HyperPASS, a New Aeroassist Tool

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ABSTRACT

A new software tool designed to perform aeroassist studies has been developed by Global Aerospace Corporation (GAC). The Hypersonic Planetary Aeroassist Simulation System (HyperPASS) [1] enables users to perform guided aerocapture, guided ballute aerocapture, aerobraking, orbit decay, or unguided entry simulations at any of six target bodies (Venus, Earth, Mars, Jupiter, Titan, or Neptune). HyperPASS is currently being used for trade studies to investigate (1) aerocapture performance with alternate aeroshell types, varying flight path angle and entry velocity, different g-load and heating limits, and angle of attack and angle of bank variations; (2) variable, attached ballute geometry; (3) railgun launched projectile trajectories, and (4) preliminary orbit decay evolution. After completing a simulation, there are numerous visualization options in which data can be plotted, saved, or exported to various formats. Several analysis examples will be described.

1 BACKGROUND

The Hypersonic Planetary Aeroassist Simulation System (HyperPASS) has been an ongoing project at Global Aerospace Corporation (GAC) for the past three years. Its beta version was completed in May 2004 and is currently undergoing validation. The validated version, HyperPASS 1.0, is set to be released sometime in Fall 2004.

2 VALIDATION

HyperPASS has been validated using a 2 degree-of-freedom (2DOF) system. This system is been used by one of the authors for contract work at NASA's Jet Propulsion Laboratory (JPL) for aeroassist and launch approval studies.

2.1 Titan Aerocapture

Titan Aerocapture was simulated using the Hunten [2] atmosphere model along with the following vehicle parameters and entry conditions:

Table 1 Titan Aerocapture Parameters

PARAMETER	VALUE
L/D	-0.242
m/CDA (kg/m^2)	61.279
Atmospheric interface altitude (km)	1000.000
Entry velocity (km/s)	6.000
Entry flight path angle (deg)	-33.300

Fig. 1 compares altitude vs. velocity at the level-off or periapsis point of each trajectory. The trajectories reach periapsis about 2 seconds apart with an altitude difference of only 62 m and a velocity difference of less than 25 m/s. During the entry phase, the velocities of the two trajectories agree within 1 m/s at any given altitude and vary by less than 8 m/s during the exit phase. This reflects a remarkable agreement between the HyperPASS and 2DOF simulations.

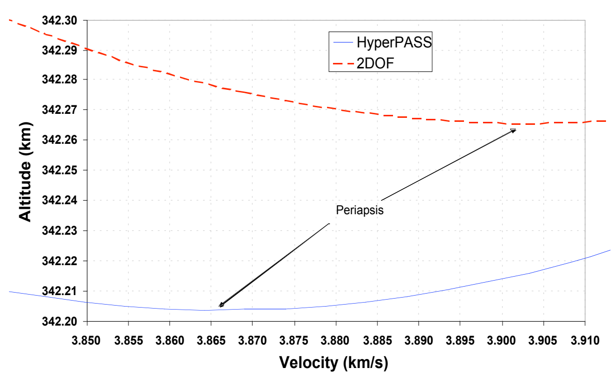

Fig. 1. Trajectory comparison at periapsis for Titan aerocapture

The flight path angles (FPA) are in close agreement throughout the entire simulation. It is seen in Fig. 2 that, upon reaching the exit altitude (1000 km), the FPA differs by less than 0.2 deg, which is the maximum FPA divergence seen in this simulation.

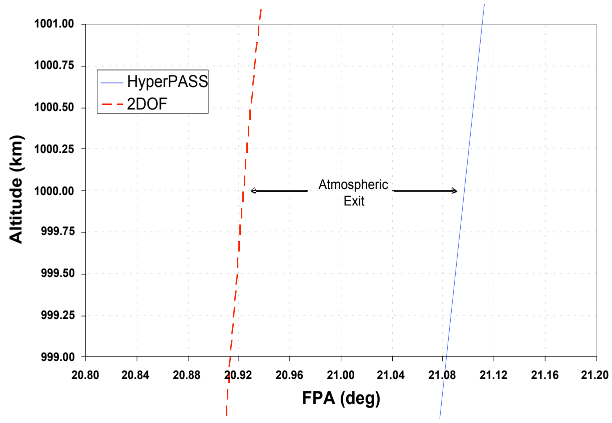

Fig. 2. FPA comparison at atmospheric exit for Titan aerocapture

The total deceleration force is likewise in agreement, with a maximum divergence of 0.015 gees.

