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Three Posters: Numbers
1 and 2 use large print while
the third tells the story on one
chart, listing references and credits

Aerogravity Assist/Ellipsled Technology Could Enable Large Reductions in Transit Durations to Enceladus and Benefits to the Orbilander Mission (with application to other OPAG and SBAG missions)

James O. Arnold[1,2], David M. Cornelius[1,3] and Min Qu1,4
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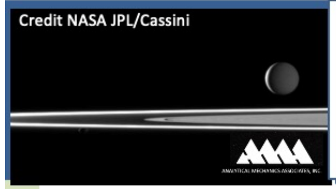


Aerogravity Assist Technology Could Cut Transit Time to Enceladus by Half, Reducing Orbilanders' Flagship Mission Duration From 15 Years To 9 While Retaining the Planned 3.5 Years for Science

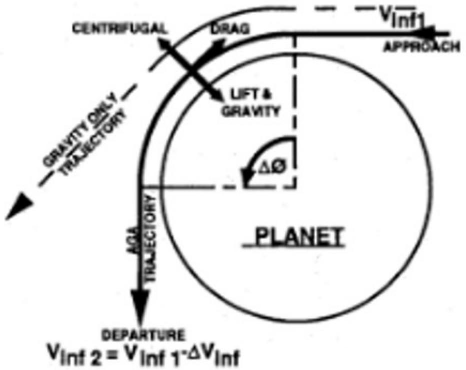
James O. Arnold[1,2], David M. Cornelius[1,3] and Min Qu[1,4]
[1]AMA-Inc. [2]James.O.Arnold@ama-inc.com, [3]cornelius@ama-inc.com, [4]minqu@ama-inc.com NASA Tech Showcase Jan. 2023

- **Orbilander is the 2nd highest priority for NASA's New Flagship Mission Listed in the 2023 Decadal Survey.**

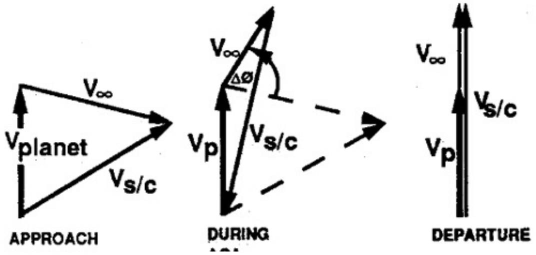
- **Orbilander's 3.5-year study of plumes will establish if life emerged on Enceladus and if not, why not?**

- **Current authors hypothesize (1) Large reductions in the transit time to Enceladus could be had via two Aerogravity Assist (AGA) maneuvers: 1st at Venus for spacecraft speed-up and 2nd at Titan for slow-down on the way to Enceladus. (2) An ellipsled fitted with a modern Thermal Protection System (TPS) could survive dual AGA heat pulses.**

- **Address concerns that life detection instruments would be contaminated during AGAs by keeping them in a bio-barrier, within the ellipsled until the Orbilander spacecraft is deployed at Enceladus.**



a) Decrease velocity, e.g., solar probe

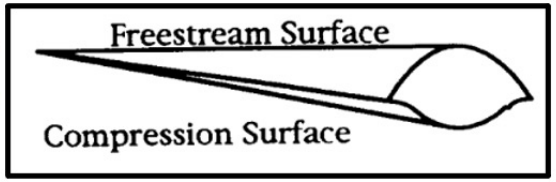


b) Increase velocity, e.g., outer planets

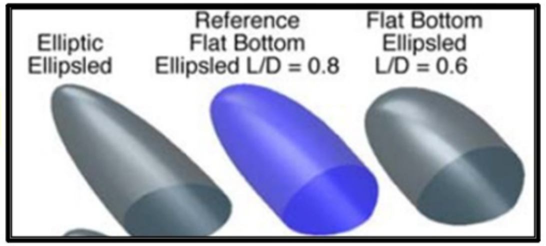
Aerogravity Assist Velocity Diagrams

Aerogravity Assist and Ellipsleds

Wave Rider



Ellipsleds



- **AGA = Gravity Assist plus atmospheric flight. TRL ~ 3.**
- **AGA can speed - up or slow - down V_{sc} depending on direction of rotation of V_{Inf}**
- **1992 AGA concept proposed wave riders for aeroshell --> Severe heating on sharp leading edges. AGA maturation stalled from lack of TPS.**

