NPOESS DWL Mass and Power Estimation

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Key West WG Meeting
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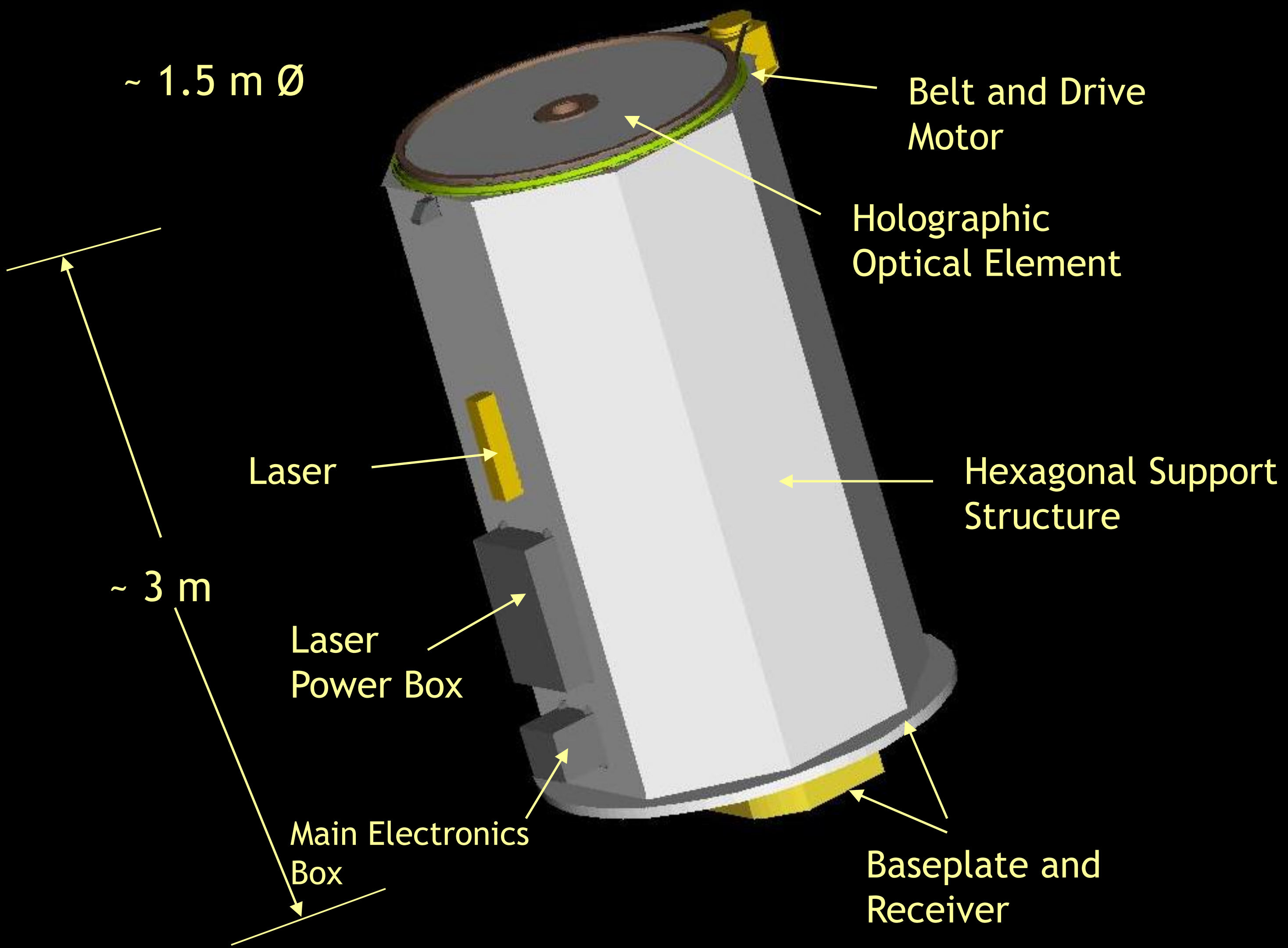
Outline

- Monochromatic DWLs
  - Global Tropospheric Winds Sounder (GTWS)
    - Direct Detection (UV 355 nm)
    - Coherent Detection (IR 2.05 micron)
  - ADM Direct Detection (UV 355 nm)
- NPOESS DWL (NDWL)
  - Constraints
  - Multispectral (UV and IR)
- Scale GTWS UV design
- Estimate mass and power
  - For NDWL UV subsystem