2.2 Mars Landing

The Mars landing validation case was performed using the COSPAR90 [3] atmosphere model and the following parameters:

Table 2 Mars Landing Parameters

PARAMETER	VALUE
L/D	0.000
m/CDA (kg/m^2)	56.420
Atmospheric interface altitude (km)	125.000
Entry velocity - planet relative (km/s)	5.763
Entry flight path angle - planet relative (deg)	-11.300

Both simulation systems propagated the trajectory until a velocity of 500m/s was achieved. HyperPASS took about 0.5 seconds longer to reach this stopping condition. Looking at altitude as a function of time as shown in Fig. 3, it is found that above 60 km the altitude variance between the two simulations does not exceed 100 m. The greatest altitude divergence (~ 250 m) occurs during the last 10 seconds of simulation and is depicted in the figure below.

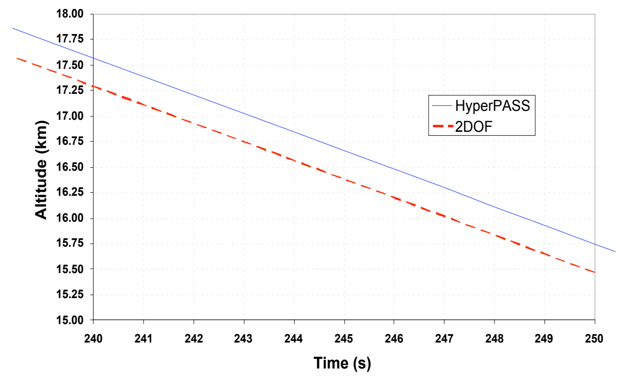

Fig. 3. Maximum altitude divergence for Mars landing

Next, attention was paid to the altitude versus velocity profiles. When each trajectory reached a 100 km altitude, the velocity difference was less than 2 m/s. At an altitude of about 38 km, the velocity divergence was at its peak (~55 m/s), as shown in Fig. 4. Upon reaching the target velocity of 500 m/s, the two trajectories showed a 162 m altitude difference.

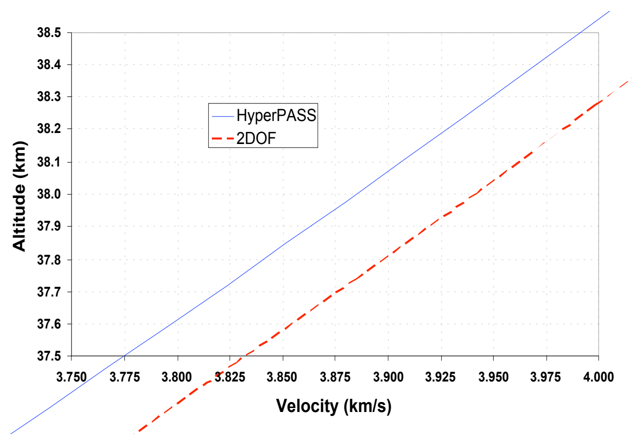

Fig. 4 Maximum velocity divergence for Mars landing

When a comparison was made between the FPA profiles, it was found that the values were extremely consistent between the two simulations, with a maximum divergence of less than 0.02deg.

2.3 Neptune Aerocapture

The Neptune aerocapture validation case uses the Hall [4] exponential atmosphere model. This run had an initial altitude of 440 km and was propagated to a 1200 km exit altitude. Parameters and initial conditions for the simulation can be viewed in Table 3.

Table 3 Neptune Aerocapture Parameters

PARAMETER	VALUE
L/D	0.632
m/CDA (kg/m^2)	208.030
Initial altitude (km)	440.000
Initial velocity - planet relative (km/s)	27.553
Initial flight path angle - planet relative (deg)	-7.440

The two simulations reached periapsis within 1 second of each other. Fig. 5 shows that HyperPASS achieved a periapsis altitude 2.08 km higher than that of the 2DOF system, but that the velocities at periapsis had less than 2 m/s difference.

