Assessment of MON-25/MMH Propellant System for Deep-Space Engines

Huu P. Trinh
Huu.p.trinh@nasa.gov
Propulsion Systems Department
NASA Marshall Space Flight Center
Huntsville, Alabama

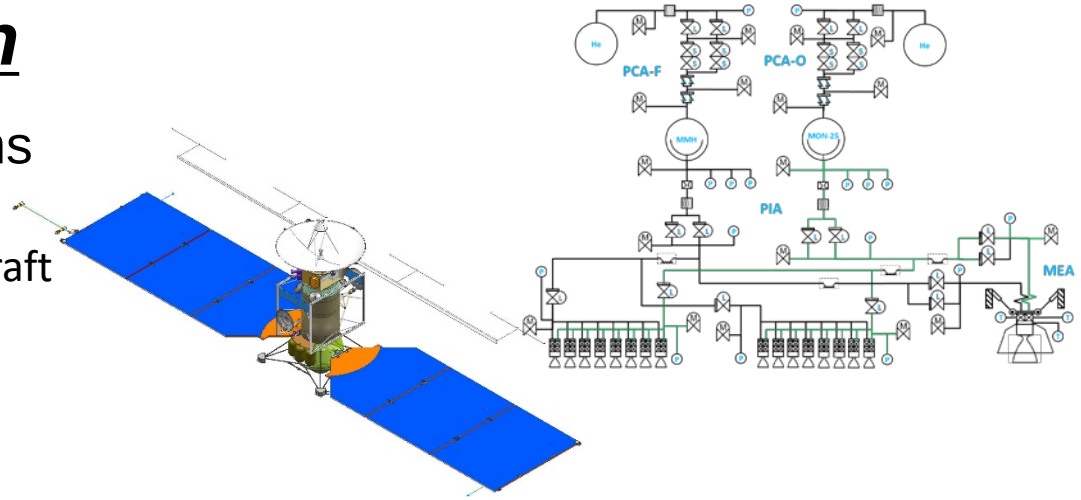
October 21, 2019

Co-authors
Christopher Burnside
Hunter Williams

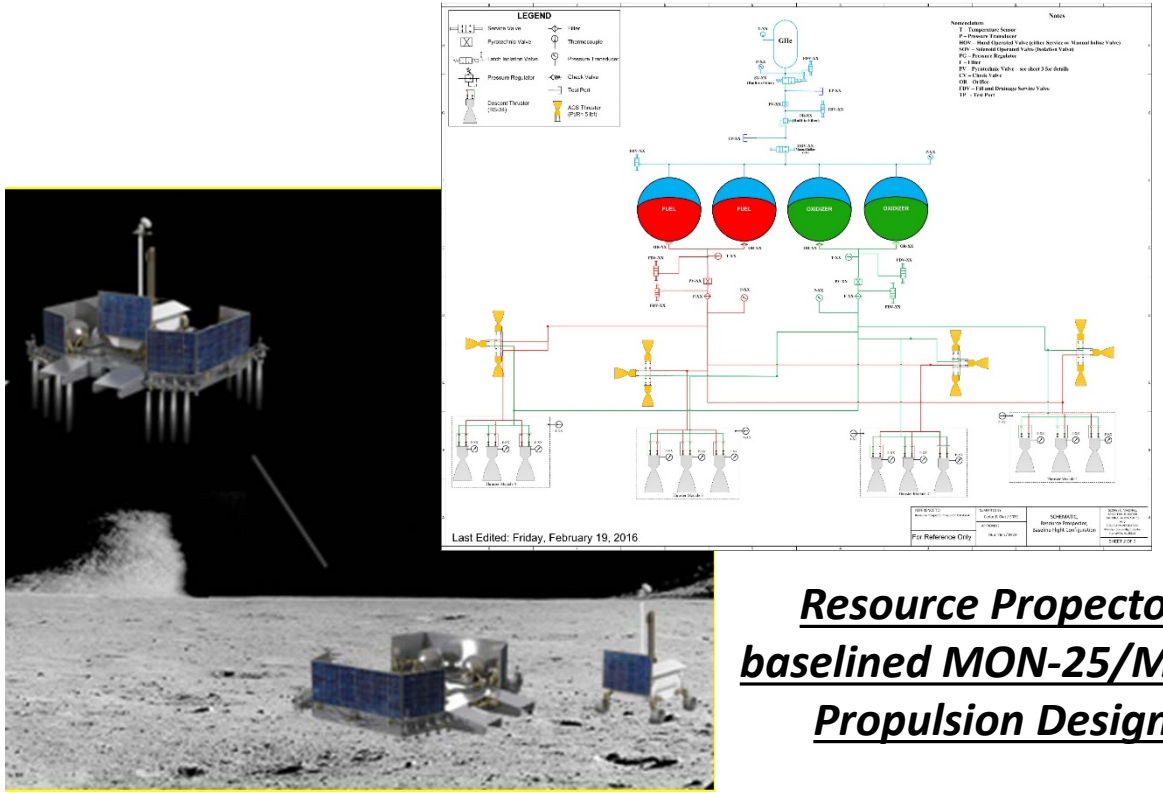
Contents

Introduction

- NASA is interested in MON-25/MMH propulsion systems for spacecraft application
  - Robotic lunar missions, International Lunar Network (ILN) spacecraft and then Resource Prospector.
  - Clipper spacecraft to orbit Europa, moon of Jupiter.



