Economical Mars Transits Outside the Hohman 26 Month Transfer Window

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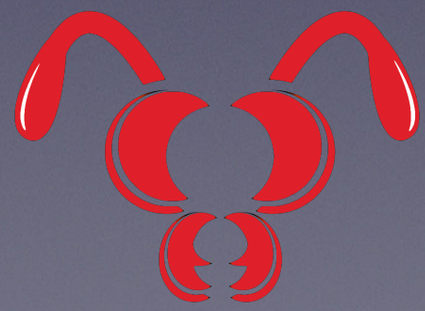
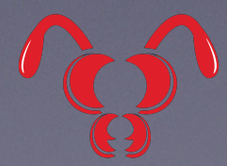


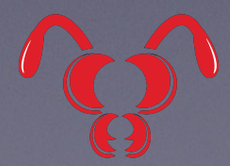
Thank you

- Thanks to Dr. Alessandra Babuscia
- Thanks to the acceptance committee
- Thanks to listeners for your patience



This is a talk about the future

- Mars will have a colony
- Regular human missions will transit to Mars
- People will forget things
- This talk is about a colonist who has just left Earth and the Hohman transfer window has just closed but they forgot their toothbrush.

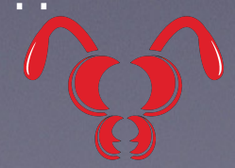


Problem Statement

- Hohman Transfer (~6 months) only available at Earth once every ~26 months. Total wait varies ~6-32 months. Thats 26 months before the toothbrush can be sent…
- Rocket equation limits the practical delta V of space ships that carry reaction mass. So rockets can't go faster.
- We want an economical option that can leave any day of synod that is faster/cheaper than next Hohman transit
- Hohman roundtrip of 12.2 km/s has a Mass Fraction of 26.47 at 380s Isp (SpaceX) or 15.61 at 453s Isp (NASA)

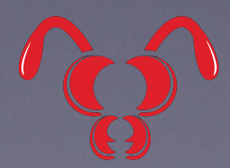
Solar Sail Performance

- Solar Sail powered spacecraft do not carry fuel and are therefore not governed by Rocket Equation
- Lifetime Delta V can far exceed that of similar mass rocket fuel.
- Lifetime Delta V is determined by spacecraft lifetime and integrated photon density (distance from sun). Not a fixed number
- Sails become impractical for heavy loads.
- Acceleration rate limited to less than 0.5 mm/s^2
- If only we could transfer this momentum to something faster…



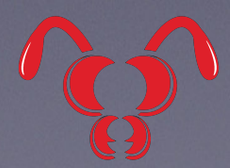
“Transferred Momentum”

- Two classes of spacecraft: a single “Pusher” and many Solar Sail powered “Bricks”
- “Pusher” pushes “Bricks” at 8 Gs acceleration over 400m track using maglev to achieve 900 km/hr which is 250 m/s or 25.5 seconds Isp
- “Bricks” match the pusher orbit and are intercepted at low differential velocity (<1m/s) and not carried by “Pusher” except for short 100 m/s segments between interception points.
- No mass is permanently consumed except the photons from the sun which are inexhaustible within Earth’s lifetime.
- “Pusher” acceleration is 19 mm/s^2 based on 30 watts per kg (10% solar cells by mass at 300 W/kg) and 10% efficient transfer of kinetic energy to “brick” (25.5s Isp over 100m/s segment)



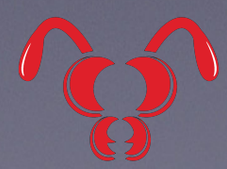
Add or Multiply?

- Carried fuel architectures Multiply the Mass Fractions when adding multiple segment lengths.
- The fuel used in future segments needs to be moved by the current segment which requires more fuel to move fuel…
- Fuel becomes 99% of initial mass when delta V = 45.13 * Isp *m/s^2
- Transferred Momentum Adds the Fuel Fractions instead of Multiplying because it intercepts its reaction mass in flight.
- The “pusher” mass at the end of each segment is the dry mass+fixed reserve. Always the same mass so segments are independent.
- Over 80km/s “Bricks” at 25.5s Isp have a mass fraction of 401.
- Over 80km/s 453s Isp rocket fuel has a mass fraction of 67,016,754

