



An Evaluation of the Impacts of AF-M315E Propulsion Systems for Varied Mission Applications

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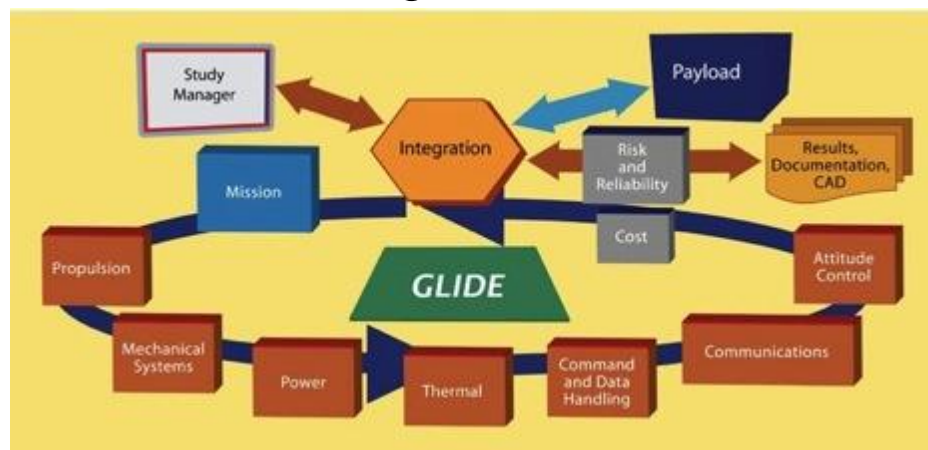
COMPASS Concurrent Engineering Team

(*Collaborative Modeling for Parametric Assessment of Space Systems*)

The **COMPASS team** is a multidisciplinary concurrent engineering team whose **primary purpose is to perform integrated vehicle systems analysis and provide conceptual designs and trades** for both Exploration and Space Science Missions.



Design Process



Data Transfer Process



Subsystem models integrated via a vehicle Master Equipment List worksheet

Over 100 designs to date!

Team formally established in 2006, Mission Driven COMPASS products tailored to support proposals, project reviews per NPR 7123.1A (especially MCRs & SRRs) and implementation of technologies COMPASS works very closely with other NASA flight centers, Gov't Organizations, Industry, and Projects

The concurrent engineering process produces solid engineering designs quickly without the rework needed by isolated teams



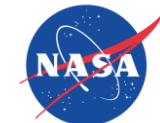
COMPASS AF-M315E Design Reference Missions (DRMs)

- Purpose: Develop design reference missions which show the advantages of the AF-M315E green propulsion system
- Approach: Utilize a combination of past COMPASS designs and selected new designs to demonstrate AF-M315E advantages
 - Use the COMPASS process to show the puts and takes of using AF-M315E at the integrated system level
- AF-M315E advantages compared to Hydrazine
 - Green propellant
 - Higher Isp
 - Better propellant density
 - Wider storage temperature range
- AF-M315E Challenges
 - Higher catalyst bed heater power

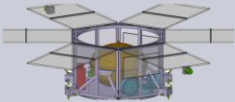
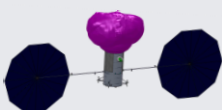
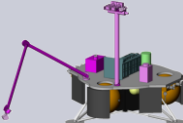
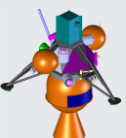
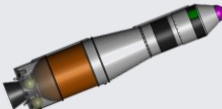
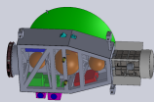


Study Purpose and Requirements

- The purpose of the AF-M315E COMPASS study is to identify near-term (3-5 years) and long term (5 years +) opportunities for infusion, specifically the thruster and associated component technologies being developed as part of the GPIM project.
- The range of potential missions that was considered for evaluation included, but not limited to:
 - Small experimental rideshare/SmallSat class
 - LEO/MEO missions
 - Operational Responsive Space
 - Missile Defense Applications
 - Launch Vehicle Roll Control
 - Satellite Servicing
 - GEO-Missions
 - Lunar/asteroid robotic missions
 - Mars missions
 - MSL follow-on
 - Mars Ascent Vehicle
 - Mars Lander
 - Mars crew vehicle
- Aerojet-Rocketdyne 1-N and 22-N thruster properties as existed prior to 7/13 were utilized
- Other Thrust levels were needed in some DRMs – Notional AF-M315E thrusters based on hydrazine equivalents were used