Clipper Spacecraft Design with MON-25/MMH propulsion system



Resource Propector baselined MON-25/MMH Propulsion Design

- Propulsion trade studies and engine developments have been carried out to mitigate design risks as well as to advance MON-25/MMH technology.
  - Propulsion trades indicate potential benefits while MON-25 may pose some challenges in design and operation.
  - Engine design can be derived on its existing flight NTO/MMH engines.

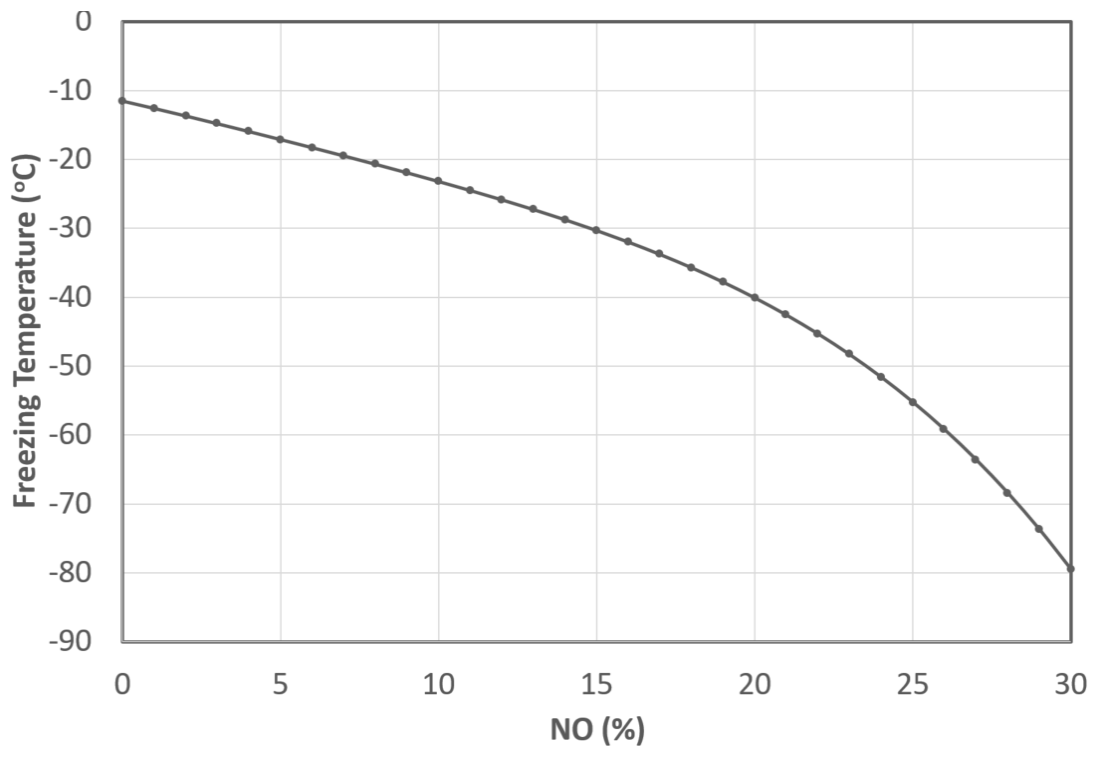
What about MON-25/MMH System ?

- Historically, nitric oxide was initially used as an inhibitor on nitrogen tetroxide propellant to resolve stress corrosion issues. Adding 1% and then 3% of NO to NTO, designated as MON-1 and MON-3, would reduce acceptable amount of iron nitrate in the oxidizer
- MON-25 is a mixture of NTO (75%) and NO (%25)
- MON-25 has a low freezing point and a similar freezing point of MMH.
- Combustion characteristic and performance are similar to existing flight MON-3/MMH.
- Most of existing hyperlogic bi-prop components can be used for MON-25/MMH propulsion.