GTWS

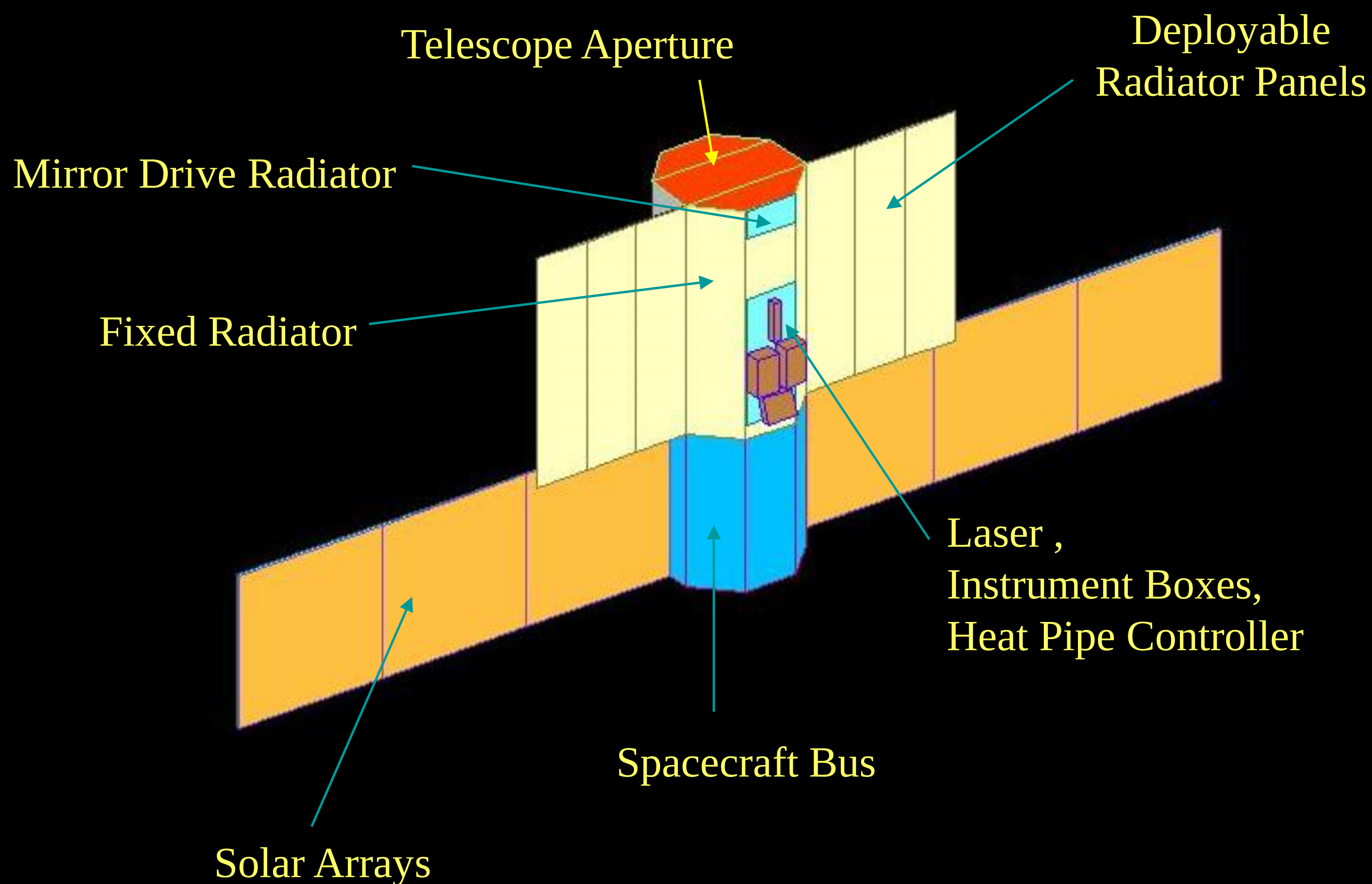
- Wind data-buy studies in 2000 and 2001
- Published wind data requirements
- Developed Government Reference Designs
  - Two monochromatic designs
  - Rapid Design Teams
    - Instrument Simulation and Analysis Laboratory (ISAL)
    - Integrated Mission Design Center (IMDC)
  - Findings
    - Very large mass, volume, and power
    - Low Technology Readiness Levels

GTWS UV Instrument Diagram



GSFC ISAL 2001

GTWS UV Instrument



GSFC ISAL 2001

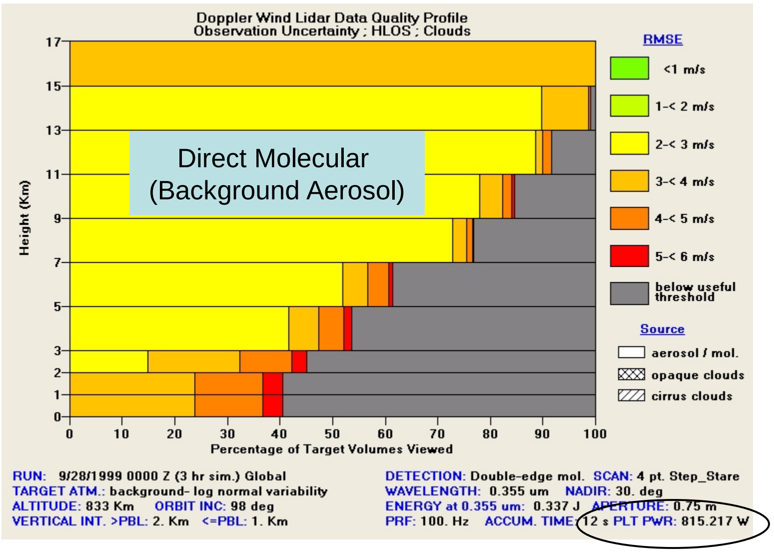
ESA ADM

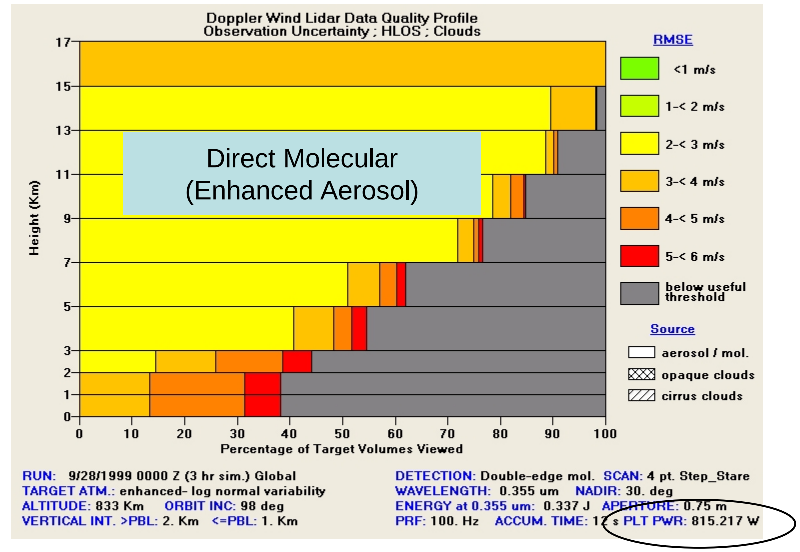
- Monochromatic UV direct detection
- Confirmed many GTWS design findings

