrazine
- Low Dermal Irritation
- Genotoxicity (Bacterial) in 2 of 5 Strains (and negligible vapor hazard)



High Performance , Reduced Toxicity Monopropellants



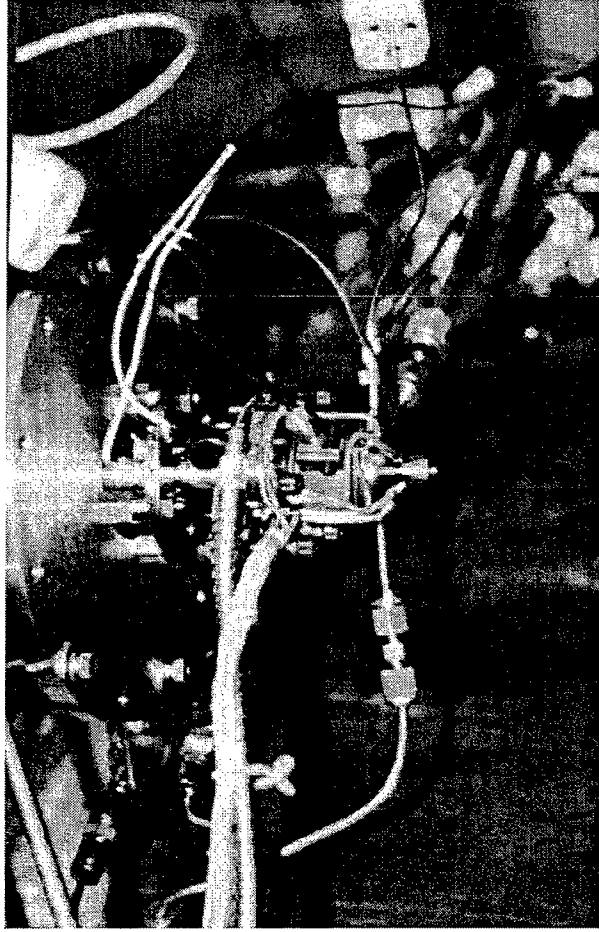
- Thruster Chamber Pressure Profile for High Performance Propellants
- Ignition Delay Varied (ca. 150 msec Rise Time)
- Stable Combustion ($\pm 5 - 15\%$ Variation in Pressure)



High Performance, Reduced Toxicity Monopropellants

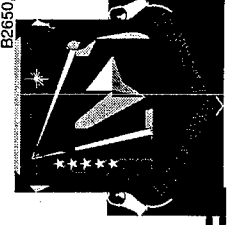


- Multi-kg scale-up of AFN1 propellant
- Testing underway with industry partners



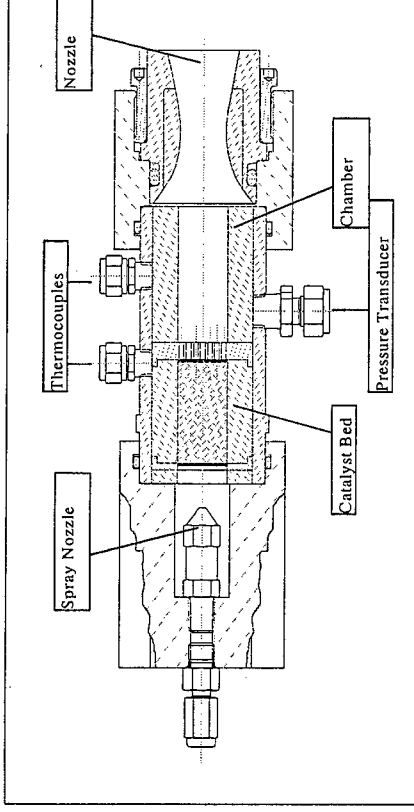
Initial Results-Thruster Test

- Repeatable Ignition
- Catalyst Degradation
- Acceptable Pc Roughness

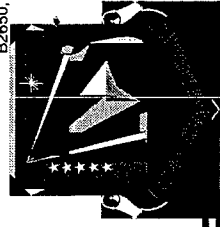


Demonstration Program

- Thruster demonstration program initiated 2002
- AFRL supplies propellant expertise, materials and characterization to commercial hardware integrator
- Incorporate high temperature hardware
- Maximize heat dissipation