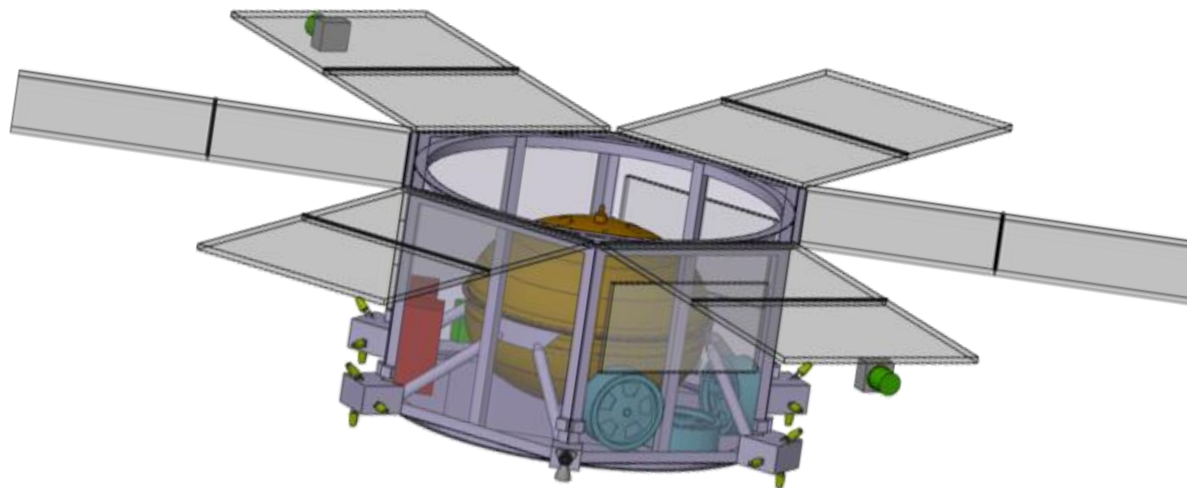
AF-M315E Mission Summary

Mission	Graphic	HAN System Functions	System Replaced	HAN Impact
CPST Bus		Primary, RCS	Hydrazine	Reduces Small LEO Bus Wet mass 7%
Asteroid Redirect		Asteroid De-spin, RCS	NTO/MMH Bipropellant	HAN replaces biprop with a Cheaper, Simpler, more compact system – only increases wet mass 0.3%! Should be safer for astronauts.
Mars Geyser Hopper		Landing, Hopping to geyser science sites	Hydrazine	Improved Isp and density allow for two extra hops, low temp capability. HAN provides an additional year of science!
Int'l Lunar Network lander		Vernier control of solid descent rocket, final landing propulsion	Hydrazine	Improved mass/Isp performance. HAN provides launch vehicle reduction: Antares to Minotaur V!
Spun Mars Ascent Vehicle: RCS		All RCS functions	Electric TVC and N2 Gas generator/Cold Gas Systems	HAN's density and low temperature capability allow replacing TVC and lower TRL gas generator RCS systems where hydrazine could not (density and temperature limits). HAN eliminates systems and reduces risk. Note: an alternate ascent vehicle was studied whereby AF-M315E was replacing a solid motor, no advantage
Deep Space Microsat		Primary ΔV s, mid-course corrections	Hydrazine blowdown	Increases primary ΔV by 70% and RCS propellant by 100% allowing for follow-on science opportunities. HAN provides additional Science opportunities!