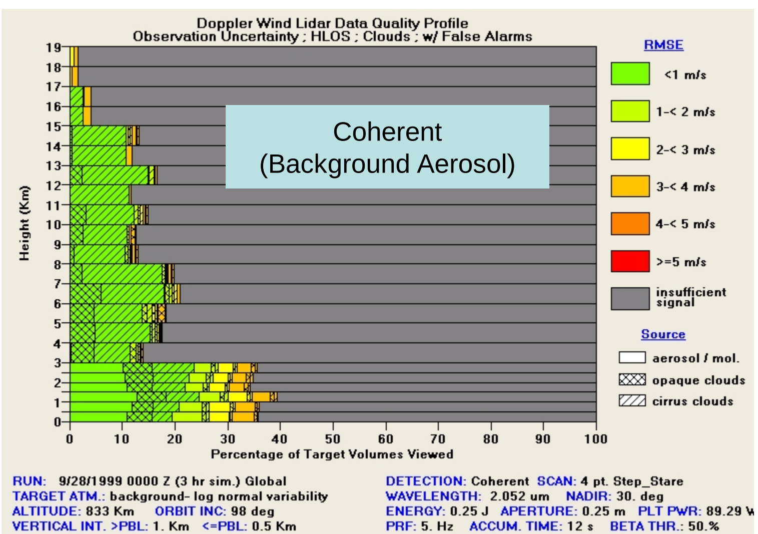
NDWL

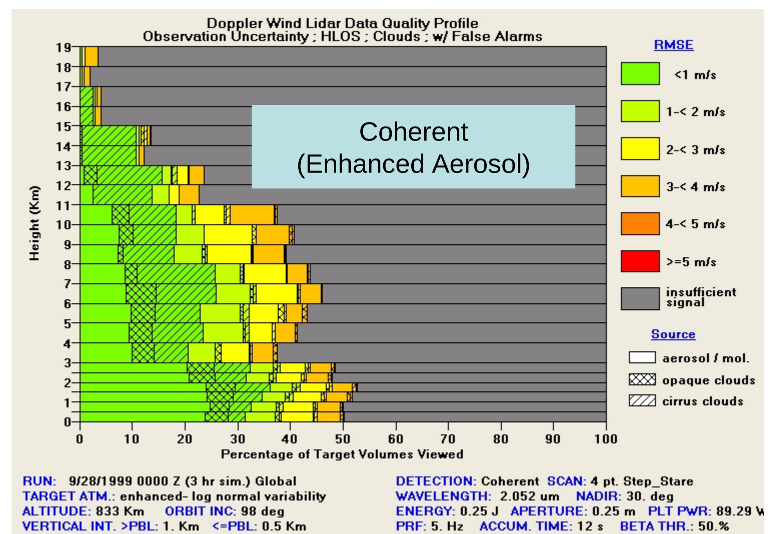
- Prospects for an NPOESS Pre-Planned Product Improvement (P3I) demonstration mission
- Constraints:
  - Mass, power, volume
  - Accommodation (shape, field of view, vibration, interference with other instruments, etc.)
  - 833 km orbit
- Monochromatic instruments are much too big
- Multispectral instrument may work
  - IR subsystem for lower atmosphere, cloud and aerosols
  - UV subsystem for upper troposphere
    - Doesn’t have to cover lower atmosphere
    - Adaptive targeting
    - Increased laser wallplug efficiency

833 km Demo Mission (Emmitt)