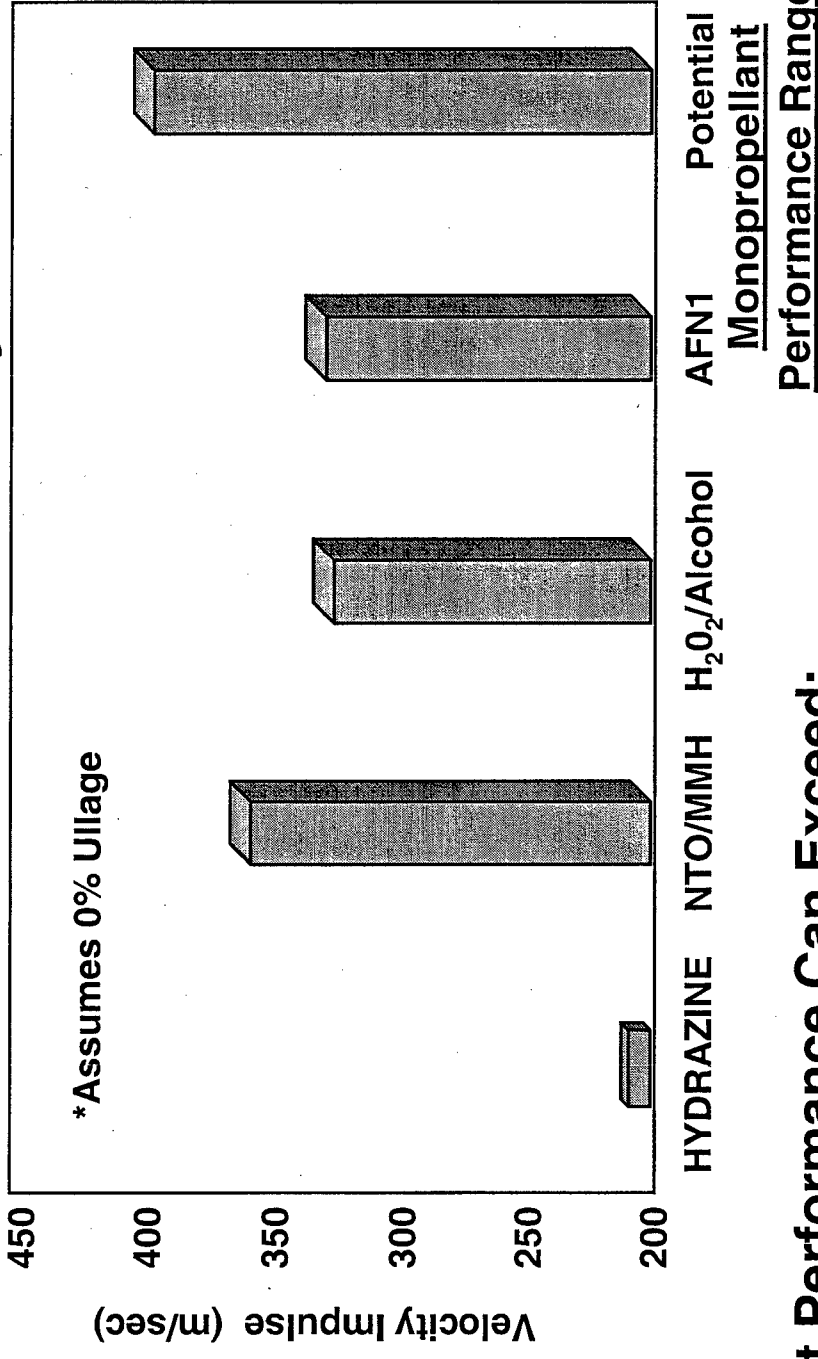


- Objectives:
 - Engineer feed and injector system
 - Design efficient catalyst bed configuration
 - Optimize propellant for fast ignition