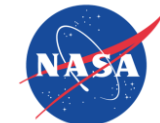
CPST Bus



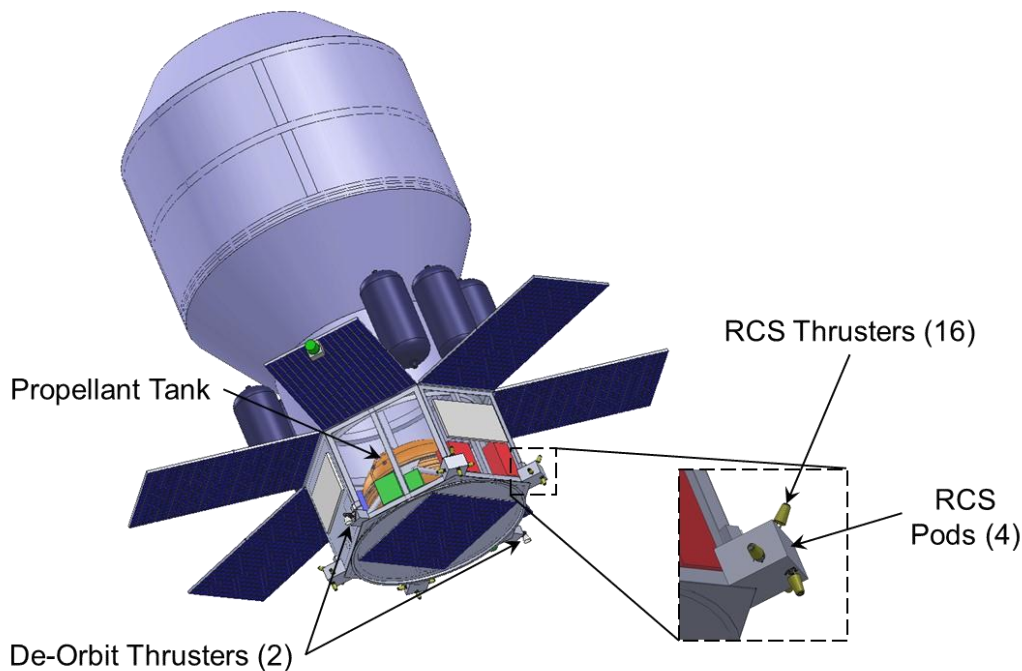
- CPST (Cryogenic Propellant Storage and Transfer) Bus provides support for cryogenic propellant storage demonstrator payload (200 m/s RCS, propulsive settlements, and deorbit)
- Change bus propellant to AF-M315E, RCS thrusters and deorbit thrusters
- Reduces propellant mass – smaller tank – less structure – less insulation
- Slightly increase power for cat-bed heaters (and ensure propulsion for safe mode)
- CPST baseline Hydrazine: 719 kg bus wet, 239 kg of propellant, Single ATK 80487-1 tank
- Sixteen MR-111C Class Equivalent Thrusters - 4.45 N Nominal Thrust (1 lbf)
- Two MR-107L Class Equivalent Thrusters - 130 N Nominal Thrust (30 lbf)



CPST Bus



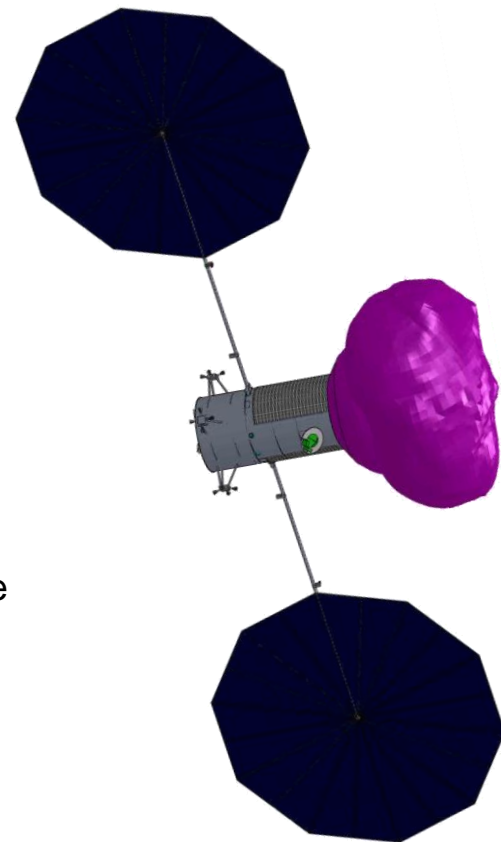
- CPST AF-M315E bus 668 kg bus wet, 213 kg of propellant:
 - Reduces propellant by 26 kg (~10%)
 - Reduces dry propulsion system mass by 10 kg (~20%)
 - Reduces structure mass by 12 kg (~10%)
 - Reduces thermal (less MLI) by 3 kg (~10%)
 - Increases power system mass (catalyst bed heaters are higher power compared to hydrazine and always on for safe mode recovery) by 5 kg (~5%)
 - Net savings in dry mass (30% growth included) by 26 kg (5%)
 - Net savings in wet mass (30% growth included) by 51 kg (7%)