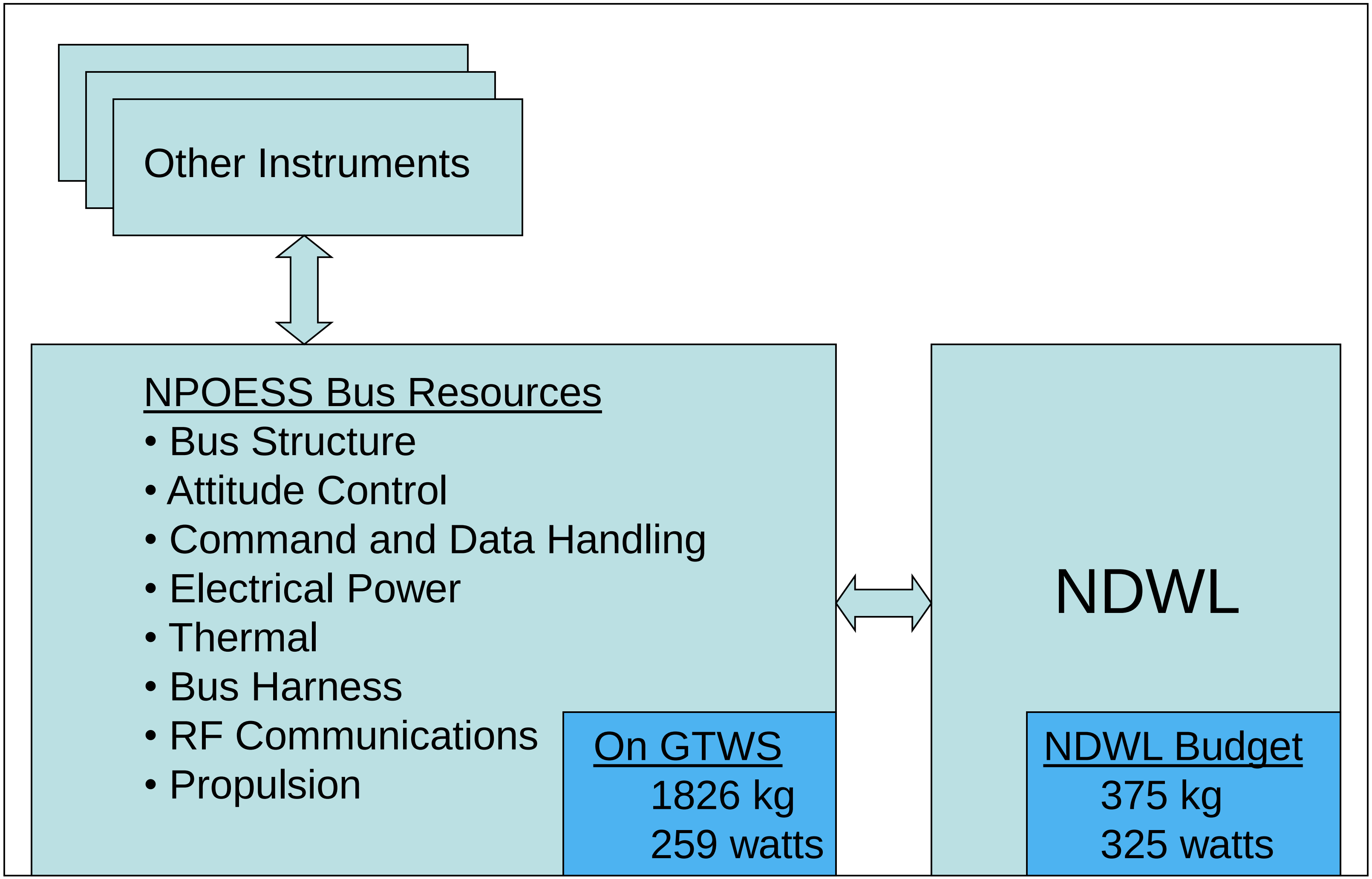




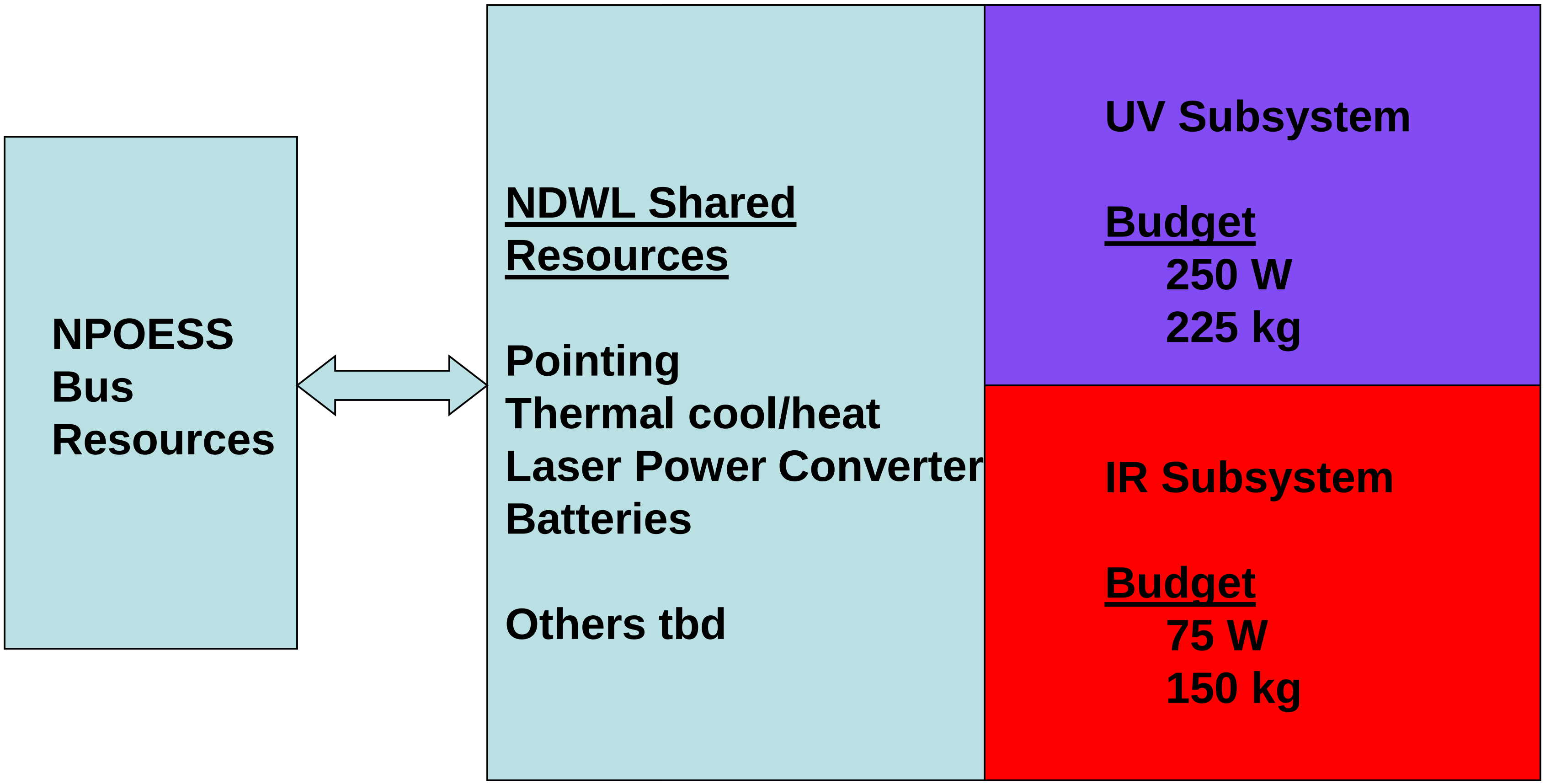
Note

At a planned 10% duty cycle, the orbit average for the Direct Molecular system is estimated to be 250 watts

NPOESS Spacecraft



NDWL


NPOESS
Bus
Resources
NDWL Shared
Resources
Pointing
Thermal cool/heat
Laser Power Converter
Batteries
Others tbd
UV Subsystem
Budget
250 W
225 kg
IR Subsystem
Budget
75 W
150 kg

Major Requirements Variations GTWS to NDWL

	GTWS Threshold	**NDWL Demonstration**
Tracks	**4**	**2**
Vertical Resolution	**1 km**	**2 km**
Horiz Resolution along track	**350 km**	**350 to 400 km**
Duty Cycle	100%	**UV subsystem 10%** **IR subsystem 100%**

UV Subsystem
GTWS to NDWL

	GTWS	NDWL
Requirements	GTWS Threshold	P3I Demonstration Requirements
Altitude Range	0 to 20 km	Upper troposphere
Wavelength	Monochromatic	Multispectral
Duty Cycle	100%	10% Adaptive Targeting
Mass, power, volume	Very large	Much smaller
Laser Wallplug Efficiency	1.6%	4.2%
Technology Readiness	Lower TRL Longer time line	Higher TRLs Shorter time line

UV Mass and Power