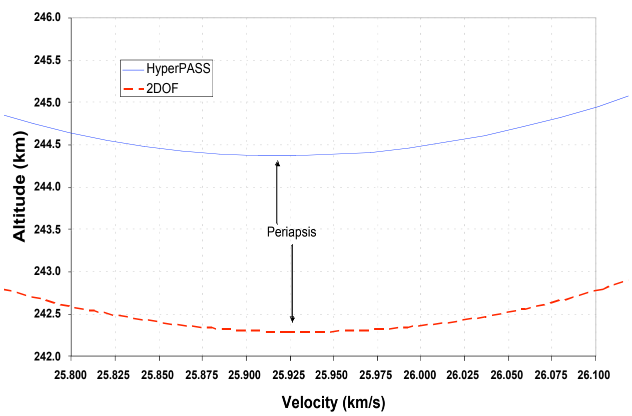

Fig. 5. Trajectory comparison at periapsis for Neptune aerocapture

The greatest variance in velocity occurred between altitudes of 450-500 km, which can be seen in Fig. 6. The systems reached exit (1200 km) less than 2 seconds apart, with a velocity difference of only 11 m/s.

The flight path angles at exit, differed by 0.03 deg and the total g-load experienced by the vehicle did not vary significantly between the two simulations. The greatest divergence occurred at periapsis, with a difference of 0.14 gees.

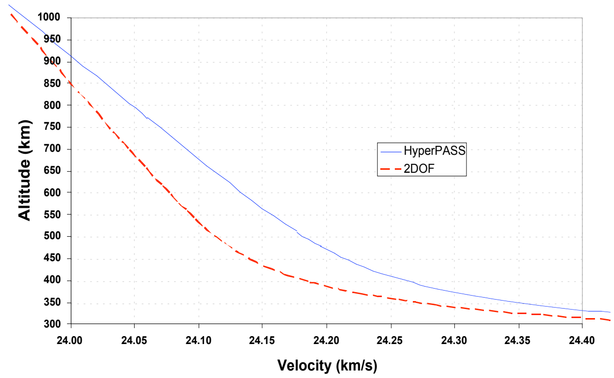

Fig. 6. Maximum velocity divergence during Neptune aerocapture

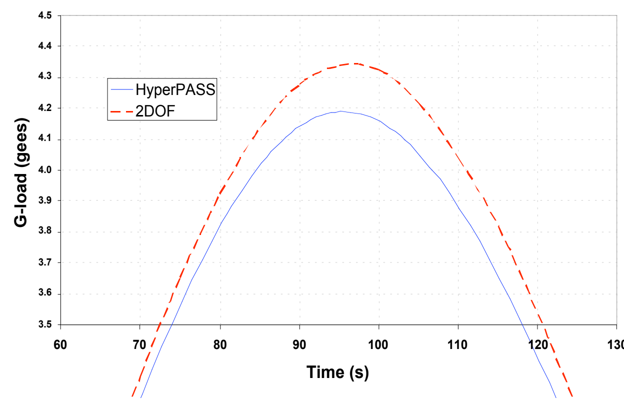

Fig. 7. Maximum g-load variance during Neptune aerocapture

3 HYPERPASS GUIDANCE CAPABILITIES

While the previous cases were performed with no implemented guidance (for validation purposes), HyperPASS possesses the ability to output the optimal trajectory, given a set of user entered initial and target conditions. The following examples include guided aerocapture at Mars, guided ballute aerocapture at Neptune, and aerobraking at Venus.

3.1 Aerocapture

HyperPASS performs guided aerocapture simulations by choosing an optimal entry FPA and guiding the vehicle through a bank-modulated aerocapture, in order to achieve the desired exit conditions. The following simulation parameters were entered into HyperPASS.

Table 4 Mars Guided Aerocapture Input Parameters

PARAMETER	VALUE
L/D	0.632
m/CDA (kg/m^2)	208.293
Entry altitude (km)	125.000
Entry velocity (km/s)	10.180
Target altitude (km)	125.000
Target velocity (km/s)	4.200

HyperPASS selected an entry FPA of -12.00 deg and was able to achieve the desired exit conditions using the angle of bank profile shown in Fig. 8. Fig. 9 displays the state parameters for the Mars guided aerocapture case.