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References /Credits listed in poster showing subject overview

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Aerogravity Assist Technology Could Cut Transit Time to Enceladus by Half, Reducing Orbilanders' Flagship Mission Duration From 15 Years To 9 While Retaining the Planned 3.5 Years for Science

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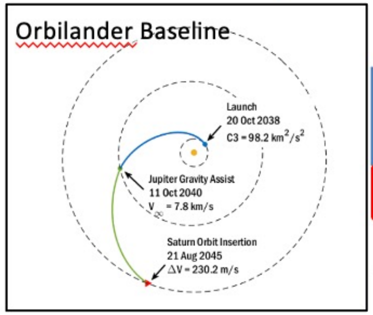
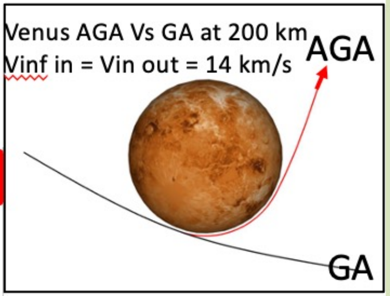
NASA Tech Showcase Jan. 2023



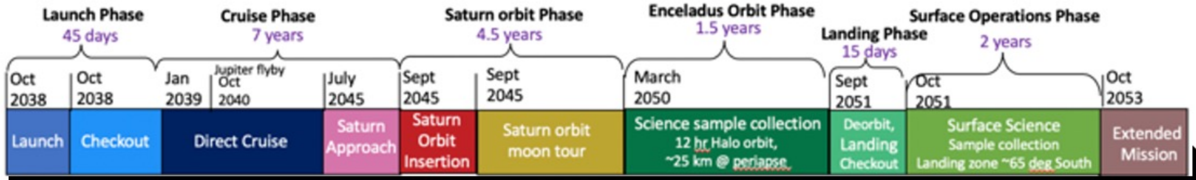
Orbilander vs Mission with AGA

Earth Depart	ED, km/s	Saturn Arr.	Duration, Yrs.	Venus Vinf, km/s	Turn Angle°	SA, km/s	VR % Vout/Vin
1/6/2049	7	4/6/2052	3.24	14	105.3	11.3	100%
1/12/2049	8	4/20/2052	3.27	15.6	102.4	11.1	90%
1/21/2049	10	1/18/2052	2.99	18.2	98.9	12.5	80%

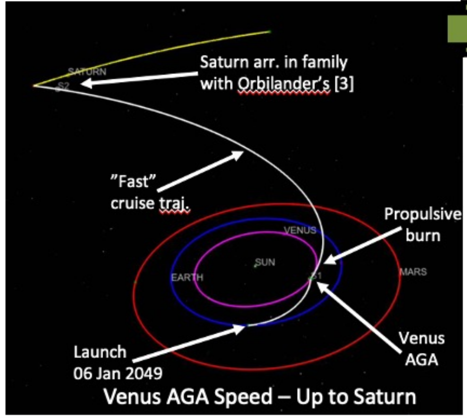


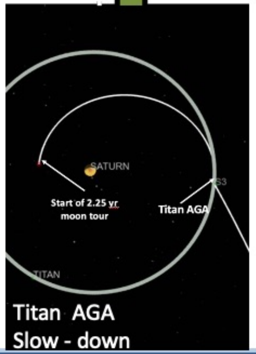
Interplanetary trajectory analysis using Copernicus code by Dr. Min Qu

Titan Vinf in = 9.9 km/s
Vinf out = 1.2 km/s, Turn angle = 122°



	Launch to Saturn, yrs.	Launch to Sci., yrs.	Science, yrs.	Mission Duration, yrs.
Orbilander Baseline	7	11.5	3.5	15
Orbilander with AGA	3.2	5.5	3.5	9





Next: AGA Analysis

- Aerodynamics
- Aerothermodynamics
- GN & C
- Thermal Protection

Mission Benefits Via AGA

Orbilander:

- 3.5 years of science retained.
- ***Win-win:*** Increased RTG power during science and $30 M saved per year during quiet cruise phases
- Eliminates certification of instruments beyond 15 - year End of Mission

Future Missions Tool?