Fetch Asteroid Return

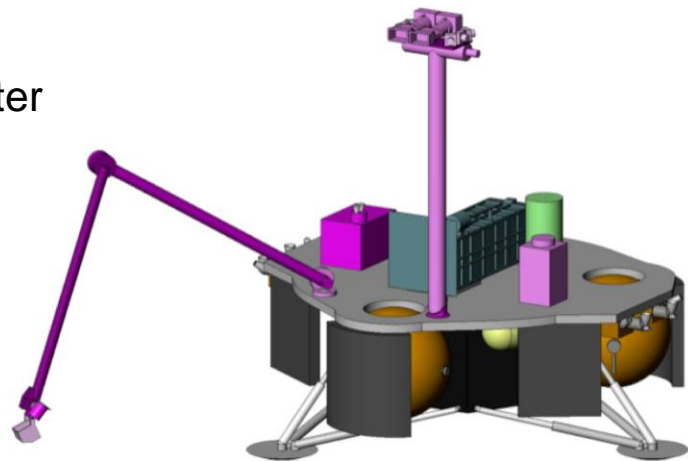
- Fetch Asteroid Retrieval (Now called ARM) 10/2011 COMPASS Design Study
- Replaces Baseline Bipropellant RCS
 - Monomethylhydrazine (MMH) and Dinitrogen Tetroxide (NTO)
 - Nitrogen Gas Pressurant
- HAN changes
 - Propulsion – slightly increased propellant but smaller tanks, simpler propulsion system
 - Launch mass only increased by <0.3%!
 - Reductions in flow system complexity and tanks
 - 3 AF-M315E Tanks versus 4 total for NTO/MMH
 - Shortens vehicle by 22” – saves structural mass
 - Since mission will later interface with crew AF-M315E should provide less toxicity issues with suits
 - Suit material interaction should be studied
- Baseline Astrium Thrusters for Bipropellant System
 - Nominal 200 N (45 lbf) Thrust
 - Nominal 287 s ISP
- MR-107N Class Thrusters for AF-M315E System
 - Nominal Thrust 267 N (60 lbf)
 - Nominal 250 s ISP
- 4 Pods of 4 thrusters





Mars Geyser Hopper

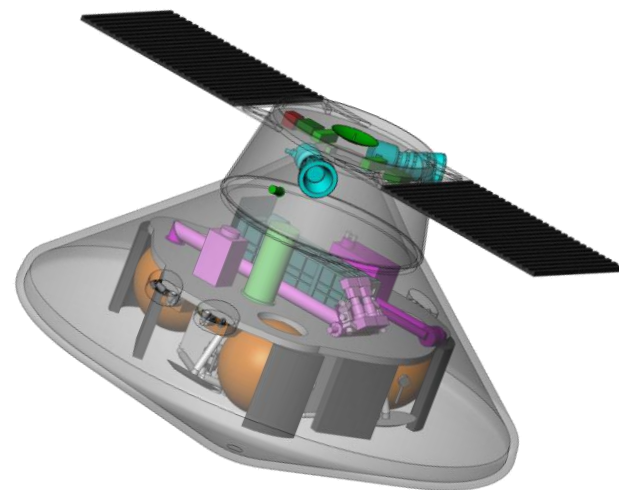
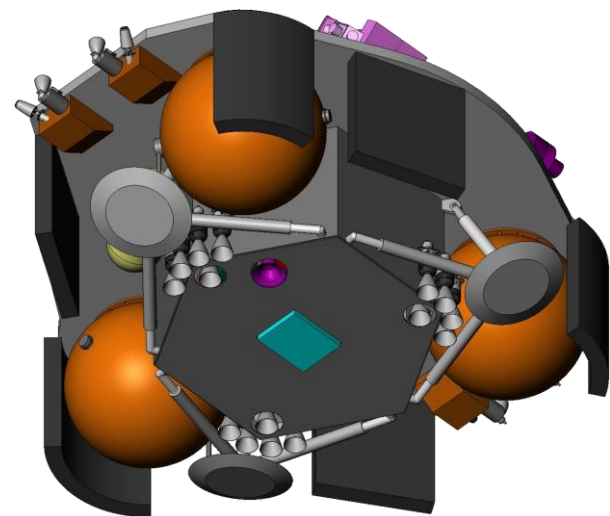
- Lands on Mars South Pole – Hops to geyser – survives winter – images geysers first day of spring, Advanced Stirling Radioisotope Generator (ASRG) powered
- Replace Hydrazine with AF-M315E
- Utilize the capabilities of AF-M315E to provide for extended mission
 - AF-M315E Low Temperature capability removes risks and provides for Hopping after winter – hops based on spring observations
 - Removes risk of letting propellant get cold
 - Allow tanks to get cold ($\sim -90^{\circ}$ C) during winter
 - Observe spring geysers
 - Allow tanks to cool to -81° C during winter
 - Add 5cm of aerogel on tanks – use 30 W to maintain tank during winter
 - Hop during summer after tanks warm up for next spring season
- Use existing tank sizes to carry more propellant (added 60 kg more than hydrazine baseline) (launcher can carry ~ 100 kg more) and allow for another year of hops
- Planetary Protection – will HAN need to be sterilized? (S/C heated to 120° C for sterilization – could load propellant afterward?)