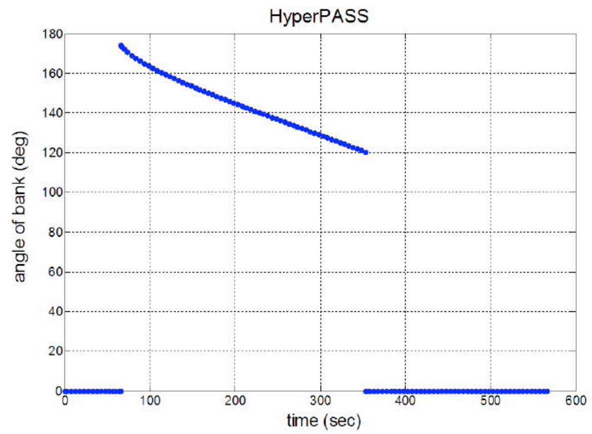

Fig. 8. Bank Angle Profile for Mars Guided Aerocapture

3.2 Ballute Aerocapture

To perform a guided ballute aerocapture simulation, HyperPASS chooses the optimal entry FPA and then determines the proper ballute cut time necessary to meet the user entered target conditions. The user can also enter ballute specifications such as shape, dimensions, and aerial density. Table 5 lists the Mars ballute case input parameters.

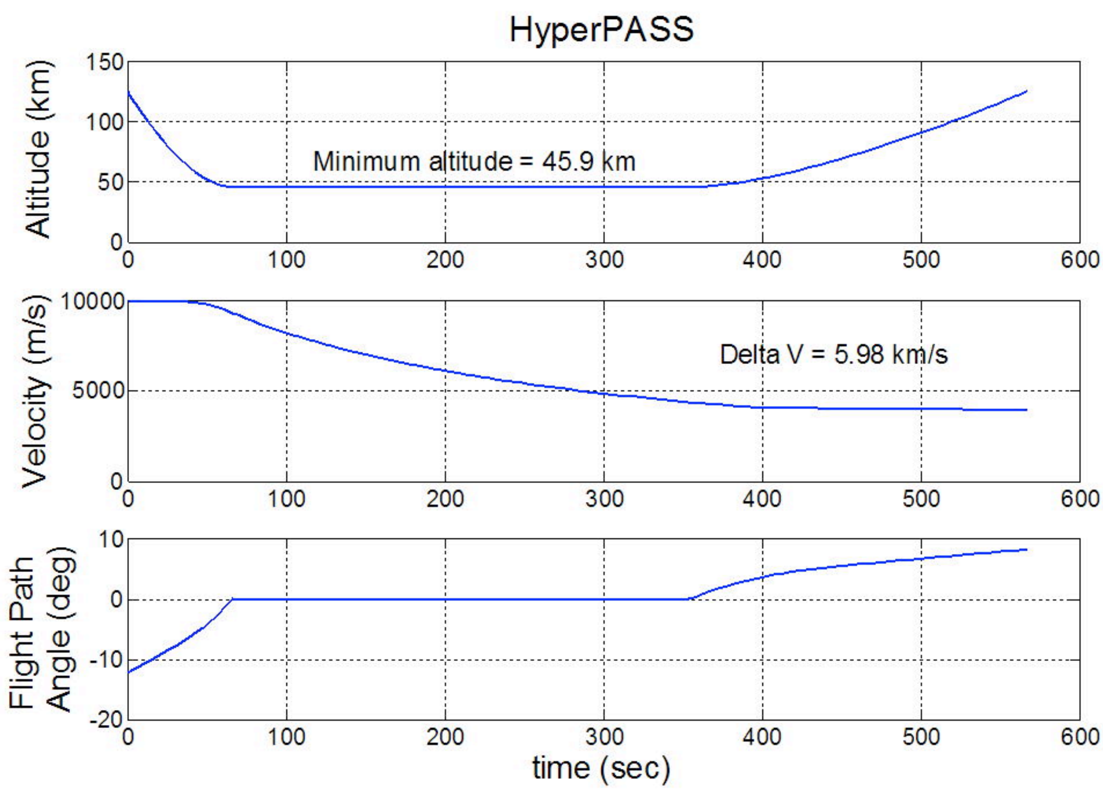

Fig. 9. State Vector for Mars Guided Aerocapture

Table 5 Mars Ballute Aerocapture Input Parameters

PARAMETER	VALUE
Ballute type	Sphere (CD = 0.9)
L/D	0.632
m/CDA - without ballute (kg/m^2)	54.072
m/CDA - with ballute (kg/m^2)	1.000
Entry altitude (km)	150.000
Entry velocity (km/s)	5.748
Target altitude (km)	150.000
Target velocity (km/s)	4.200