Dual AGAs

- Saturn Multiple Flyby
- Saturn Probe

Single AGA

- Interstellar Object Interceptors
- Kuiper Belt Objects
- Distant Minor Planets
- SBAG - Planetary Defense

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NASA Tech Showcase Jan. 2023

Abstract

The focus of this work is to determine the reduction in transit times to Encleadus and mission benefits that Aerogravity/ellipsled technology could afford in comparison to the 2021 Orbilander mission study. Trajectory analysis has demonstrated that use of the technology could cut transit time to Enceladus by half, reducing Orbilanders' Flagship Mission duration from 15 years to 9 while retaining the planned 3.5 years for science. Key research remaining to be done is to test the hypothesis that slender body "ellipsleds" fitted with modern thermal protection heat shielding materials could survive dual heat pulse Aerogravity Assist (AGA) maneuvers associated with the Orbilander mission. Speed-up is accomplished by an AGA at Venus and slow-down is achieved by a second AGA in Titan's atmosphere. The study is focused on Orbilander, but the results are relevant to other Tech Showcase Abstracts including the Enceladus Multiple Flyby and Planetary Defense. Benefits for the latter from a single AGA speed-up at an inner planet could enable higher momentum transfer (mV), greater debris recoil (mV^2), faster response time and/or increased distance to the impact avert. Astrobiologists are concerned that sensitive life detection instrumentation would be contaminated during during AGA maneuvers. These concerns could be addressed by keeping the science instruments within a bio-barrier, in turn kept inside the ellipsled until the Orbilander would be ready for deployment into Enceladus' orbit.

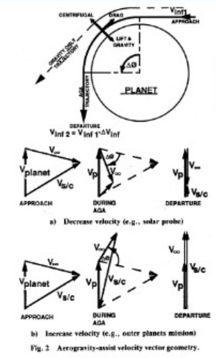
Introduction

The Orbilander mission is described in [1] and was recommended to be the second highest priority for NASA's New Flagship mission within the Origins, Worlds, and Life (OWL) 2023 Decadal Strategy for Planetary Science and Astrobiology [2]. The science produced by the Orbilander spacecraft via 3.5 year in-situ orbital and surface explorations will establish if a second genesis occurred on Enceladus and if not, why not [2].

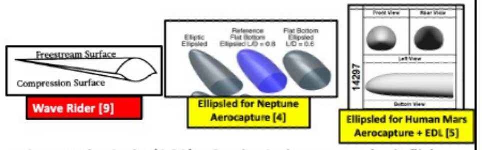
A hypothesis presented in [3], suggested that large reductions in the transit time to Enceladus could be realized by incorporating Aerogravity Assist (AGA) maneuvers first at Venus for spacecraft speed-up, and a second AGA at Titan to slow-down on the way to Enceladus. Interplanetary trajectory analysis validated that the reduction in transit time is feasible. Benefits that would arise from the shortened mission duration have been identified. Further, it was suggested [3] that a single ellipsled aeroshell [4,5] fitted with modern Thermal Protection System materials [6,7] might be capable of surviving the dual heat pulse AGA maneuvers. Analysis remains to be done to validate this part of the hypothesis.

Concerns that sensitive life detection instrumentation would be contaminated during atmospheric passages could be addressed by keeping the science instruments within a bio-barrier [8], in turn kept inside the ellipsled until the Orbilander would be ready for deployment into Enceladus' orbit.

Methods

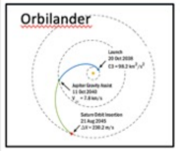


Figures adopted from [9]



- **Aerogravity Assist (AGA) = Gravity Assist + atmospheric flight. Technology Readiness Level (TRL) ~3.**
- **AGA can be used to decrease or increase a spacecraft's helio-centric velocity Vs/c depending on whether it is desired to travel to or away from the sun.**
- **Ref. [9] (1992) Proposed wave rider aeroshells for AGA -> Severe leading-edge heating. Issues: Lack of Thermal Protection System (TPS) materials and poor packaging.**

