Innovative Strategy for Z9 Reentry

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Innovative Strategy for Z9 Reentry - Outline

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- Retro Rockets Employment for Z9 reentry
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Innovative Strategy for Z9 Reentry - Introduction

Z9 → third stage of VEGA launcher

- High altitudes
- High velocities

Actual reentry approach employs neutral axis maneuver to reduce reentry areas

Proposed new reentry strategy by means of retro rockets

→ **Pros**

- Reduction of Z9 footprint
- Exploitation of the whole Z9 energetic capacity

→ **Cons**

- Layout modification
- Mass increase

Innovative Strategy for Z9 Reentry – Neutral Axis Maneuver

Neutral Axis Maneuver (NAM) is the current solution for Z9 footprint reduction

NA approach is based on the ballistic technique "Null Miss Condition"

- Neutral axis is a specific direction linked to every point of the trajectory
- Velocity impulse applied along NA does not change the impact point

NAM is performed in open loop guidance several seconds before Z9 burnout reducing significantly Z9 footprint

Drawbacks

→ **Footprint remains large**: about 2000 km for equatorial mission and 1300 for polar ones

→ **Some of Z9 energy is lost** during the maneuver reducing VEGA performances

Innovative Strategy for Z9 Reentry – RRs employment (1)

New reentry strategy proposed →

Retro rockets employed at the end of Z9 + closed loop guidance to reach desired impact point

- No NAM is performed
- Z9 used up its exhaustion
- Desired impact point defined during missionization phase
- Optimal reentry angle computed after Z9 exhaustion
- Slew maneuver achieved during coasting phase by Roll & Attitude Control System
- Retro rockets ignited in the third separated stage

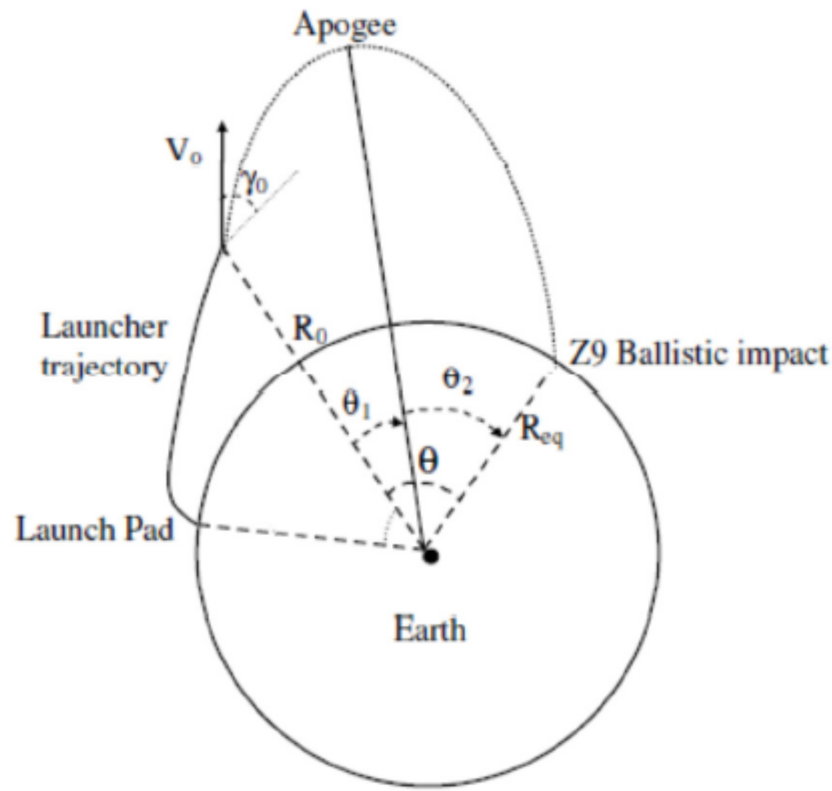
Optimal angle computation

$$p=\frac{R_0^2 V_0^2 \cos\gamma_0}{\mu};$$

$$e=\sqrt{\sin^2\gamma_0+\left(\frac{V_0^2 R_0}{\mu}-1\right)^2\cos^2\gamma_0}$$

$$\theta_1=\frac{(1-p/R_0)}{e};\ \theta_2=\frac{(1-p/R_{eq})}{e};$$

$$\theta=\text{sign}(\sin\gamma_0)\,\text{acos}\,\theta_1+\text{acos}\,\theta_2;$$