For the Mars ballute case, HyperPASS selected an entry FPA of -8.86 deg and cut the ballute after 195 seconds, in order to exit at the indicated target conditions. Fig. 10 displays the altitude, velocity, and FPA as a function of time.

3.3 Aerobraking

Aerobraking is simulated by performing consecutive atmospheric passes until the desired apoapsis altitude is reached. HyperPASS automatically implements raise periapsis maneuvers if the user entered heating limit is exceeded during aerobraking. Also, HyperPASS will perform orbit insertion and orbit circularization maneuvers if so desired. Table 6 gives the parameters used for the simulation presented here.

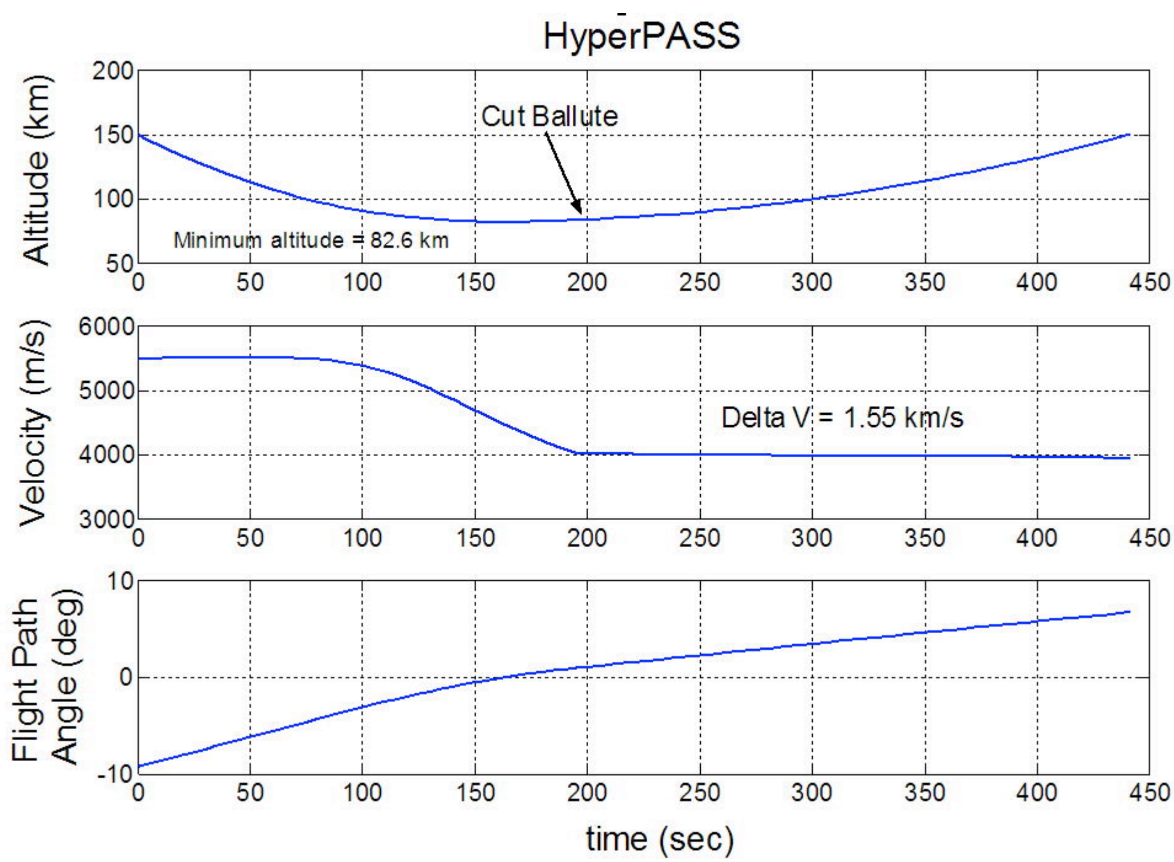

Fig. 10. State Vector for Mars Ballute Aerocapture

Table 6 Venus Aerobraking Input Parameters

PARAMETER	VALUE
L/D	0.000
Drag coefficient	2.200
m/CDA (kg/m^2)	21.739
1st periapsis altitude (km)	129.500
1st periapsis velocity (km/s)	8.586
Desired apoapsis altitude (km)	1500.000
Free Molecular Heating Limit (W/cm^2)	0.300
Raise periapsis altitude (km)	1.000

The desired apoapsis altitude was achieved in 689 atmospheric passes. Orbit period is given as a function of periapsis pass in Fig. 11.

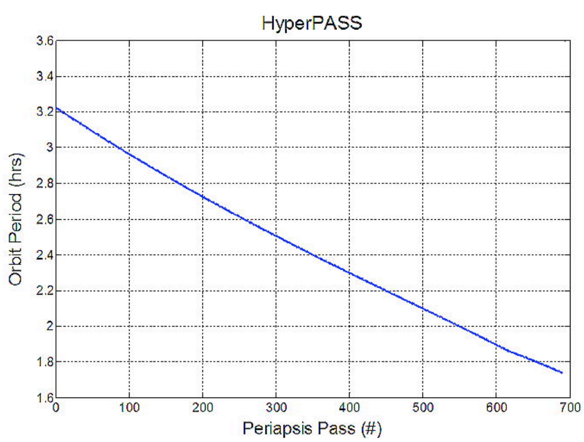

Fig. 11 Orbit period over time for Venus aerobraking