Primary interest of MON-25 is its low freezing point

Characteristics of MON-25 properties

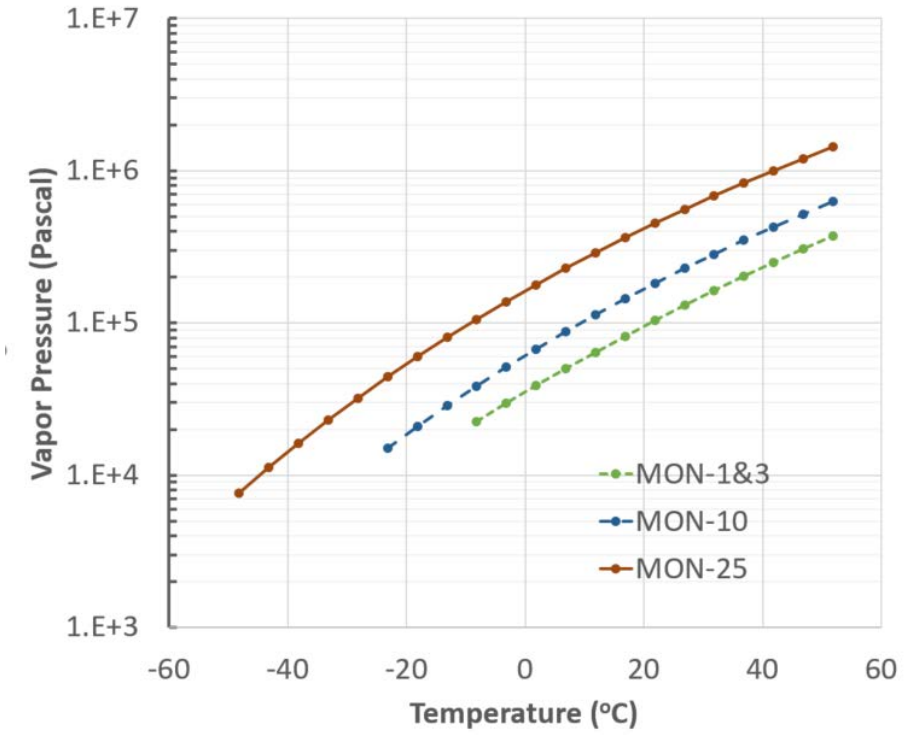
- Low freezing point
  - Increasing nitric oxide content to 25% (MON-25) to depress the freezing point of the oxidizer.
  - Freezing temperature is changed from -13°C [9°F] with 1% of NO added to the mixture down to -55°C [-67°F] when 25% of NO in the mixture.
  - Fuel MMH is frozen around -52°C [-62°F], similar to the one of MON-25.
  - There is a concern of NTO crystallization at low temperature. MON-25 should only be used in rocket engines at above -40°C [-40°F].
  - Ignition delay was much lower than anticipated. The ignition delay difference between the two hot fires at 20°C [68°F] to -40°C [-40°F] was about 3 msec.



MON-25 for its hypergolic fuel companion MMH would be easy in the thermal management

Characteristics of MON-25 properties

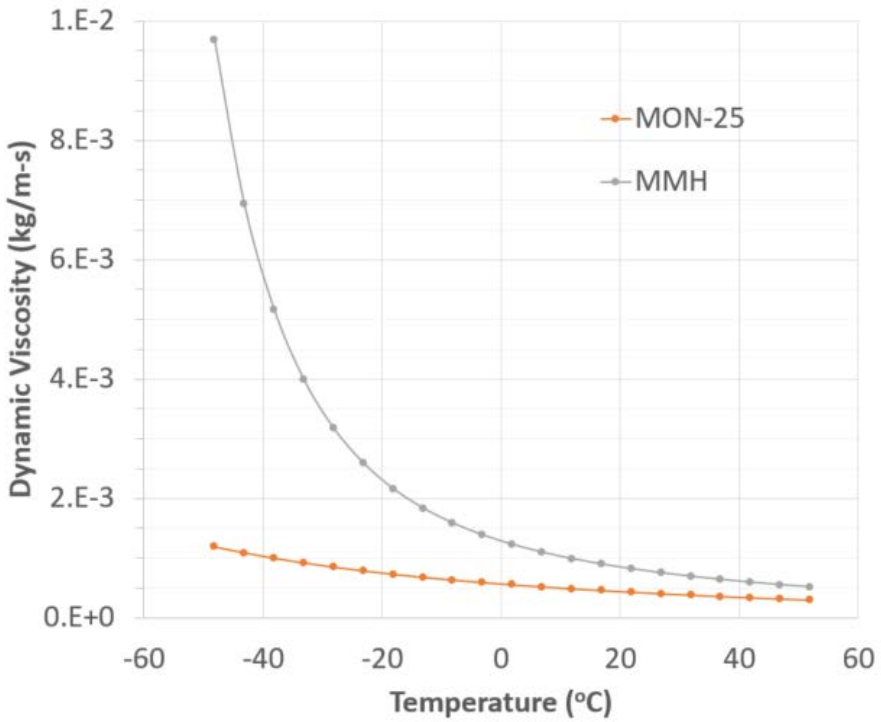
- Vaporization
  - Vapor pressure of MON-25 is higher than MON-3 and mismatching with MMH.
  - Transferring liquid MON-25 must be performed under a pad pressure above 452 kPa [66 psia] and maintain this pressure level all time during the storage at the room temperature.
  - For a mission that the temperature may fluctuate due to the change in the space environments, propulsion system of MON-25/MMH can be susceptible and operate at a wider temperature swing than NTO/MMH.
  - Significant increase in the vapor pressure of MON-25 at the elevated temperatures can have repercussions with respect to tank design and the maximum design pressure of the system.
  - Isolated gaseous bubbles of MON-25 are formed. The bubbles can be collapsed as traveling downstream. This phenomena causes undesirable propellant flow oscillations that can lead to chamber pressure fluctuations



