# *Comparison of Return to Launch Site Options for a Reusable Booster Stage*


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# Presentation Overview

- Motivation of Study
- Historical Background
- Study Conclusions
- Technical Approach
- Staging Point Comparison
- Results of Trajectory and Vehicle Sizing
- Future Plans

# Study Motivation

- Current desire to develop reusable booster
  - Study uses expendable upper stage (ARES)
- Booster recovery options
  - Return to Launch Site (RTLS)
  - Land at a site downrange
- RTLS Requirements
  - Velocity direction must be reversed
    - Staging occurs in near vacuum
  - Enough margin to land safely
    - 15,000 ft over launch site (KSC)

# Booster RTLS Methods

- Glideback
  - Re-enter at high alpha, aerodynamic turn, and glide to launch site
  - Completely unpowered after staging
- Flyback
  - Re-enter at high alpha, aerodynamic turn
  - Glide to subsonic cruising altitude
  - Use airbreathing engine to cruise back to launch site
  - Currently felt to be the proper solution
- Boostback
  - Pitch booster around after staging
  - Fire ascent engine until booster's velocity vector points towards launch site
  - Unpowered re-entry and glide to launch site
- Compare methods based on gross and dry weight
- 15,000 lb payload direct insertion into 100 nmi circular

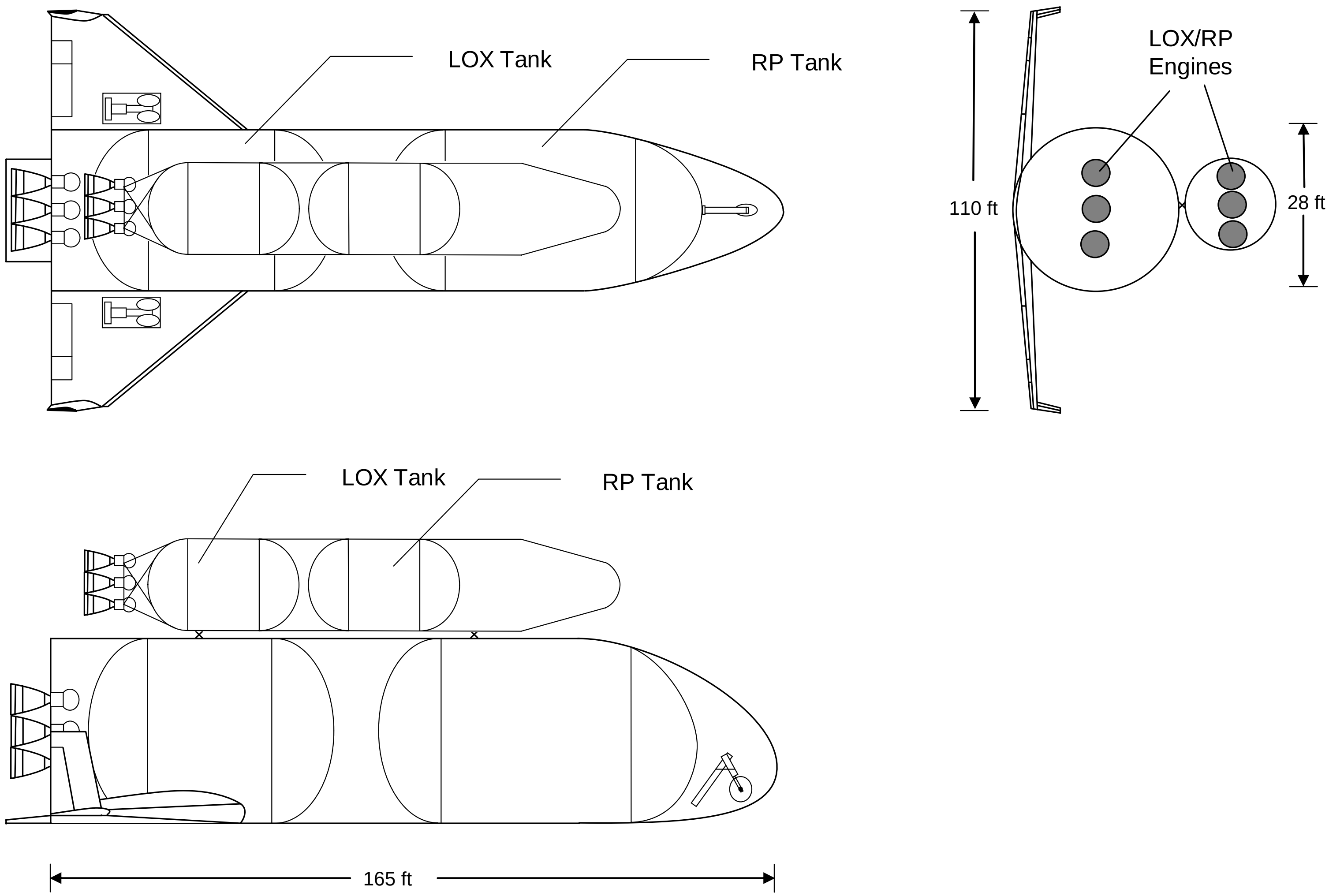
***Boostback Shows Significant Potential***