Results



Orbilander Vs AGA

Earth Depart	ED Vinf, km/s	Saturn Arr.	Duration, yrs	Venus Vinf km/s	Turn angle	SA Vinf.km/s	VR,%
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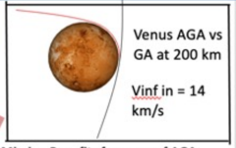
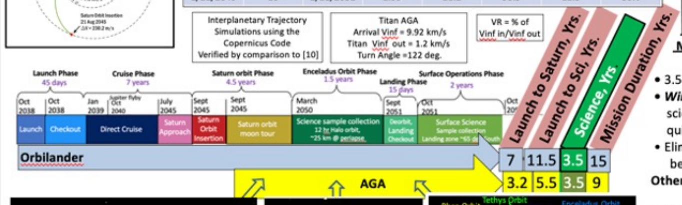
1/12/2049	8	4/20/2052	3.27	15.6	102.4	11.1	90%
1/21/2049	10	1/18/2052	2.99	18.2	98.9	12.5	80%

Interplanetary Trajectory Simulations using the Copernicus Code Verified by comparison to [10]

Titan AGA Arrival Vinf = 9.92 km/s Titan Vinf out = 1.2 km/s Turn Angle =122 deg.

VR = % of Vinf in/Vinf out





Mission Benefits from use of AGA Orbilander

- 3.5 years of science retained.
- ***Win-win:*** Increased RTG power during science and $ 30 M saved/year during quiet cruise phases.
- Eliminates certification of instruments beyond 15 - year End of Mission.

Others (Probable, but Analysis Not Done)

Dual AGAs

- Enceladus Multiple Flyby
- Saturn Probe

Single AGA

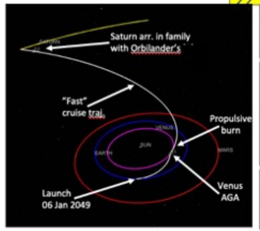
- Interstellar Object Interceptors
- **SBAG Planetary Defense**: Higher mV, greater debris recoil mV^2, faster response/Increased distance to impact
- Kuiper Belt Objects.
- Distant Minor Planets.

If AGA were a Mission Tool:

- Outer Solar System Proposals more competitive with those for inner planets.
- Overall RTG needs reduced.

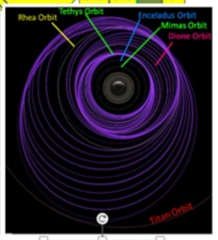
Next Major Step: Analysis that aeroshells with modern TPS could endure dual AGAs, drag losses and propulsion needs.

Issue: AGA Tech maturation $ vs benefits.



Venus AGA speed-up reduces duration to Saturnian system from 7 to 3.24 years

Titan AGA slow-down reduces moon tour from 4.5 to 2.25 years [11]



Post Titan AGA 2.25 yr. moon tour [12]

Discussion

Results based on interplanetary trajectory analysis have demonstrated that the use of AGA Technology could cut transit time to Enceladus by half, reducing Orbilanders' Flagship Mission duration From 15 Years To 9 While Retaining the Planned 3.5 Years for Science. The hypothesis that an ellipsled aeroshell fitted with modern TPS technology could enable survival of the dual heat pulse aerothermal maneuver environment remains to be validated by analysis, and a possible flight demonstration. Benefits from reduced mission duration include **increased RTG power during science acquisition** and **$30 M/yr reduction in cruise-phase costs** [2].

Inspection of the list of abstracts on the Tech Showcase webpage suggests that other missions to the Saturnian system could receive benefits from the application of AGA/ellipsled technology like those for Orbilander's. For OPAG, other missions that could benefit from AGA Technology are: Enceladus multiple flyby, Saturn probe, the Titan Orbiter, and Interstellar object Interceptors. Referring to the SBAG list, the use of AGA can enable benefits to asteroid deflection missions as demonstrated by the recent DART experiment [13]. These including higher momentum transfer (mV), and greater debris recoil (mV^2).

Finally, it is estimated that the Technology Readiness Level for AGA is about 3, so the cost for its technology development and its risk for a mission application must be considered as an issue.

Conclusions

It is noted that the present interplanetary trajectory simulations compare well with the results published by Sims, et al.[10]. Also, it is noted that several missions to the Saturnian system could use AGA at Titan to reduce moon tour durations for slow-down by about half. Further, single AGA maneuvers at the inner planets to significantly reduce cruise time to the outer planets and Kuiper Belt Objects could help the competitiveness of such proposals as compared to those for the inner planets (Private communication with Morgan Cable/JPL). Finally, it is noted that the major next step for this research is an aerothermal/TPS analysis to evaluate the capability of slender body ellipsleds to withstand dual heat pulse environments and severe cool-down between the two AGA maneuvers.

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