	GTWS UV (DD) Reference Designs	ADM	NPOESS UV Target
Instrument Mass (kg)	656	470	225
Bus Mass (kg) with fuel	1826	630	
Instrument Average Power (W)	3438	830	250
Bus Average Power (W)	259	570	

Comparative Design Parameters

Parameters	GTWS UV	NPOESS UV
Orbit (km)	400	833
Duty Cycle	100%	10%
Collector Diameter (m)	1.5	.75 to .90
Laser Power		
Input (W avg)	3125	56 to 80 *
J/shot	0.4	.234 to .337
PRF	125	100
Tracks per orbit	4	2
Time / data set	48.5	53.2
Integration time	5.1	12
Scan time	1	1.3
Integration Distance (km)	36.8	74.4
Laser Wallplug Efficiency	0.016	.042

* 10% duty cycle

Comparative Design Parameters With ADM

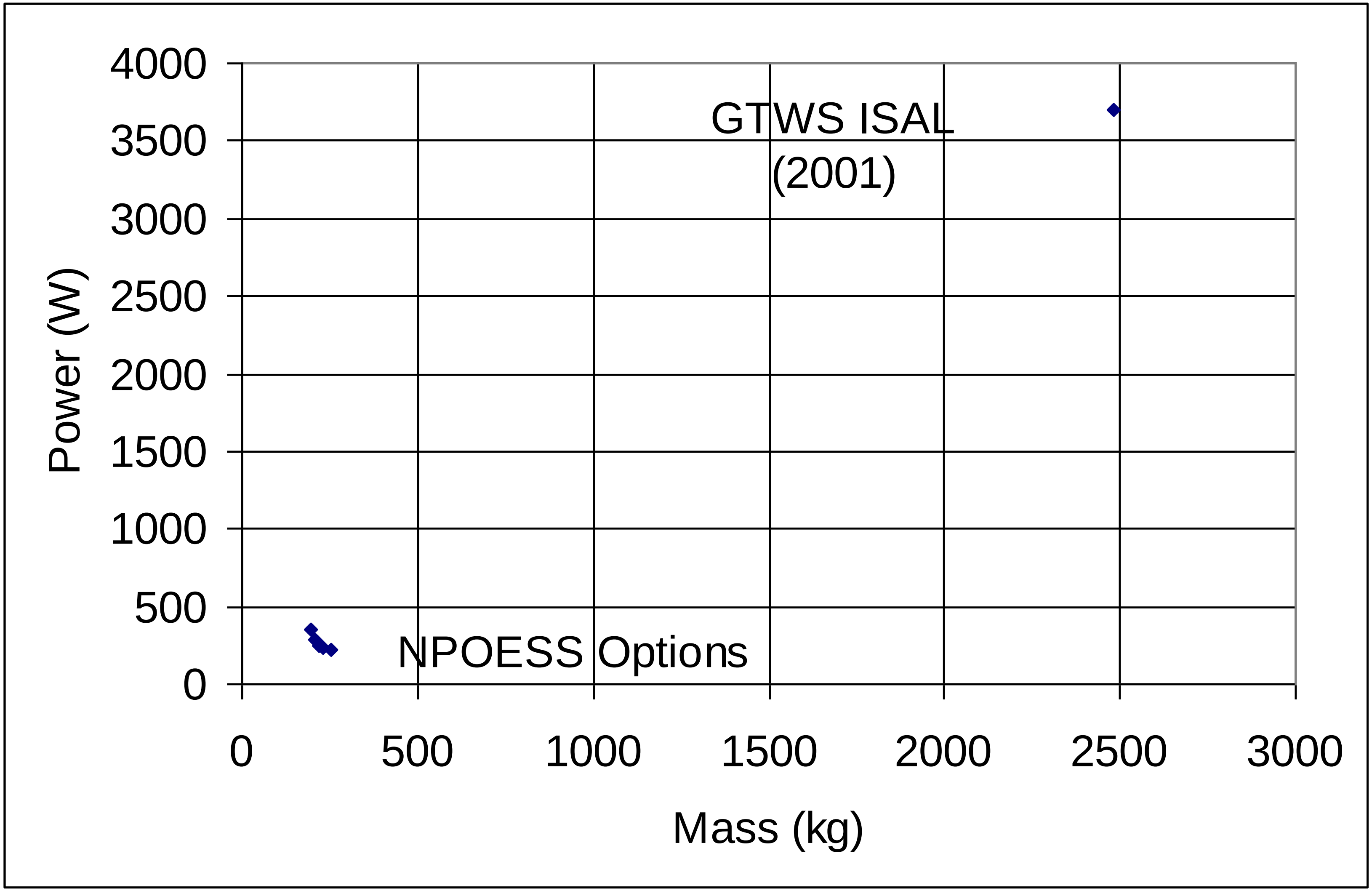
Parameters	GTWS	NPOESS UV	ADM**
Orbit (km)	400	833	400
Duty Cycle	100%	10%	25%
Collector Diameter (m)	1.5	.75 to .90	1.5
Laser Power Input (W avg) J/shot PRF	 3125 0.4 125	 56 to 80 * .234 to .337 100	 830 0.15 100
Tracks per orbit Time / data set Integration time Scan time	4 48.5 5.1 1	2 53.2 12 1.3	1 28 7 n/a
Integration Distance (km)	36.8	74.4	50
Laser Wallplug Efficiency	0.016	.042	

