PACE 2012

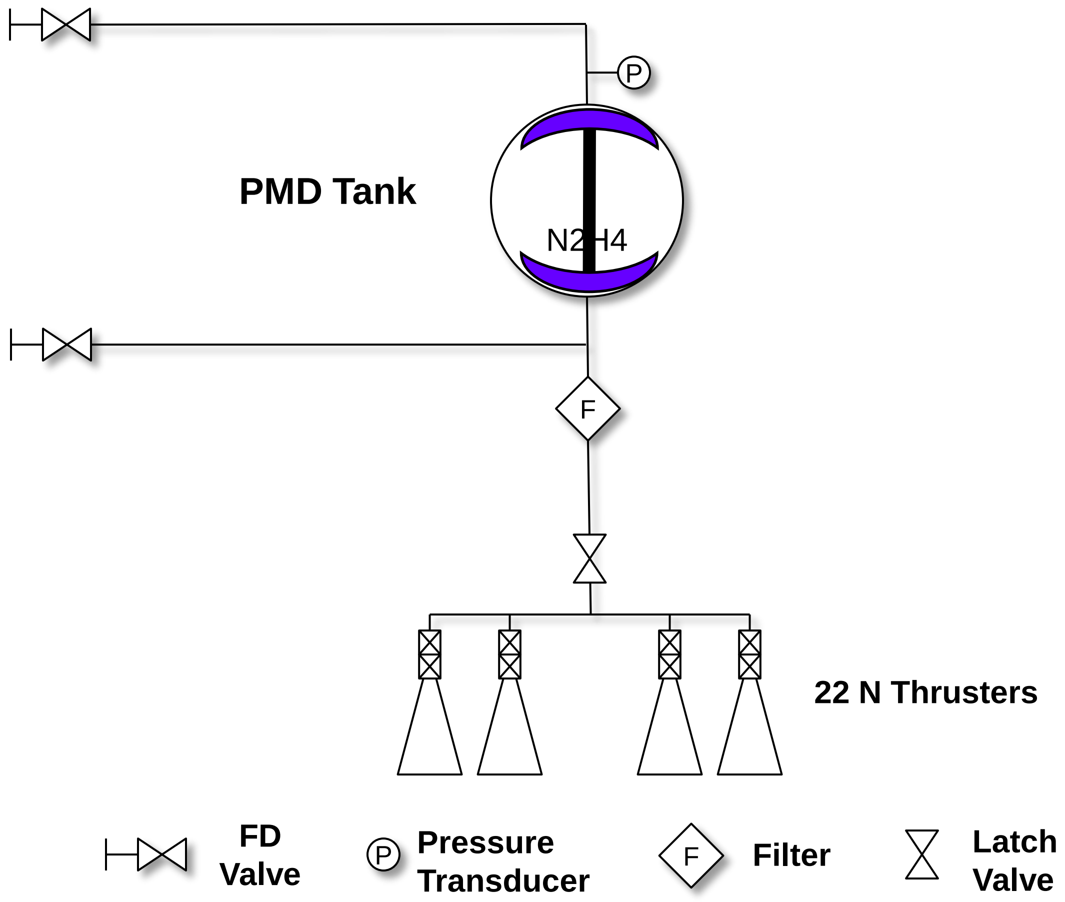
Propulsion

14 – 18 May, 2012

Summary

- Monopropellant (hydrazine) propulsion subsystem operating in a blow-down mode
- One 33 inch spherical propellant tank with propellant management device (PMD)
- Thrusters: Four 22 N class (Aerojet MR-50E)
- Propellant Mass: 165.1 kg including controlled deorbit of 1400 kg (dry mass) S/C to 50 km x 700 km
  - Propellant mass reduction > 50% for uncontrolled reentry EOM disposal (see later charts)
- Subsystem Dry Mass: 29 kg
- Subsystem is single-fault tolerant (dual-fault tolerant for Range Safety)
- All components are TRL9