# Historical Look at Reusable Boosters

- Glideback
  - Future Space Transportation System (early 80's)
- Flyback
  - Liquid Flyback Space Shuttle Boosters (80's – 90's)
  - Tokyo University Flyback vs. Glideback Study ('03)
- Boostback
  - Kistler K-1 (late 90's - present )

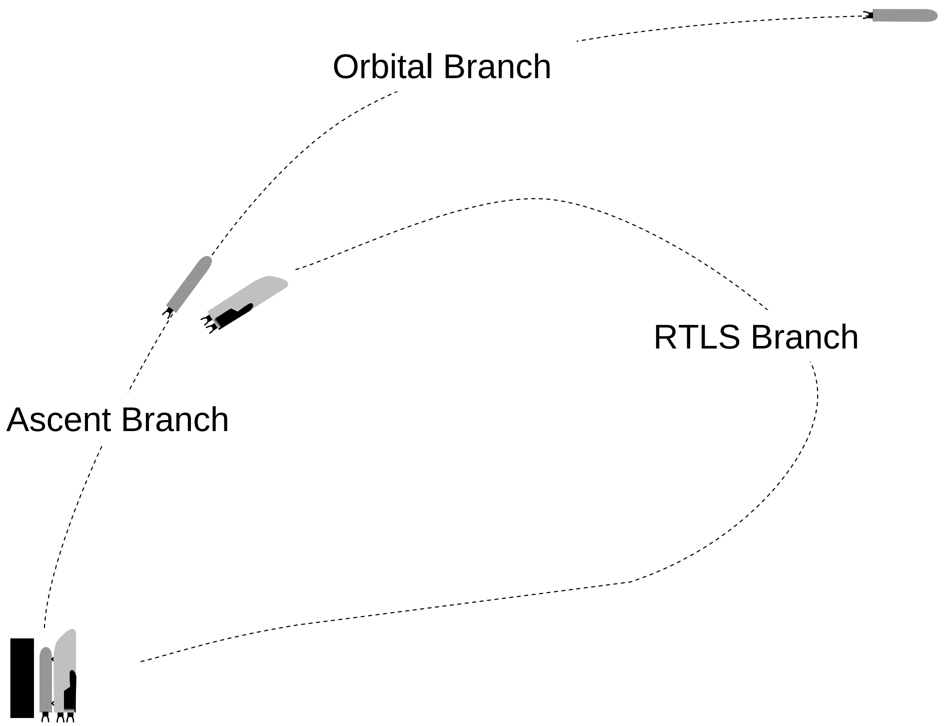
***Which is Best for a Hybrid System?***