* 10% duty cycle
** Single perspective

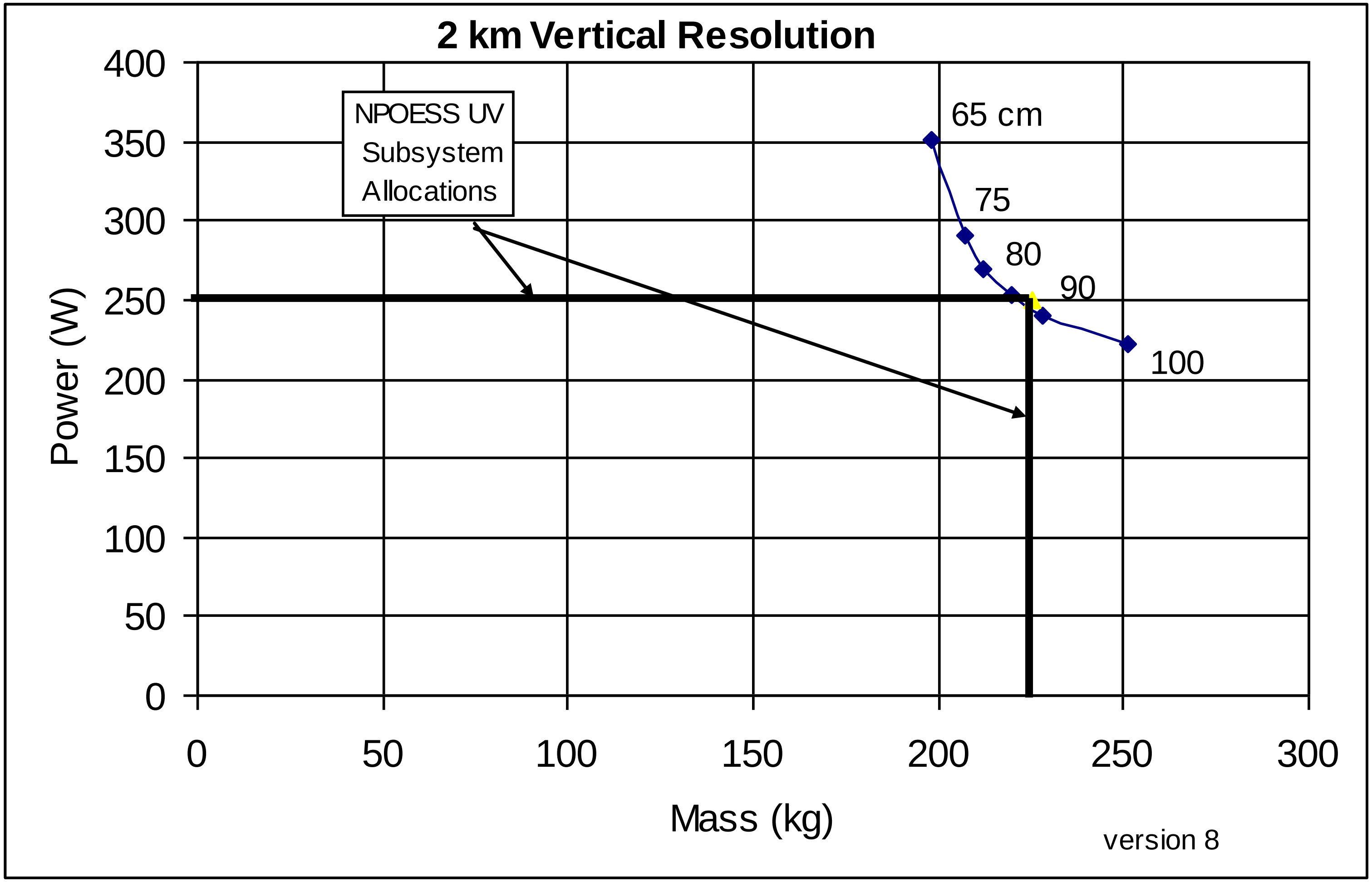
Some Trades

- Number of tracks
- Aperture
- Laser output power per shot and prf
- Duty cycle
- Shot accumulation time
- Scan and settle time
- Optical, detector, and laser efficiencies
- Vertical resolution
- Horizontal along-track resolution

NDWL UV Subsystem vs. GTWS



UV Subsystem vs. NPOESS Budget



UV Instrument Subsystem Mass

85 cm Aperture **2 km Vertical Resolution**	**GTWS Mass (kg)**	**NDWL UV Mass**
Primary Structure	165	41
HOE	42	8
Laser	30	30
Step/Stare Motor Drive System	10	1
Etalon System, Detector	16	16
Detectors (PMTs)	4	4
Fasteners, misc mechanical	5	1
Laser Power Converter Box	55	1
Main Electronics & Box, Mech Board	15	15
Cabling, misc electrical	4	1
Thermal Subsystem	260	9
Instrument Total	**656**	**127**

UV Bus Mass Estimate

85 cm Aperture **2 km Vertical Resolution**	**GTWS Mass**	**NDWL Bus Mass**
Bus Structure & Extra Stiffeners	348	16
Attitude Control System	149	20
Command & Data Handling	24	24
Electrical Power System	460	19
Thermal (support Instrument EPS)	54	4
Bus Harness	21	9
RF Communications	26	0
Propulsion	748	0
Total Bus Mass	**1830**	**92**

UV Subsystem
Mass Totals

85 cm Aperture 2 km Vertical Resolution	GTWS Mass (kg)	NDWL Mass
Bus Total	1826	92
Instrument	656	127
Total	2482	219

UV Instrument Power Estimate

85 cm Aperture **2 km Vertical Resolution**	**GTWS Power (W)**	**NDWL Avg. UV Power**
Laser	3125	62
Step/Stare Motor Drive System	65	0.3
Etalon System, Detector	4	4
Detectors (PMTs)	10	10
Main Electronics & Box, Mech Board	8	8
Thermal Subsystem	180	12
Processor, A/D, Housekeeping Board	6	6
Keep-alive component heaters	Not used when active	58
Power Box Dissipation	40	2
Instrument Total	**3438**	**162**

UV Bus Power Estimate

85 cm Aperture **2 km Vertical Resolution**	**GTWS Power**	**NDWL UV Bus Power**
Attitude Control System	112	26
Command & Data Handling	36	36
Electrical Power System	0	26
Thermal (support Instrument EPS)	50	3
RF Communication	61	0
Bus Total	**259**	**91**