Propulsion Subsystem Schematic

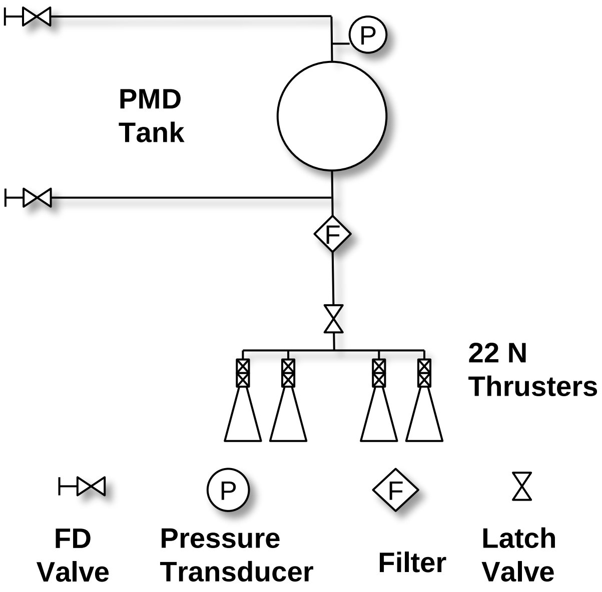


Propulsion Subsystem Drivers

- Provide ΔV (244.7 m/s) for assumed 1400 kg maximum dry mass
- Provide pitch/yaw control to spacecraft during ΔV via thrusters (no roll control)
- Not used during science mission
- Unload pitch/yaw momentum (no roll component)
- Size the propulsion system for orbit insertion and deorbit – no station keeping
- Single fault tolerant
- Dual fault tolerant with respect to range safety
- Minimize plume contamination
- No product qualification

Subsystem Description

- **Mono-Propellant, blow-down system using hydrazine fuel**
- **Single propellant tank**
  - Diameter ~33 inch, 18390 in^3
  - Max capacity ~211 kg of fuel (total required = 165 kg)
  - Sized for 400 psi (50 C) to 100 psi (10 C) blowdown
  - <1% residual propellant
  - PMD tank can be customized to reduce slosh as required
  - Polar boss mount
- **Four 22 N thrusters**
  - Thrusters in single bank (latch valve normally closed)
  - Provide ΔV and pitch/yaw control
  - No roll control
  - Dual seat thrusters
  - All thrusters on "bottom" of S/C
  - Baseline alignment is uncanted (aligned to long axis)
- **One dual coil latch valve (single bank of thrusters)**
- **One filter and pressure transducer, two fill/drain valves**
- **Subsystem dry mass = 29 kg**



Baseline ΔV Budget

- Propellant was budgeted assuming a 1400 kg (dry mass) S/C
- Add 5% attitude control "tax" (normally 10%, reduced because will have long well calibrated burns)
- Specific Impulse (I_{sp}) = 227 sec
  - Conservative
  - Assumes 10^o cant in two planes (no cant is baseline)
  - Cant costs 4.6 kg hydrazine
- Total ΔV 244.7 m/sec
- Total propellant mass = 165.1 kg (min tank 14371 in^3)*

Maneuver	ΔV
Orbit Insertion Correction	50 m/s
End of Mission Disposal (700 x 50 km)	183 m/s*
ACS penalty (5%)	11.7 m/s*
Total	244.7 m/s*

* See later charts for comparison with uncontrolled reentry EOM disposal strategy

Launch Dispersion Corrections

How does 50 m/sec relate to orbit corrections?

- **0.38º inclination change**

  or

- **95 km orbit change**

  or

- **640 circular + 0.23º inclination change to 700 km circular with corrected inclination (Example only)**

Controlled Deorbit Burn Characteristics

- Deorbit/controlled reentry from 700 km circular to 700 x 50 km
  - 50 km perigee target is standard disposal strategy
  - 183 m/sec
  - Ideal* burn duration ~ 54 minutes total (for avg. thrust = 83 N)
  - Four orbits (include 9 minute short calibration burn)