# Technical Approach
## Baseline Configuration (Hybrid)



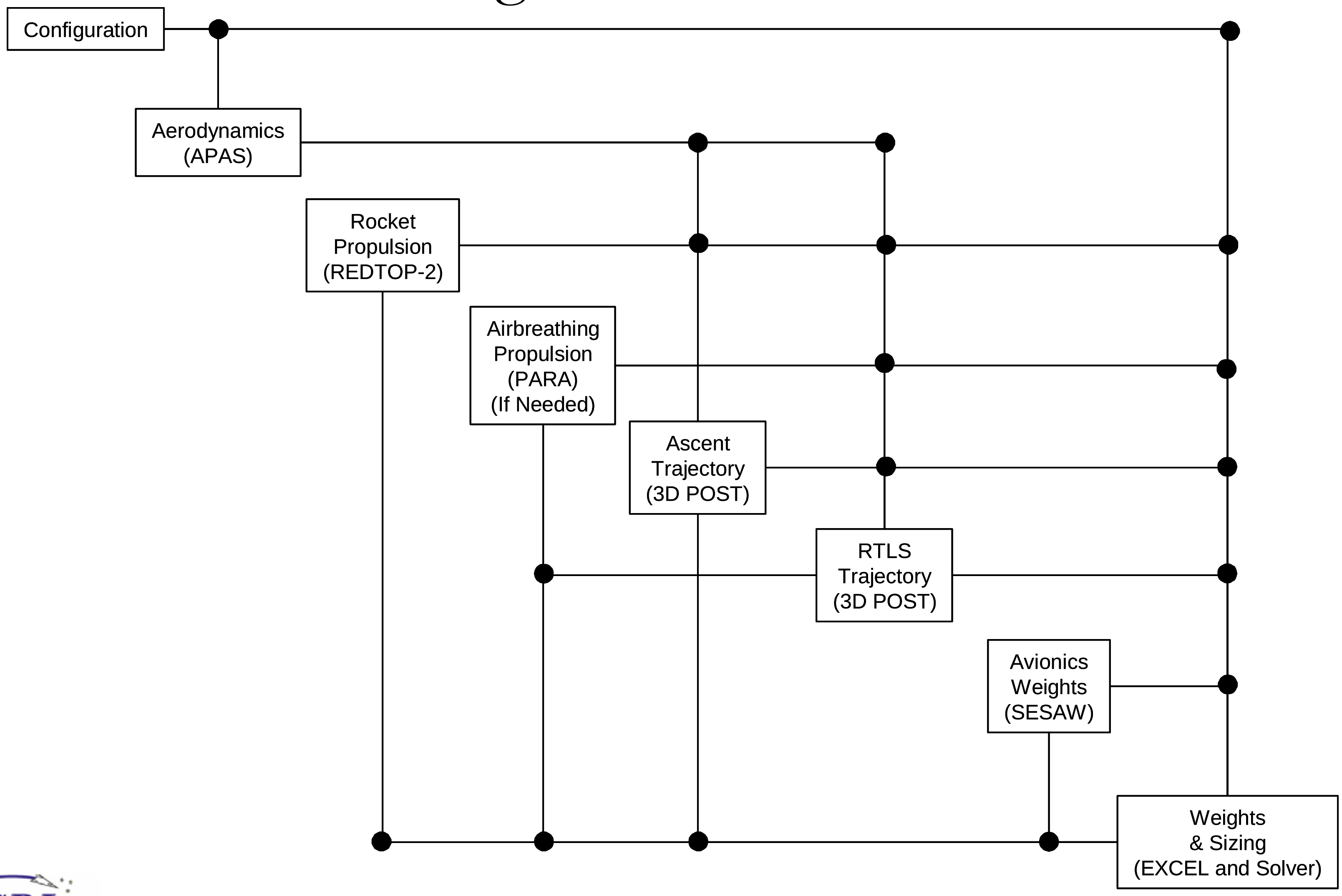
# Technical Approach
## Branching Trajectories