UV Subsystem
Power Totals

85 cm Aperture 2 km Vertical Resolution	GTWS Power (W)	NDWL UV Power
Bus Total	259	91
Instrument	3438	162
Total	3697	253

Conclusions

- Preliminary look
- UV mass and power seem to fit NPOESS P3I budget allocation
- Need to look at
  - IR mass and power
  - UV and IR volume
  - Accommodation study underway
- Next step: GSFC ISAL NDWL design

Backup Slides

Reducing the Aperture

- May eliminate scanner problems
  - HOE instead of SHADOE
  - Scanner energy & vibration ~ $1/d^5$
  - Moment of Inertia ~ $1/d^3$
- Telescope volume ~ $1/d^3$

2 Tracks vs. 4

- Laser and scanner power reduced
- More time to rotate
  - Smaller motor
  - Less vibration
- Longer accumulation time

Thermal Subsystem

- GTWS design had large radiator and circulation system
- Reduced in NDWL
  - Less laser power
  - Less duty cycle
  - Upper atmosphere only
  - Get downtime heating from IR subsystem
  - Assume NPOESS dissipates DWL power budget

Laser Power

- Reduced from GTWS ISAL
  - Adaptive Targeting reduces duty cycle
  - Multispectral: UV only covers upper troposphere
  - Improved laser efficency estimates

Laser Wallplug Efficiency

- Consensus from laser engineers at GSFC
  - ~ 1.9% GLAS and CALIPSO experience
  - > 5% now
    - 80% DC to DC conversion
    - 45% diode
    - 15% optical to optical
  - > 8% in 5 years
    - 80% DC to DC
    - 55% diode
    - 20% optical to optical
- Barry Coyle: current prototype flight laser design
  - Feels 7% to 8% may be possible now

Pulsed Laser Efficiency

		DC-DC Converter	Pump Laser Diodes Electrical-to-Optical	Laser Optical-to-Optical	Wave-length Conversion	WPE	Notes
0.355-Micron Nd:YAG Laser	Now	0.8	0.50 (808 nm)	0.18	0.4	0.029	Steve Li, 12/22/05, 0.8 J @ 100 Hz (1 micron)
	In 5 Years	0.8	0.55 (808 nm)	0.21	0.45	0.042	Steve Li, 12/22/05, 0.8 J @ 100 Hz (1 micron)
2-Micron Ho:Tm: LuLiF Laser	Now	0.8	0.45 (792 nm)	0.025	N/A	0.009	Jirong Yu, 12/8/05, 250 mJ, 10 Hz
	In 5 Years	0.8	0.55 (792 nm)	0.032	N/A	0.014	Jirong Yu, 12/8/05, 250 mJ, 10 Hz