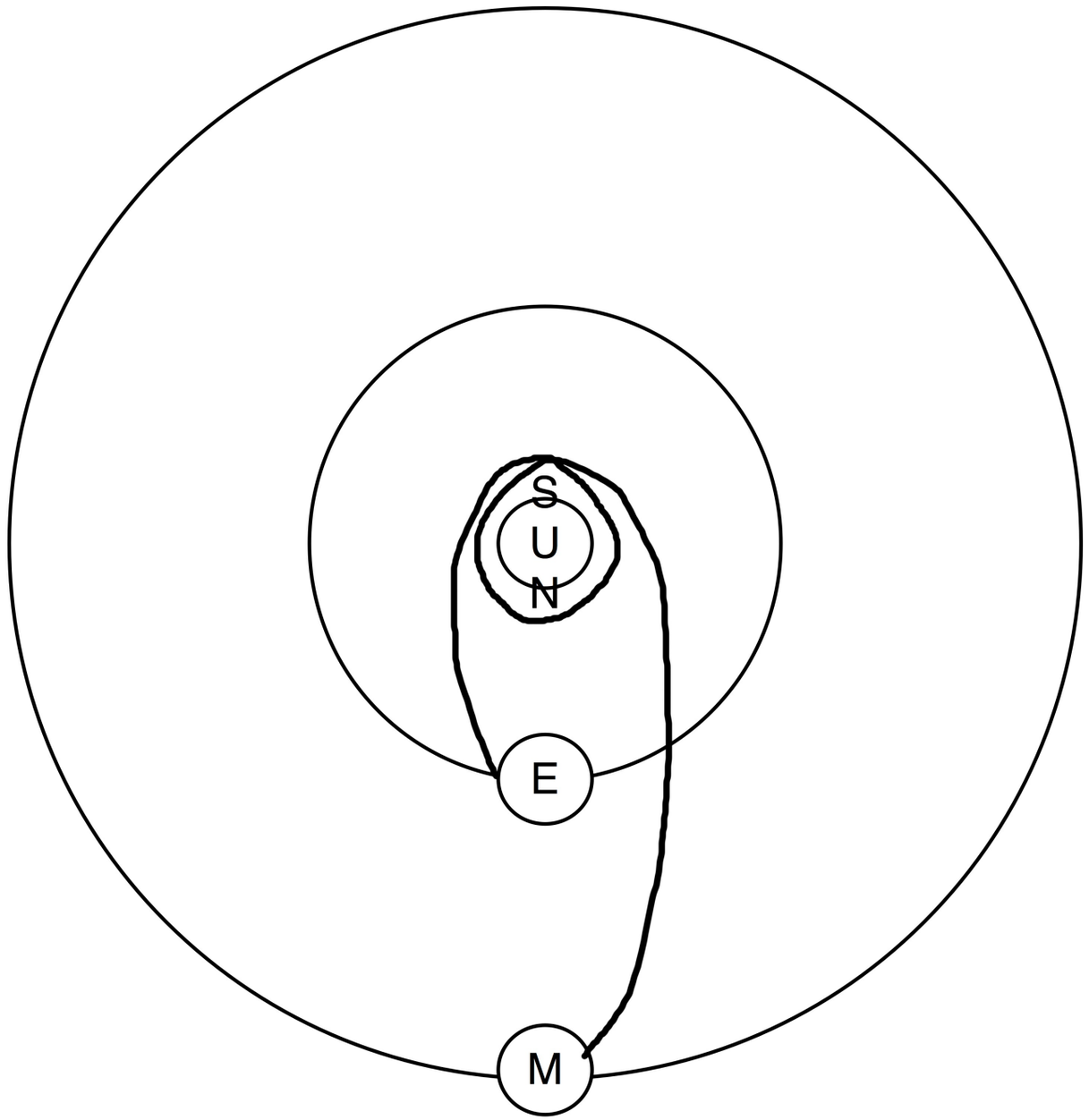


Recycle or Consume?

- Rocket fuel is available for a single use. After this single use the mass is vented into space in a way unlikely to ever be usable in the future.
- “Bricks” are solar sail powered spacecraft able to navigate back to a useful location to rendezvous with another “Pusher”.
- CisLunar “Bricks” could be used 60-120+ times in a 30 year lifetime. The delta V removed from “Bricks” is 150-250 m/s and the CisLunar “Bricks” can accelerate at 460 m/s per month. Mass Fraction of 1.5 gives Delta V=6-12km/s
- Near Martian “bricks” would deliver slightly poorer performance.