- Three branches of flight
  - Ascent
  - Orbital
  - RTLS
- Requires an MDO method handle growth of booster due to RTLS



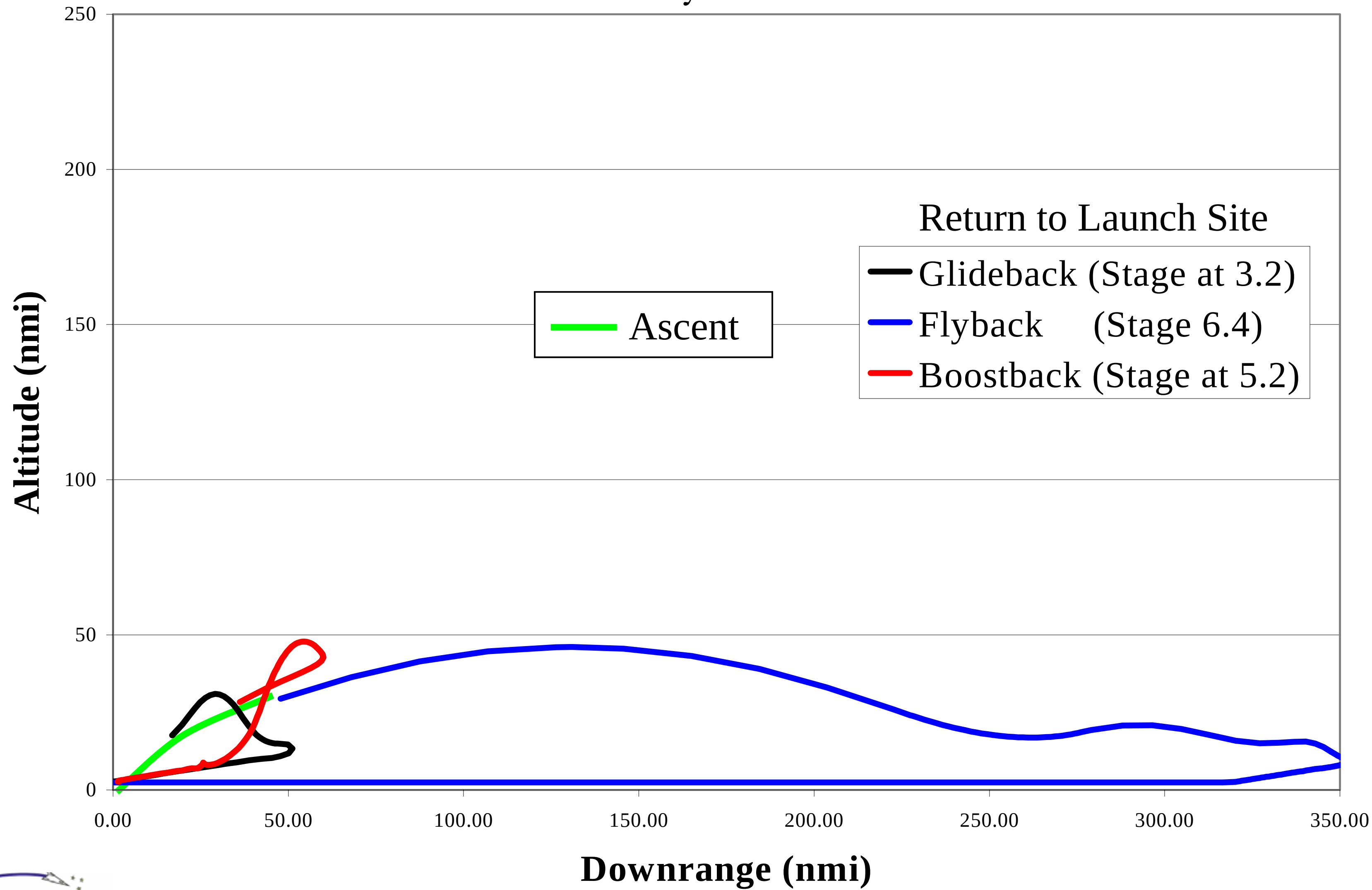
# Technical Approach

## Design Structure Matrix

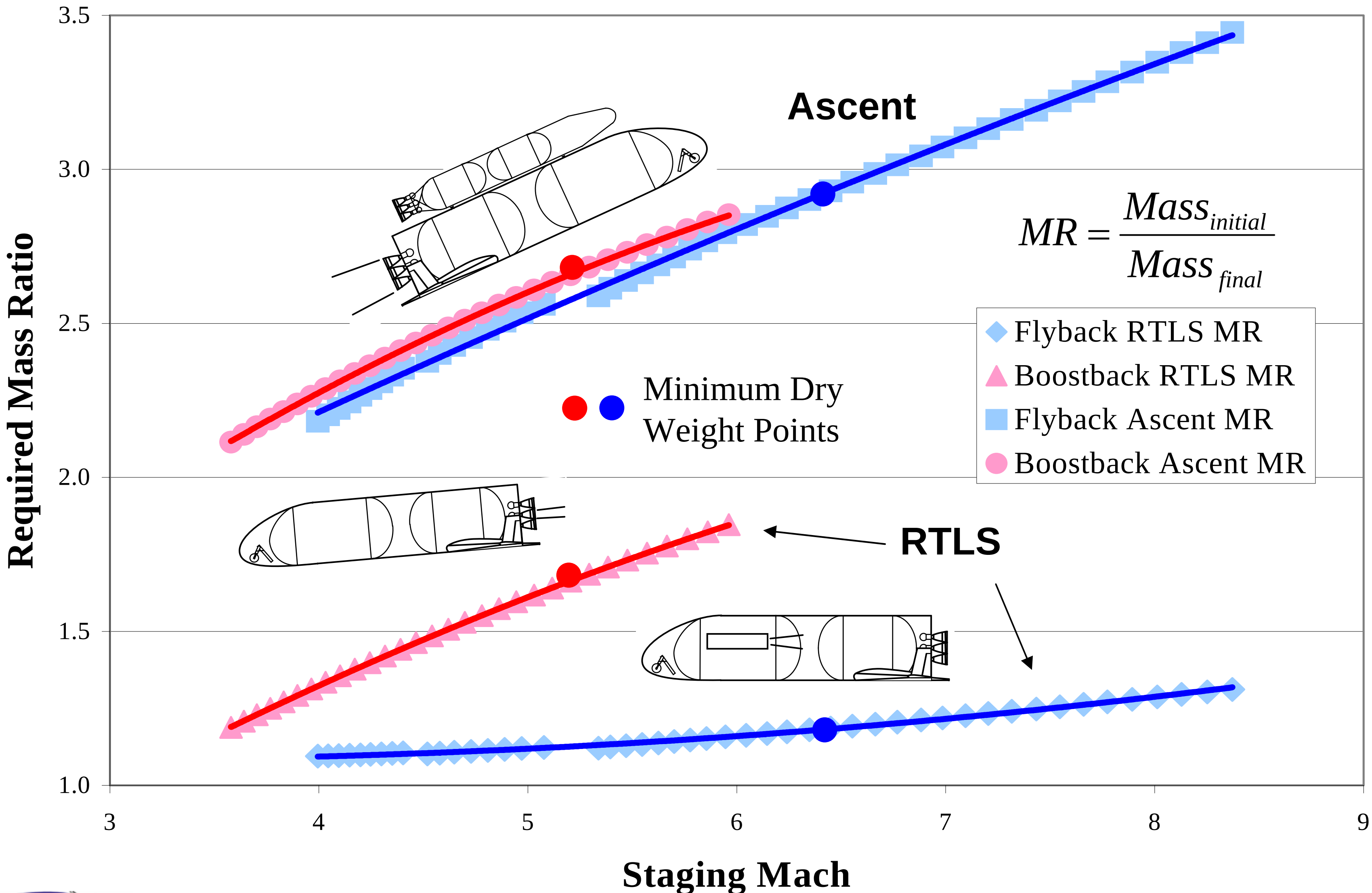


# Trajectories

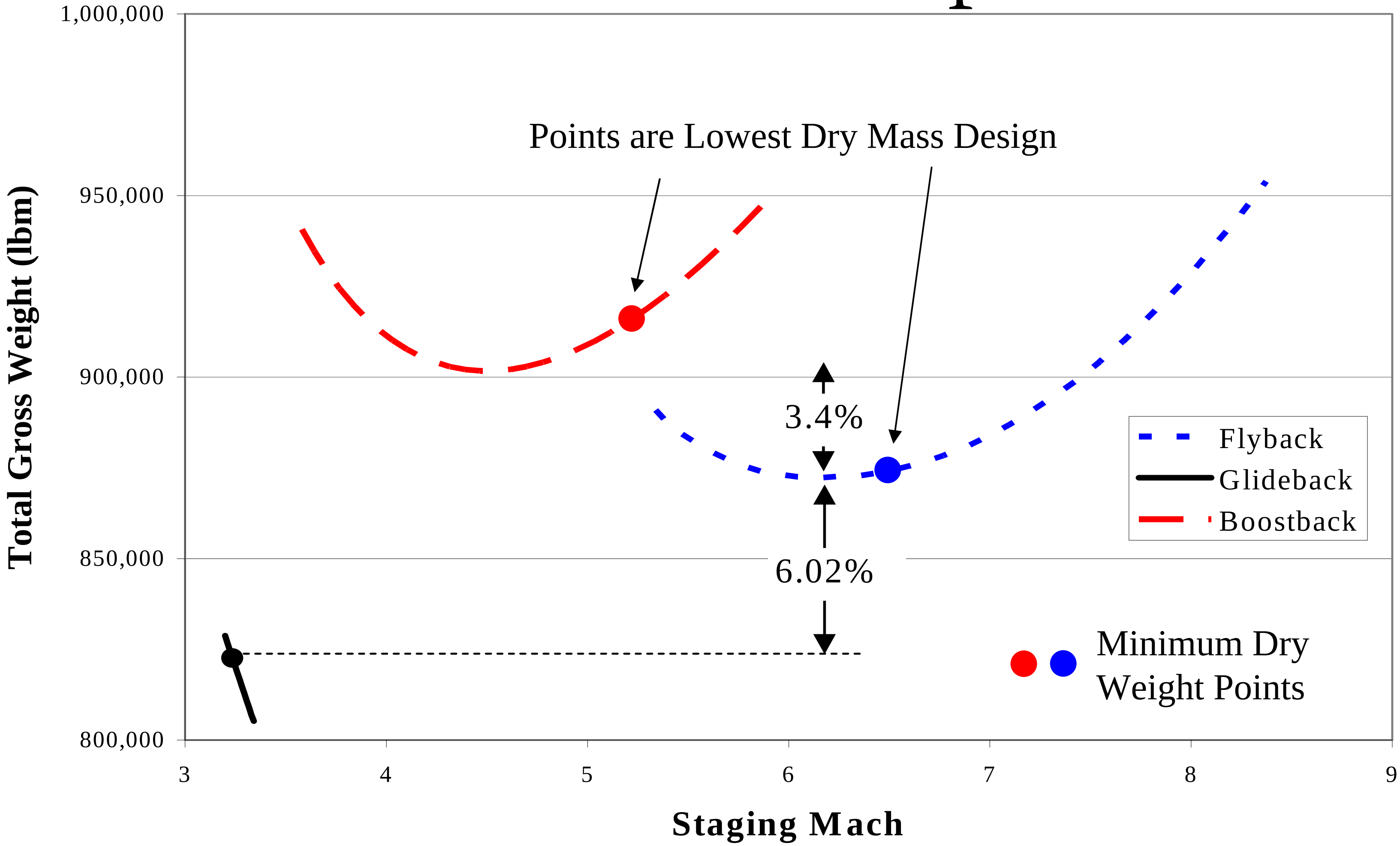
## Minimum Dry Mass Vehicles



# RTLS Booster Required MRs

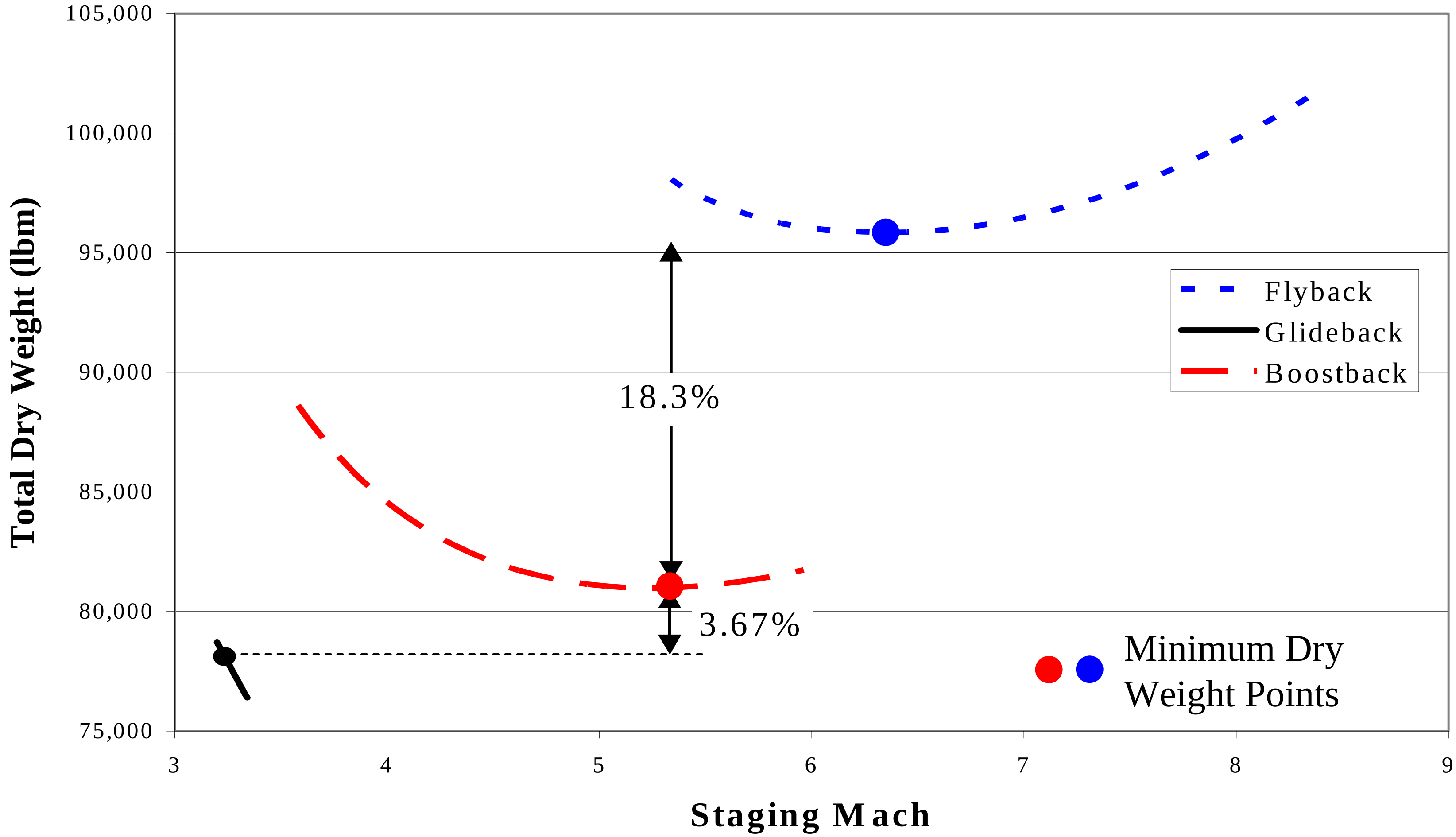


# Gross Mass Comparison




***Gross Mass is not a Direct Indicator of Cost***