Mars Geyser Hopper

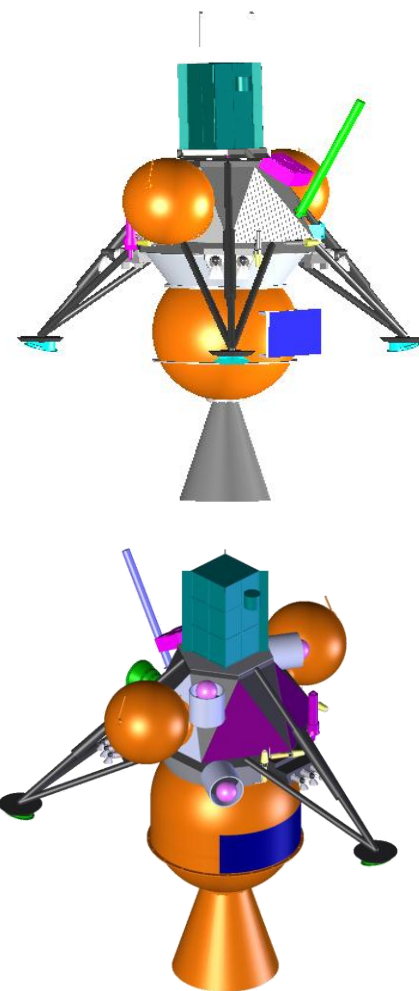
- Propulsion/Thermal
 - Switch to rechargeable, blow-down tanks of same size
 - Allows for ~60 kg more propellant: adds 308 m/s of hops – an additional year of science!!!
 - Utilize the 5 cm aerogel with 30 W heaters (or 30 RHUs) to maintain tanks at -81°C during deep winter
 - Can AF-M315E survive -120°C ?
 - 15 Aerojet MR-107N Class Thrusters for Landing and Hops
 - 270N (60 Lbf) Thrust
 - Grouped in 3 Clusters of 5 Thrusters
 - RCS Thrusters
 - 4 Aerojet MR-120 Class – 111 N (25 lbf) Thrust
 - 4 Aerojet MR-103D Class – 1 N (0.2 lbf) Thrust
- Power
 - Same ASRG – repurpose spring science power for heater power during winter (~30W)
 - Battery margin
- Structures
 - Loaded tanks (same size) but ~ 30% heavier due to extra propellant
 - Changed deck structure to support additional mass
- Overall changes added 13 kg dry mass