Innovative Strategy for Z9 Reentry - RRs employment (3)

Performances impact

- Retro rockets as those used for VEGA 1-2 separation
- Impulse of velocity delivered in about one second
- A set of **4 RRs** assures a certain margin wrt to desired DV applied and considering Z9 mass

→ Increase of mass mitigated by reduction of constraints to the trajectory due to much smaller footprint

Innovative Strategy for Z9 Reentry – Results (1)

Error with respect to desired impact point is very small both for nominal and scattered thrust profiles→ **reduction of two order of magnitude for footprint extension wrt NAM case**

- VEGA equatorial mission
- Optimal angle calculated 50s before separation
- RRs acceleration assumed almost impulsive (75 m/s2 in 1s of burning time)

Case	Optimal Angle [°]	Error [km]
Nominal	98.0	22.9
dIsp +	153.5	23.6
dIsp –	42.5	26.8
dTc +	94.0	24.8
dTc –	87.5	19.7
dTc + dIsp +	147.0	28.9
dTc + dIsp –	34.5	22.4
dTc – dIsp +	73.0	17.9
dTc – dIsp –	48.5	24.0

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Innovative Strategy for Z9 Reentry – Results (2)

Error presented before refers to ideal case.

→only error on approximation of optimal angle ("guidance error")

Different error sources are present in the real case

- **Control errors**
- **Separation disturbances**
- **Navigation errors on position and velocity**
- **Mass error on Z9 inert mass**
- **RRs impulse error**
- **Orbital propagation error**

Innovative Strategy for Z9 Reentry – Results (3)

Attitude Control Error

RACS 3 axes controlled phase after Z9 burn out → RACS pointing accuracy of order of tenth of degree. It could be limited under 0.5° but not null

Separation Disturbances

Expressed as disturbance on transversal angular rate

Attitude error (considering a RR firing time of 1s) can reach 2°

→footprint sensitivity of **40km/°**

Propagation Errors

Due to accepted assumptions

- J2 gravity term neglected
- Orbit perturbation due to RACS thrusters neglected

→ **< 500 m on position and 0.5 m/s on velocity**

Innovative Strategy for Z9 Reentry – Results (4)

Navigation Error

Evaluated on a MC campaign of 1000 runs for a VEGA equatorial mission

→ **Maximum error on position of 2 km**

→ **Maximum error on velocity of 12 m/s**

Error on footprint extension still remains acceptable

Case	Error [km]
Nominal	104.3
dIsp +	145.2
dIsp –	142.5
dTc +	105.4
dTc –	65.8
dTc + dIsp +	107.8
dTc + dIsp –	115.8
dTc – dIsp +	146.9
dTc – dIsp –	126.3

Innovative Strategy for Z9 Reentry – Results (5)

Mass Error

Error on Z9 inert mass = 5% at 3σ

Case	Error [km]
Nominal	22.9
dIsp +	121.6
dIsp –	76.8
dTc +	16.8
dTc –	5.0
dTc + dIsp +	117.3
dTc + dIsp –	91.0
dTc – dIsp +	51.7
dTc – dIsp –	72.3

RRs Impulse Error

RRs impulse scattering = 2% at 3σ

Combustion time scattering does not impact reentry performances

Case	Error [km]
Nominal	22.9
dIsp +	33.4
dIsp –	16.7
dTc +	24.0
dTc –	17.2
dTc + dIsp +	37.8
dTc + dIsp –	11.7
dTc – dIsp +	11.0
dTc – dIsp –	14.5

Error synthesis

Error Sources	Footprint Impact
Navigation Error	147 km
Attitude Error (control, separation, guidance optimization errors)	40 km/°
Mass Scattering (worst SRM scattering combination)	122 km
Retro Rocket Impulse Error	40 km
Propagation Error	Negligible
Quadratic Sum (considering 3° of attitude error)	**230 km**

Also considering the whole set of errors the Z9 footprint remains an order of magnitude lower than footprint obtained with NAM!

Innovative Strategy for Z9 Reentry – Conclusions

- **New Z9 reentry strategy proposed**
- **Feasible solution is constituted by a set of 4 Retro Rockets**
- **Footprint extension halved for polar missions and reduced of an order of magnitude for equatorial ones**
- **Main drawback: layout impact du to RRs introduction**

THANK YOU