# Dry Mass Comparison




***Unfortunately Dry Mass is not a Direct Indicator of Hybrid System Cost***
***A Cost Trade will be Needed***

# Optimal Staging Points

| Parameters from Optimal Staging Point | Glideback | Flyback (Lowest Dry Mass) | Boostback (Lowest Dry Mass) |
|---|---|---|---|
| Staging Ideal ΔV (ft/sec) | 7,248 | 11,200 | 10,200 |
| **Staging Mach Number** | **3.23** | **6.35** | **5.20** |
| Staging Altitude (ft) | 106,944 | 178,938 | 172,224 |
| Staging FPA (deg) | 44.6 | 20.0 | 31.0 |
| **Max Re-Entry Mach** | **1.86** | **6.93** | **2.72** |
| Total Gross Mass (lbm) | 822,600 | 872,800 | 915,300 |
| **Upper Stage Dry Weight (lbm)** | **20,100** | **17,200** | **18,600** |
| **Total Dry Mass (lbm)** | **78,100** | **95,800** | **81,000** |
| Booster Length (ft) | 74.4 | 85.7 | 84.9 |
| Upper Stage Length (ft) | 80.0 | 72.6 | 73.2 |
| **RTLS Time (sec)** | **846** | **4651** | **750** |

***Too Close to Call: Need Cost Study***

# Results

- Glideback