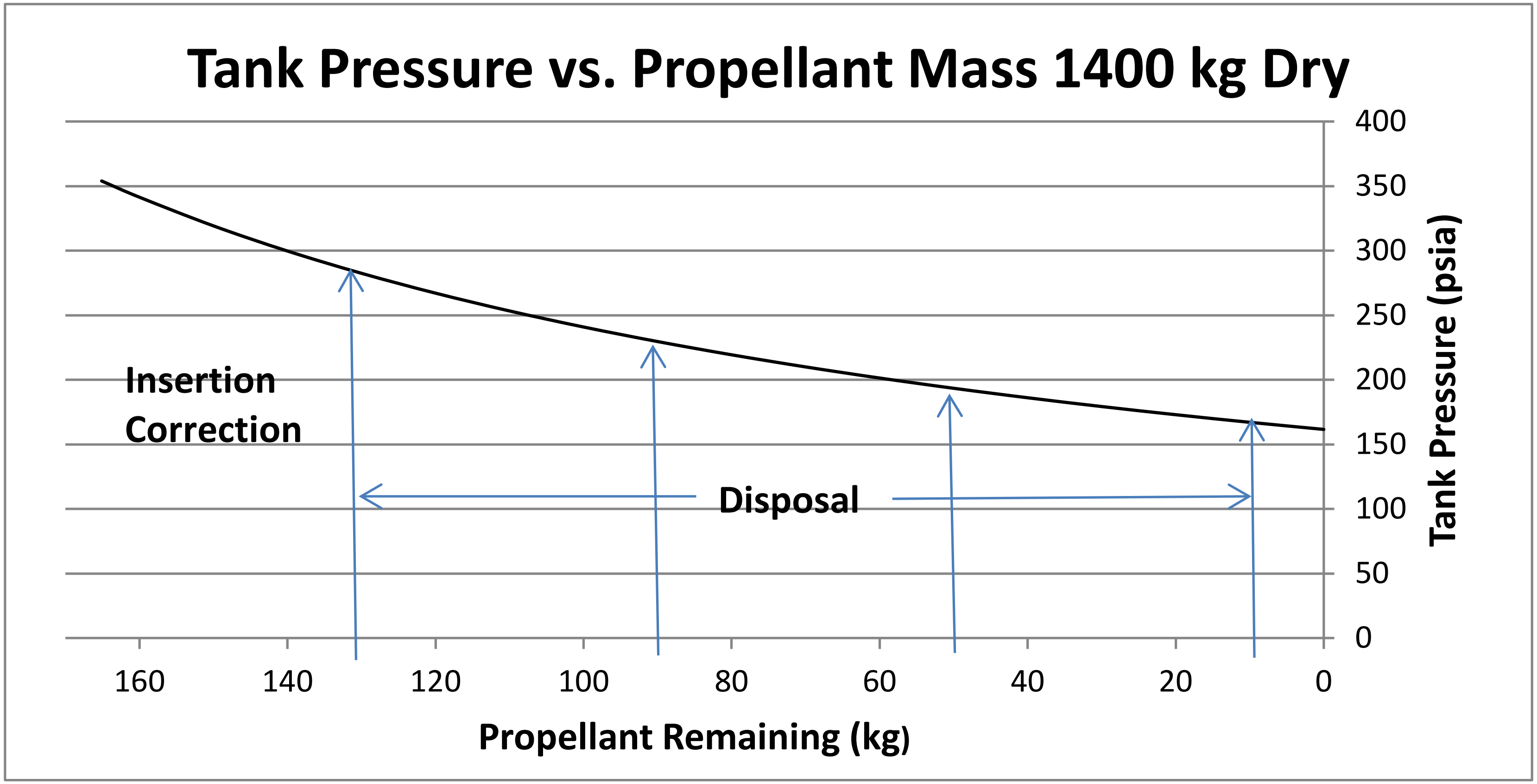
* No finite burn penalty

S/C Mass Sensitivity

- **S/C wet mass and propellant mass linear with dry mass (almost)**
  - Constant .5 kg for momentum unload makes slightly non-linear
  - Δ(dry mass) x 0.1175 = Δ(propellant mass), 900 kg – 1600 kg dry mass range

S/C Dry	Margined S/C Dry	S/C Wet	N2H4
692.3	900	1006.4	106.4
769.2	1000	1118.1	118.1
923.1	1200	1341.6	141.6
1076.9	1400	1565.2	165.1
1230.8	1600	1788.6	188.6

Blowdown (20ºC)



Equipment List

Vendor	Part No.	Description	Flight Units	Spares	Unit Mass (kg)	Total Mass (kg)
ATK	80324-1	Sperical titanium PMD tank, 33" OD, 400 psi MEOP.	1	0	20.2	20.2
Aerojet	MR-50E	22-N Monopropellant	4	0	0.68	2.72
VACCO	V1E10430	1/4" LP, 3-seat	2	0	0.113	0.226
Tavis	30004	Low pressure, magnetic reluctance type	1	0	0.22	0.22
VACCO	F1D10559	Etched disc	1	0	0.91	0.91
VACCO	FV1E10453	3/8 LP latching valve with dual coils	1	0	0.75	0.75
NA	NA	CRES - 1/4 and 3/8 inch OD	1	0	4	4
						29.03 kg