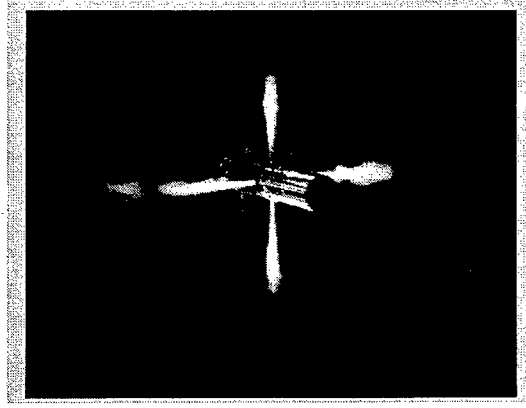
Performance Payoff

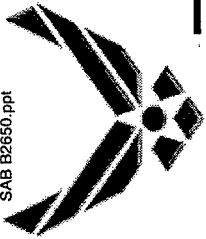
Microsatellite Trade Study



Monopropellant Performance Can Exceed:

- Hydrazine
- H₂O₂/Alcohol
- NTO/MMH



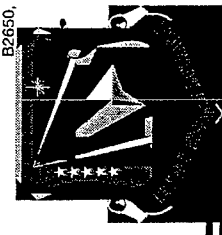


High Performance Monopropellants

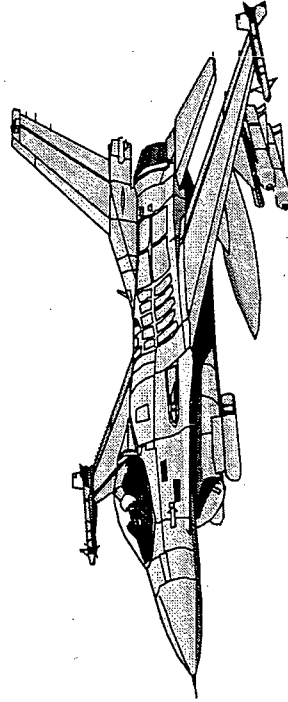
-Summary-



- Continue monopropellant development & characterization
 - Promising, new approaches
 - Incorporating high energy density molecules
 - Encouraging propellant properties
 - Performance potential to meet/exceed bipropellant
 - Simpler, lighter propulsion system
 - Critical work remains
 - Stability, material compatibility, rheology
 - Propellant ignition , high temperature catalyst/materials
 - Teamed with industry to transition research product



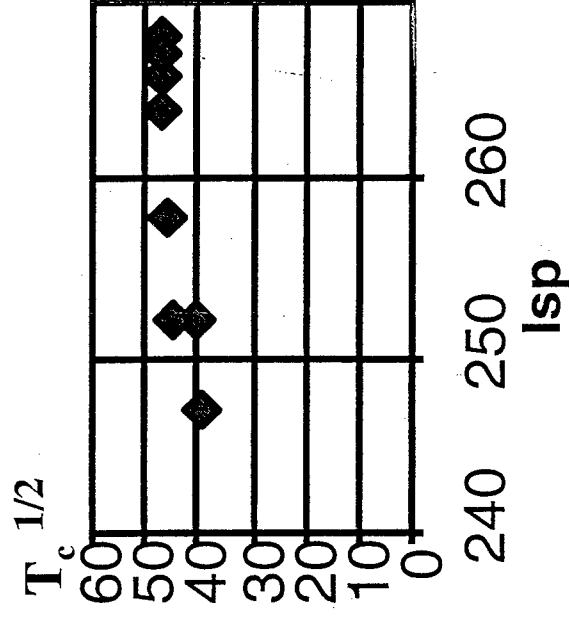
Hydrazine Replacement for Auxiliary Power Units

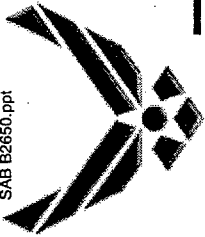


Can Spacecraft Monopropellant
Approaches be Modified for APUs?