The free molecular heating limit was exceeded only once, which is apparent from the heating profile given in Fig. 12. At this point in the simulation, a maneuver was implemented to raise the periapsis altitude by the user specified "raise periapsis altitude".

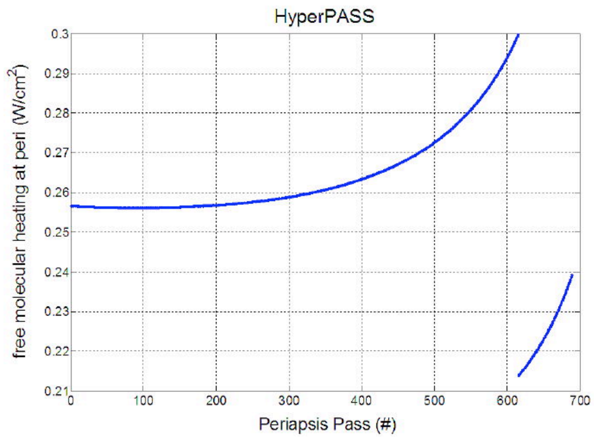

Fig. 12. Heating at periapsis for Venus aerobraking

4 CONTINUING DEVELOPMENT

HyperPASS is currently awaiting validation from a high fidelity simulation system. Planned improvements for future versions of HyperPASS include the generation of atmospheric data from Global Reference Atmospheric Models (GRAM) [5] and automated vehicle parameterization. Also, further bank modulated aerocapture development will include the added capability to maintain orbit inclination as opposed to the simple one-sided profile currently being used.

5 REFERENCES

1. Gates K. L. and Nock K. T. *HyperPASS User and Installation Manual,* http://www.gaerospace.com/projects/HyperPASS/HyperPASS_Manual.pdf.

2. Hunten, Titan Atmosphere Model, Prepared for NASA AIMES RC Preliminary Draft, 1981.

3. Pitts D. E., et al. The Mars Atmosphere: Observations and Model Profiles for Mars Missions, NASA Johnson Space Center report JSC-24455, 1990.

4. Hall J. L. and Lee A. K., Aerocapture Trajectories for Spacecraft with Large Towed Ballutes, AAS 01-235.

5. Justus C. G., "A Mars Global Reference Atmosphere Model (Mars-GRAM) for mission planning and analysis, *AIAA Paper No. 90-0004,* 28th Aerospace Sciences Meeting, 1990.