Lunar Lander: International Lunar Network

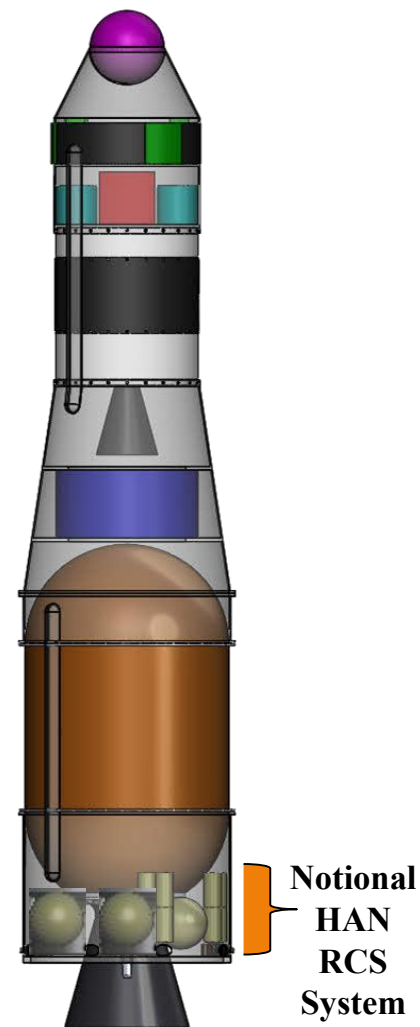
- Existing design used ~350 km/s of hydrazine for vernier control and final landing
 - Lunar landers are propulsively intensive – ‘gear ratio’ (inert mass to initial mass) ~ 5
- Hydrazine design unable to fit on Minotaur V launcher – requiring the larger, more expensive Antares
- Use of AF-M315E saves enough mass to allow launch stepdown to a Minotaur V
- AF-M315E Provides
 - Higher Isp, denser propellant, alleviates insulation/heater reqt’s of Hydrazine
 - Removed pyros normally needed for hydrazine - launched wet
 - Lower mass/denser propulsion system reduces structure mass
 - Net reduction in wet lander mass allows use of a smaller solid rocket motor (from Star 27 down to Star 24) – and thus the smaller Minotaur V launcher
- Six MR-107K Thrusters - Nominal 220 N (50 lbf) Thrust
- Six MR-111C RCS Thrusters - Nominal 4.4 N (1.0 lbf) Thrust

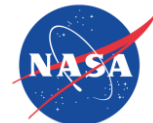




Mars Ascent Vehicle

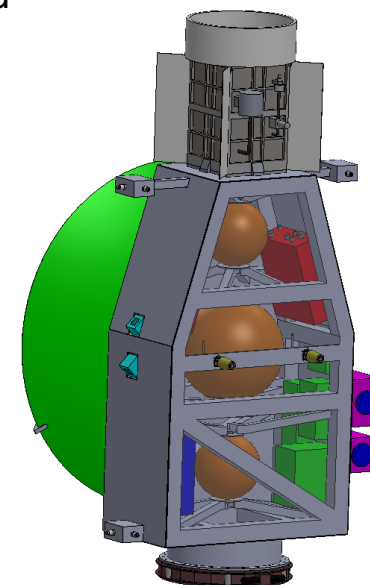
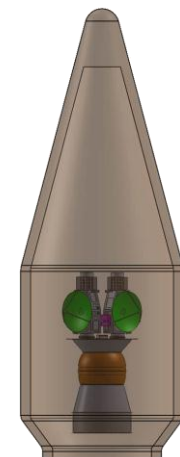
- Mars Ascent Vehicle (MAV) launches a 5kg sample capsule to low mars orbit
- Baseline uses two solid stages with an electric TVC and a N2 gas generator cold gas roll control system (yaw-pitch during coast) only on the first stage
- MAV volume (deployed using skycrane), mass, and temperature (potential winter-time launch -60° C ambient) challenged
- AF-M315E provides
 - Low temperature resistance (less risk)
 - Eliminates risk of a TVC system
 - Eliminates need for a low TRL N2 Gas generator system
 - Hydrazine does not have the temperature nor volume capability
 - Provides for lower risk, more compact system
- Propulsion: removed N2 gas generators/tanks and TVC system, added twelve 22 N (5 lbf) AF-M315E thrusters, six 3.5" bladder tanks
- Power: required additional batteries on first stage for HAN heaters/valves
- Thermal and structures remain the same
- AF-M315E option requires only a 5% growth in initial mass (~15 kg) and reduces risks by eliminating the need for a TVC system and a gas generator system
- Note: Alternate system replacing propulsion system with AF-M315E considered.
 - Goal was to replace solid, TVC, and and cold gas RCS with single system
 - Though AF-M315E is significantly more dense than hydrazine, still not as dense and properly packaged for this application as a solid motor.





