Evaluation of the Mars Pathfinder Parachute Drag Coefficient

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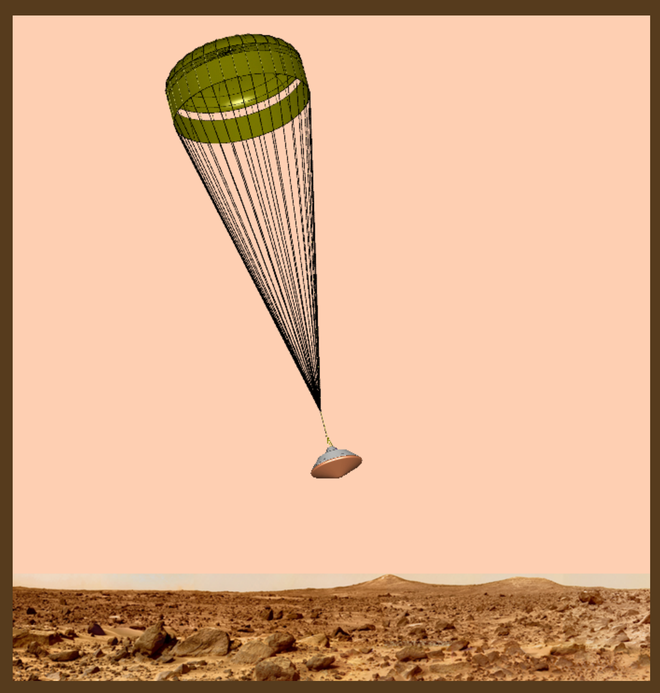
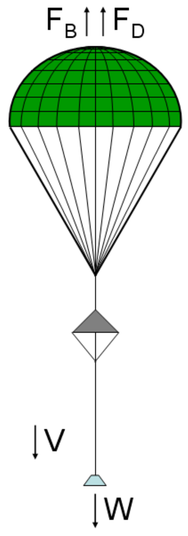
SSDL



Langley/JPL Parachute Drag Coefficient Reconstruction

The Mars Pathfinder parachute drag coefficient (C_{DPar}) reconstruction performed by NASA Langley and JPL† assumed that the parachute was in terminal descent at a constant velocity (quasi-steady state) at 1000 m. This implies that the acceleration term in the equation of motion is zero (i.e., $d^2h/dt^2 = 0$). Other implicit assumptions include vertical descent and a non-gliding parachute. This 1000-case Monte Carlo reconstruction yielded C_{DPar} = 0.4133 with a 3-sigma uncertainty of 0.0514.

$A_{B/S}$	backshell area	g	gravitational acceleration
A_{Lan}	lander area	h	altitude
A_{Par}	parachute nominal area	m	mass of the system
$C_{DB/S}$	backshell drag coefficient	ρ	atmospheric density
C_{DLan}	lander drag coefficient	t	time
C_{DPar}	parachute drag coefficient	v	velocity
F_B	buoyancy force	Vol	lander volume
F_D	drag force	W	weight



$$F_D + F_B - W = m\frac{d^2h}{dt^2}$$

$$F_D = \frac{1}{2}\rho v^2 (C_{D_{Par}} A_{Par} + C_{D_{B/S}} A_{B/S} + C_{D_{Lan}} A_{Lan})$$

$$F_B = \rho g Vol$$

$$W = mg$$

$$C_{D_{Par}} = \frac{2(m\frac{d^2h}{dt^2} + mg - \rho g Vol)}{(\rho v^2 A_{Par})} - \frac{C_{D_{B/S}} A_{B/S} + C_{D_{Lan}} A_{Lan}}{A_{Par}}$$

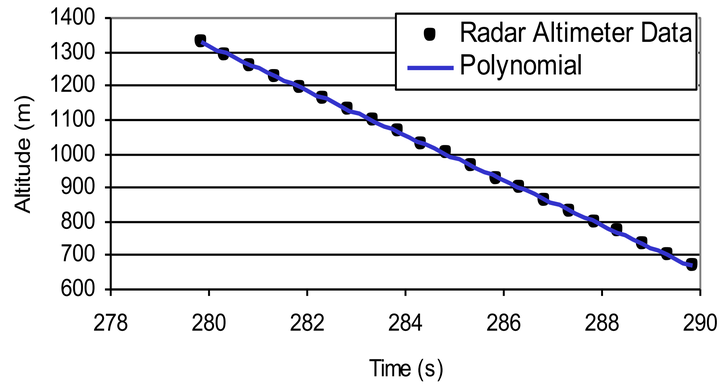
Evaluation of C_{DPar} Including Nonzero Acceleration