~ 14 FTE labor from preliminary design through launch site processing

Issues / Potential Risks / Future work

- **Simple propulsion system – No issues**

<u>Future work</u>

- **Roll control**
- **Higher level of redundancy**
- **Isolated thruster banks**
- **Custom composite overwrapped tank**
  - Sized to required propellant load
  - Potential to save up to 10 kg
  - Smaller
  - Demiseable if use aluminum for liner and PMD
  - ROM development cost + flight unit
    - $5M titanium lined, titanium PMD
    - $8M for demiseable tank (lower cost if titanium PMD can be used)

Alternate EOM Disposal Strategy

- **Design S/C to demise**
  - Allows for uncontrolled reentry
  - Remaining debris after reentry must pose less than 1:10000 risk of serious injury or death of people on the ground
  - Debris casualty area (DCA) is a convenient translation of impact risk (1:10000 ~ DCA = 7 – 8 m^2)
- **S/C will not reenter within 25 years from 700 km**
- **EOM Disposal Strategy for Demiseable S/C design**
  - Lower perigee to increase drag
  - Select highest perigee (lowest propellant required) to achieve 25 year reentry
  - A lower S/C mass allows selection of higher perigee target (lighter S/C drag down quicker)
- **Advantages over Baseline controlled reentry design**
  - Significant propellant savings
  - Al tank lighter
    - Lower volume
    - Customized to required volume
  - Simplified EOM planning

		BOL N2H4 Mass, kg	
S/C Dry Mass, kg	**S/C Wet Mass, kg**	**Controlled Reentry**	**Uncontrolled Reentry**
823	**920.3**	**97.3**	**38.8**
1100	**1229.9**	**129.87**	**54.9**
1400	**1565.2**	**165.1**	**73.6**

ΔV Budget: Baseline vs Uncontrolled Reentry

	ΔV, m/s		
Maneuver	**Baseline: Controlled Reentry, 1400 kg dry (700 x 50 km)**	**Uncontrolled Reentry, 1400 kg dry, 700x490 km**	**Uncontrolled Reentry, 1100 kg dry, 700x510 km**
Orbit Insertion Correction	**50**	**50**	**50**
End of Mission Disposal	**183**	**56.7**	**51.2**
ACS penalty (5%)	**11.7**	**5.3**	**5.1**
Total	**244.7**	**112**	**106.3**

Tanks For Uncontrolled Reentry

- **Propellant tanks made from traditional Ti survive reentry**
  - Significant contributors to impact risk
  - DCA for BL Ti tank ~ 1.5 m^2
- **Monolithic aluminum tanks will demise, weight penalty is insignificant vs Ti or COPV's in this small size**
- **Al tank development costs less than Al lined COPV development**
- **Assumptions for aluminum tanks in table**
  - MDP = 400 psi
  - Design Burst Factor, lowest DBF = 1.5 x MDP
  - Al2219-T62, FTU = 42000 psi
  - Wall thickness tolerance = ±0.005"
  - Sphere to tank factor = 1.4 (based on historical data base)

S/C Dry Mass, Perigee for disposal	N2H4 Mass, kg	Volume, in^3	ID, in	Thickness, in	Mass, tank, DBF=1.5, kg	Mass, tank, DBF=2.0, kg
823 kg, 540 km	37.8	3290	18.5	0.0709	5.0	6.5
1100 kg, 510 km	54.9	4779	20.9	0.0796	7.2	9.4
1400 kg, 490 km	73.6	6406	23.0	0.0873	9.5	12.5

Acronym List

- BOL Beginning of Life
- EOM End of Mission
- PMD Propellant Management Device
- N2H4 Hydrazine
- FD Fill/Drain (valve)
- ΔV Delta Velocity
- S/C Spacecraft
- I_{sp} Specific impulse
- OD Outside Diameter
- ID Inside Diameter
- DBF Design Burst Factor
- FTU Force Tensile Ultimate
- MDP Maximum Design Pressure
- COPV Composite Overwrap Pressure Vessel