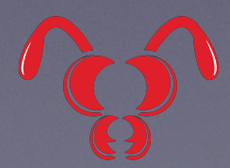


Proposed Transit



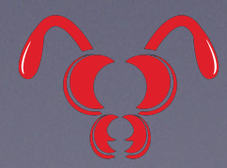
Excessive delta V

- Optimum performance involves moving closer to Sun
- Expands the lifetime delta V of solar sail “Bricks”
- Allows fast phase adjustment in orbit
- Lowers the delta V for realignment to Mars orbital plane
- Minimizes ejected “Brick” orbital period and radius from sun. This shortens time to recycle for next trip.



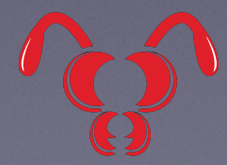
The “Fast”Transfer

- From Earth execute a Hohman transfer to 35.4 Million km from Sun.
- Hold at this radius to adjust phase 0-360 degrees relative to Mars Hohman departure location.
- Take Hohman transfer from 35.4 Million km to Mars
- Total delta V ~80 km/s oneway, 160km/s roundtrip
- Total one way transit time <281 days (9.39 months)



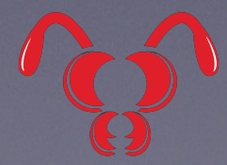
The “Medium” Transfer

- From Earth execute a Hohman transfer to 96.2 Million km from Sun.
- Hold at this radius to adjust phase 0-360 degrees relative to Mars Hohman departure location.
- Take Hohman transfer from 96.2 Million km to Mars
- Total delta V ~40 km/s oneway, 80km/s roundtrip
- Total one way transit time <530 days (17.67 months)



The “Slow” Transfer

- From Earth execute a Hohman transfer to 131.8 Million km from Sun.
- Hold at this radius to adjust phase 0-360 degrees relative to Mars Hohman departure location.
- Take Hohman transfer from 131.8 Million km to Mars
- Total delta V ~25 km/s oneway, 50 km/s roundtrip
- Total one way transit time <708 days (23.65 months)

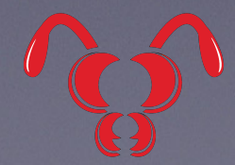


Average Mass Fraction

- Round trip Fuel Fraction is 800, 400, or 250
- 30 year lifetime “brick” reuse of 5 would give 160, 80, 50 average fuel fraction
- Equivalent Isp if rocket fuel was used is 3213 s, 1858 s, 1298 s if we allow rocket fuel refueling each time at Earth.

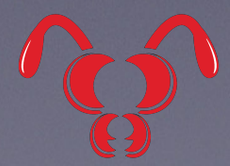
Generational Recycling

- “Bricks” ~46% solar sail by mass with a large fraction of the remainder being aluminum
- 1st Generation EOL recycling should be able to remanufacture “bricks” in space using only 50% new material from Earth.
- 2nd Generation EOL recycling should be able to remanufacture “bricks” in space using only 25% new material from Earth
- nth Generation EOL will recycle 99% of “brick” mass requiring only 1% new material from Earth
- Future average mass fractions will become 2.6, 1.8, 1.5 for the 3 transits once 99% generational recycling is achieved at End of Life



Conclusion

- 1st gen. Transferred Momentum any day Mars transit has a fuel fraction of ~6X, ~3X or ~2X of SpaceX 380 s Isp (or ~11X, ~6X, ~3X of SLS 453 s Isp) Hohman transfer.
- Transferred Momentum transit time from Earth to Mars is <9.39, <17.67 or <23.65, months
- Acceleration of 19 mm/s^2 is fast enough to compete against rocket fuel for interplanetary
- Essentially no reaction mass destroyed or permanently consumed over entire system life.



Conclusion cont.

- nth Generation: mass fractions for 160 km/s round trip transit could be 2.6 giving equivalent 17087 s Isp and 9.39 months each way departing daily.
- nth Generation160km/s Transferred Momentum transit beats Hohman window 12.2km/s Transits by 15.9 times vs. SpaceX, 9.1 times vs. SLS
- nth generation 160km/s “Transferred Momentum” uses 2.8 E15 times less reaction mass that SLS at 453 s Isp.
- After arrival at Mars our colonist could expect their toothbrush in roughly 3-4 months vs. 26 months using traditional Hohman Transfer.

Questions

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