WPE = Wall Plug Efficiency

Laser Duty Cycle

$P_{standby} \sim 10\% \ P_{tot}$

Duty Cycle = 10%

$P_{avg} = .1 \ P_{tot} + .9 * .1 * P_{tot} = 0.19 * P_{tot}$

Notes:

- VCL laser designed to operate in a 10-15% duty cycle
- For frequency stability
  - Seeder and oscillator can run 100 %
  - Amplifiers cycled
  - Assume seeder and oscillator consume 10% of Ptot and the amplifiers consume 90%

Duty Cycle (cont'd)

- Thermal cycling
  - *May* stress diode array and laser slabs bonds leading to reduced laser life
  - No test data at this point
  - May be partially compensated since duty cycle reduces number of laser shots by ~ factor of 10

Reducing Mass

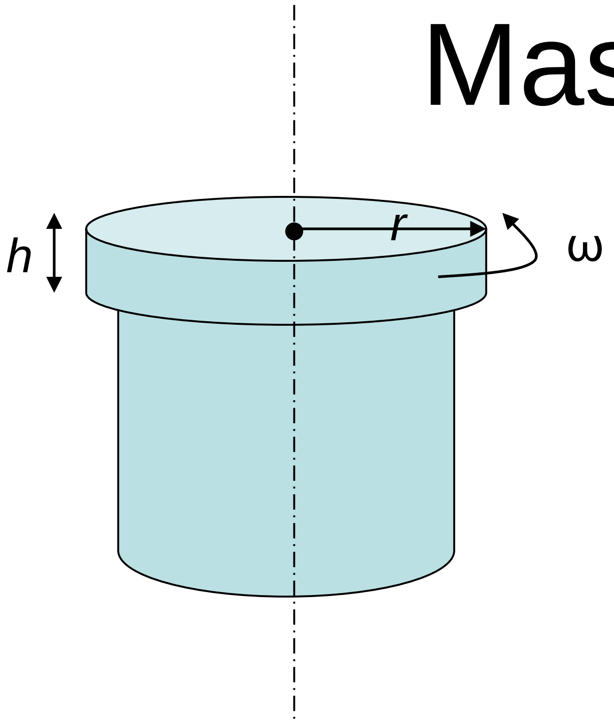
- Attitude Control System (55 kg)
  - Share Internal Reference Unit, Star Tracker?
  - Reduce HOE diameter
- Look at
  - Spacecraft Computer (24 kg)
  - Power System Electronics (40 kg)
  - Bus Harness (21 kg)

Moment of Inertia Scaling

Raj Khanna

11 January 2006

Mass, Energy, & Power



Mass & Energy Equations

$$m = \rho \cdot \pi r^2 \cdot h$$

$$v = r\,\omega$$

$$KE = \frac{1}{2} m v^2 = \frac{1}{2} m r^2 \omega^2$$

$$KE = \frac{1}{2} \rho \cdot \pi r^2 \cdot h \cdot r^2 \omega^2 = \frac{1}{2} \rho \pi r^4 h \omega^2$$

$$P = \frac{\partial KE}{\partial t} = m r^2 \omega \frac{\partial \omega}{\partial t} = \rho \pi\, r^4 h\, \omega \frac{\partial \omega}{\partial t}$$

Torque Equations

$$f = ma = m\frac{dv}{dt} = mr\frac{d\omega}{dt}$$

$$\tau = rf = mr^2 \frac{d\omega}{dt} = \rho \pi\, r^4 h \frac{d\omega}{dt}$$

$$P = \tau\omega = \rho \pi\, r^4 h \omega \frac{d\omega}{dt}$$

Reference
(link): http://en.wikipedia.org/wiki/Torque

Mass Scaling

$$m_1 = \rho \cdot \pi r_1^{\,2} \cdot h_1$$

$$m_2 = \rho \cdot \pi r_2^{\,2} \cdot h_2$$

$$\frac{m_2}{m_1} = \frac{\rho \cdot \pi r_2^{\,2} \cdot h_2}{\rho \cdot \pi r_1^{\,2} \cdot h_1} = \frac{r_2^{\,2} \cdot h_2}{r_1^{\,2} \cdot h_1}$$

$$\frac{m_2}{m_1} = \left(\frac{r_2}{r_1}\right)^3 \quad if \;\; \frac{h_2}{h_1} = \frac{r_2}{r_1}$$

Power Scaling

$$P_1 = \frac{\partial KE}{\partial t} = mr_1^{\,2}\omega\frac{\partial \omega}{\partial t} = \rho\pi r_1^{\,4} h_1 \omega \frac{\partial \omega}{\partial t}$$

$$P_2 = \rho\pi r_2^{\,4} h_2 \omega \frac{\partial \omega}{\partial t}$$

$$\frac{P_2}{P_1} = \frac{\rho\pi r_2^{\,4} h_2 \omega \frac{\partial \omega}{\partial t}}{\rho\pi r_1^{\,4} h_1 \omega \frac{\partial \omega}{\partial t}} = \frac{r_2^{\,4} h_2}{r_1^{\,4} h_1}$$

$$\frac{P_2}{P_1} = \left(\frac{r_2}{r_1}\right)^5 \quad if \quad \frac{h_2}{h_1} = \frac{r_2}{r_1}$$