MON-25/MMH can be operated at wide temperature swing ; however, significant vapor pressure increase at an elevated temperature can have repercussions in system design

Characteristics of MON-25 properties

- Viscosity
  - the viscosity of the fluids would increase as the temperature reduces.
  - The change in viscosity of MON-25 is gentle and behaves well. In contrast, the trend of MMH viscosity is similar to the one of MON-25 down to 0°C [32°F]. However, as can be seen from the plot, the rate of MMH viscosity drastically picks up when the temperature is below 0°C [32°F].
  - From the engine performance perspective, drastic increase in viscosity from reducing temperature would cause a flow changing from turbulent regime to a laminar one through the injection orifices



Rate of MMH viscosity drastically picks up when the temperature is below 0°C [32°F] can be a challenge in engine design

Summary - Pros

- Mixing additional NO into NTO, particularly with 25% of NO in mass, results low freezing point for the mixture. Subsequently, using MON-25 for in-space propulsion system would reduce heater power requirements and increase operation robustness.
- Propulsion system of MON-25/MMH is capably susceptible and operate at a wider temperature swing than NTO/MMH.
- Since both MON-25 and MMH have a similar freezing point around -50oC. With a concern of NTO crystallization at low temperature, MON-25 should only be used in rocket engines at above -40oC [-40oF].
- It was experimentally observed that engine has more quite [soft] start when the initial temperature of the engine and propellants are low.
- High temperature behavior of MON-25 shows no anomalies and no pressure hysteresis was observed. The diffusion rates of the vapors in the ullage space are rapid are enough to return into the liquid as temperature decreases.
- Liquid ammonia has a relatively high vapor pressure compatible with MON-30. Engine hot-fire tests show ammonia with lithium additives reacts hypergolically with MON-30.
- MON-25 may have more benefits of reducing the corrosiveness of materials than MON-3 since more NO content in the oxidizer would further reduce formulation of iron nitrate.

Summary - Cons

- Significant increase in the vapor pressure of MON-25 at the elevated temperatures can have repercussions with respect to tank design and the maximum design pressure of the system.
- As liquid MON-25 flows through sharp-curvature lines and abrupt geometries, bubbles are formed due to local flow-field pressure is dropped below the propellant vapor pressure. This phenomena causes undesirable propellant flow oscillations that can lead to chamber pressure fluctuation.
- Hot-fire tests of engine indicates the ignition delay difference between 20oC [68oF] and -40oC [-40oF] is about 3 msec. It is much less than anticipated.
- Most existing propulsion components have been used at normal benign temperature. They may need to be re-qualified or redesigned to accommodate for use in the low temperature environments.
- Because of the low temperature, more pressurant, such as helium, would be required to pressurize propellant tanks as compared to systems at higher temperature
- Regarding MON-25/MMH system, a drastic increase of MMH viscosity when the temperature swing below 0oC [32oF] would become challenging in system design. Such a change in viscosity has strong effects on the propellant injection characteristics.

Conclusions

- For deep-space missions, spacecraft often faces extreme temperature environments throughout its flight duration. In comparison with its MON family, such as widely used MON-1 and MON-3, oxidizer MON-25 can offer a capability of operating at lower temperature and a wider temperature range. Subsequently, MON-25 benefits the reduction of heater power requirement and robustness in operation.
- High vapor pressure of MON-25 can hinder a desire of its use in a practical application, especially for a mission on which a large environmental temperature swing is anticipated. Although oxidizer MON-25 and its companion fuel MMH have a similar freezing point, an exponential increase in viscosity of MMH when reducing in temperature below 0oC [32oF] poses a unique challenging in propulsion system and engine designs. A way of overcoming these disadvantages is to operate the system at optimal pressure and to limit the temperature, particularly at the low end of the temperature.
- Overall, a comprehensive trade study should be conducted when selecting MON-25 as a propellant for spacecraft. Depending missions, MON-25 can be attractive for certain missions while it may be not a great payoff for others.