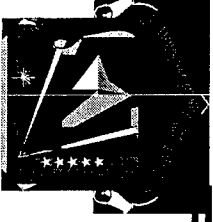
I. Reformulate Propellants

- Lower Performance/Combustion
Temperature (Compatible with Shell 405
Catalyst)





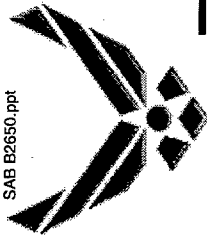
APU Feasibility Assessment Objectives



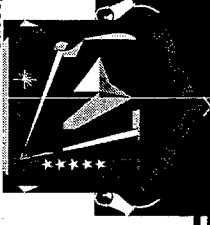
II. Property Characterization

- Select Propellant Types
- Produce Candidates for Evaluation
- Assess Physical, Safety/Hazard Sensitivities
 - Liquidity (233 K)
 - Detonability
 - Impact/Friction
 - Adiabatic Compressibility
 - Toxicity (Qualitative)





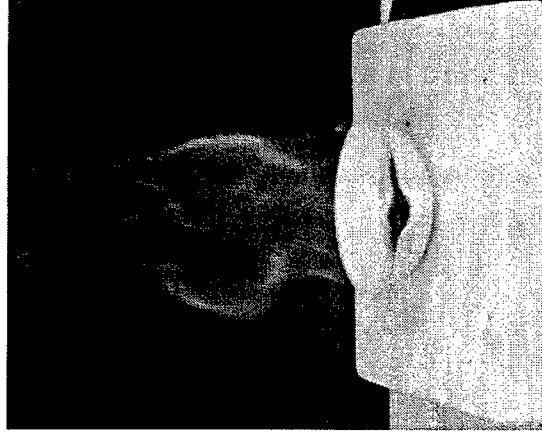
APU Feasibility Assessment -Objectives-

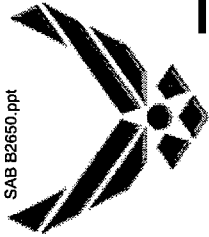


II. Property Characterization (cont.)

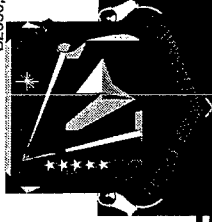
- Evaluate Ignition Delay of Candidates on Shell 405
- Drop/Splash Plate Test
- AFRL Pino Test

SPLASH PLATE TEST OF A
PROPELLANT





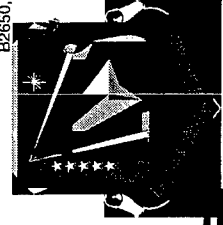
Propellant Ignition Assessment



AFRL Pino Test

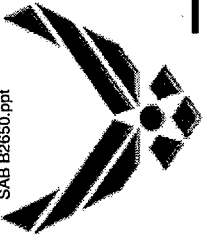
- Pressure: 750 torr
- Catalyst Temp: 400 C
- Ignition Response
Time < 20 msec

Shell 405
Catalyst



APU Program Summary

- Monopropellant Formulation Study
 - Candidate assessment and selection completed
- Property Characterization
 - Propellant candidate production completed
 - Physical property tests completed
 - Safety/Hazard tests completed
 - Catalyst reactivity tests in progress



Conclusions



- **USAF sees winning combination of green propulsion coupled with high performance**
- **Significant technical progress made in “green” solid propellants, liquid bipropellants and monopropellants**
- **Continued support for this type of research and development is expected**