Deep Space Microsat

- Deep Space Microsat (<200kg) to flyby Centaur asteroids (>10AU distance)
 - Four microsats launched on Atlas 431, flyby Jupiter then each to flyby different Centaur
 - Current propulsion:
 - Hydrazine only for midcourse corrections (~100 m/s)
 - Filling the tank provided for 147 m/s
 - Power for catbed heaters available since no science during mid course corrections
 - Cold gas for spinup/spin down and flyby pointing (~10 m/s)
 - Spacecraft power limited – power for catbed heaters NOT available during flybys
- Replacing Hydrazine with AF-M315E Allows:
- Using same size tank adds ~100 m/s ΔV (~70% increase) for mission flexibility and follow-on mission
 - Improved AF-M315E Isp allows for loading more cold gas (top off tanks) for extended mission (~100%)
 - Lower temperature capability of AF-M315E reduces risk for cold environment
- AF-M315E System Changes
 - Power: None - Pulsed Battery power (sized for science flyby) sufficient for increased catalyst heater power
 - Propulsion: Reused hydrazine tank – improved density increases propellant load, two ~2 N (0.5) lbf thrusters
 - Thermal: Reduced risk to propulsion system due to low temperature capability





Lessons Learned HAN Design Studies

- Landers: AF-M315E Isp and Density very powerful design impacts – especially on landers when replacing hydrazine systems
 - Can allow for increasing science or launch vehicle stepdown
- Bipropellant Replacement: AF-M315E can replace bipropellant systems for roughly the same volume – although propellant mass increases
 - Simpler propulsion system
 - Can be offset somewhat by adding expansion ratio (nozzle height) available due to reduction in valve train of an equivalent bipropellant motor
- Small Spacecraft Hydrazine Replacement: AF-M315E can replace hydrazine on small spacecraft – either by reducing wet mass by nearly 10% or providing for longer science missions
- Launchers: At least for the Mars Ascent Vehicle AF-M315E makes an attractive RCS propulsion system but NOT as a primary system (can't compete with solids)
- Environments: AF-M315E's lower temperature capability reduces risks or enables extended missions (Mars hopper)
 - Could change design philosophy on propellant storage (does not need to be buried inside the spacecraft)
- Power Needs: AF-M315E's higher cat-bed power only an impact in some instances
 - May be a challenge for power limited vehicles



Potential Follow-on Work

- Evaluate AF-M315E with Piloted missions
- Evaluate AF-M315E with astronaut suits, etc.
- Evaluate AF-M315E for planetary science
- How does AF-M315E change planetary protection procedures?
- How does AF-M315E exhaust impact science readings?
- Other potential COMPASS design studies to run
 - Replace HAPS upper stage on launchers
 - ESPA ring microsat – may enable large maneuvers compared to cold gas, butane, etc. systems
 - Cubesat design reference mission
 - Skycrane



Thank you!

Questions, Comments?



Backup



Geosynchronous Spacecraft

- Lunar space relay
- Replace NTO-MMH with a AF-M315E system
 - Mass increased (~400 kg wet) but still fits on same launcher using a mono-propellant HAN system
 - AF-M315E utilizes the same tank layout at bipropellant system
- AF-M315E provides apogee insertion, RCS and Station-keeping, off-setting solar pressure
 - Relatively low power does not lend itself to SEP
 - Many GEO spacecraft are similar (GOES, small geo S/C)
- Propulsion
 - 200:1 AF-M315E 100 lbf motor (shorter valve train allows longer nozzle)
 - Used same size four tank layout as bipropellant system
 - No major layout/mechanical change to bus
 - Reduced feed system complexity
- Mechanical – Propellant mass up from 1700 kg to 2100 kg – (but in same tanks) – structures strengthened to hold additional mass
- Thermal – Propellant stored inside with same sized tanks – fewer line heaters
- Power – Avg. 90W more for RCS cat-bed heaters