The zero acceleration (i.e., constant velocity) assumption may not be justified. In order to assess the impact of the acceleration term, C_{DPar} is recalculated in the present 1000-case Monte Carlo study to include the acceleration term (i.e., $d^2h/dt^2 \neq 0$). All other quantities required to calculate C_{DPar} remain the same as in the original quasi-steady state Langley/JPL reconstruction.

Determination of Acceleration

The MPF radar altimeter data, taken at a sampling rate of 8 Hz, was fitted with a polynomial in a 10 second interval around the 1000 m altitude (284.83 s). This is the altitude used in the in the quasi-steady state Langley/JPL reconstruction.

The second derivative of the polynomial yields an acceleration of 0.240 m/s^2 at an altitude of 1000 m. Note that this acceleration is significant when compared to the acceleration of gravity on the surface of Mars (3.7245 m/s^2).

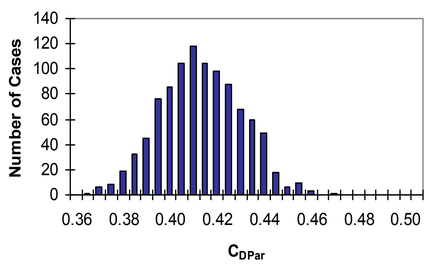


Results

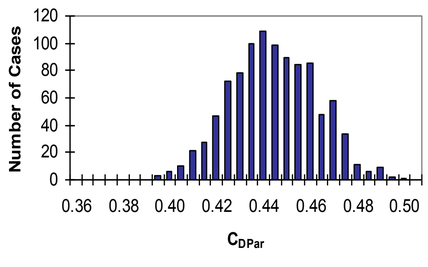
Including the acceleration term yields a mean value of C_{DPar} approximately 7% higher than the quasi-steady state (zero acceleration) value. The noticeable increase in C_{DPar} indicates the importance of the acceleration term in reconstructing the parachute drag coefficient when the acceleration of the vehicle is significant as compared to the acceleration of gravity.

Value	Quasi-Steady State Reconstruction	Acceleration Term Reconstruction	% Difference
Mean	0.4108	0.4419	7.04
3-σ	0.0514	0.0549	6.12

Quasi-Steady State Reconstruction



Non-Zero Acceleration Term Reconstruction



Comparison to Previous Results

The C_{DPar} values can be compared to estimated values from previous results, namely an aerial drop test‡ and a wind tunnel test§. Due to uncertainties and differences in the tests, the C_{DPar} results are within acceptable range of the present study results, yielding consistent data sets.

It is of historical interest to note that a C_{DPar} of 0.5 was used in all Mars Pathfinder pre-flight and operations engineering analysis¥. While this value is statistically possible, it is unlikely that such a high drag coefficient was achieved by the MPF system in flight on Mars.

To summarize, based on consideration of multiple estimates of the Mars Pathfinder parachute drag coefficient, it is felt that the present reconstruction, inclusive of the acceleration term, provides the best estimate of the Mars Pathfinder parachute flight system drag coefficient as 0.4419 ± 0.0549 (3-σ).

	C_{DPar}	% Difference
Non-Zero Acceleration Term Reconstruction	0.4419±0.0549	---
Aerial Drop Test	0.43	2.69
Wind Tunnel Test	0.405±0.023	8.35

†Desai P. N., et al., Flight Reconstruction of the Mars Pathfinder Disk-Gap-Band Parachute Drag Coefficients, *Journal of Spacecraft and Rockets*, Vol. 42, No. 4, 2005, pp. 672-676.
‡Witkowski A., Mars Pathfinder Parachute System Performance, *AIAA Paper 99-1701,* 1999.
§Cruz J. R., et al., Wind Tunnel Testing of Various Disk-Gap-Band Parachutes, *AIAA Paper 2003-2129,* 2003.
¥Braun, R. D., et al., Mars Pathfinder Six Degree-of-Freedom Entry Analysis, *Journal of Spacecraft & Rockets*, Vol. 32, No. 6, pp. 993-1000.