  - Lowest dry and gross mass
  - Low Complexity
  - Requires No TPS (Re-entry Mach 1.8)
  - Probably not lowest cost due to large expendable upper stage
- Flyback
  - Very low RTLS propellant required
  - Flyback requires turbofan and installation hardware
  - Highest dry mass
  - Powered landing and go-around capability
  - Long Return TOF ~ 78 min
  - Requires Significant TPS (Re-entry Mach 6.9)
- Boostback
  - Requires Minimal TPS (Re-entry Mach 2.7)
  - Short Return TOF ~ 13
  - Boostback requires more return propellant
  - Unpowered landing

***Boostback Deserves Consideration***
***Cost Study Needed***

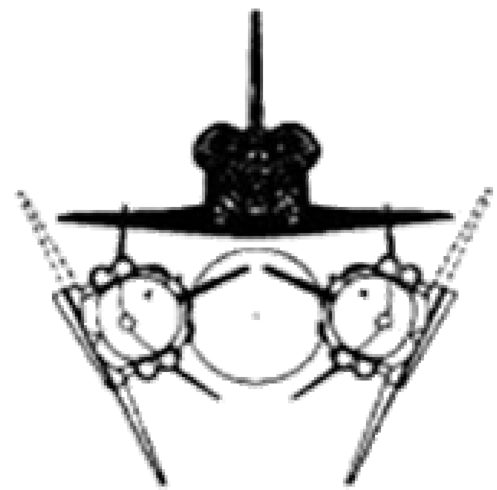
# Future Work

- Need to pick staging point based on cost for hybrid system
  - Booster cost is amortized over 100 – 200 flights
  - New upper stage for each launch
- Staging concerns
  - Rocket relight vs. continuous burn
  - Separation
- More in depth look at TPS requirements
- Compare maintenance requirements between Boostback and Flyback

- Backup

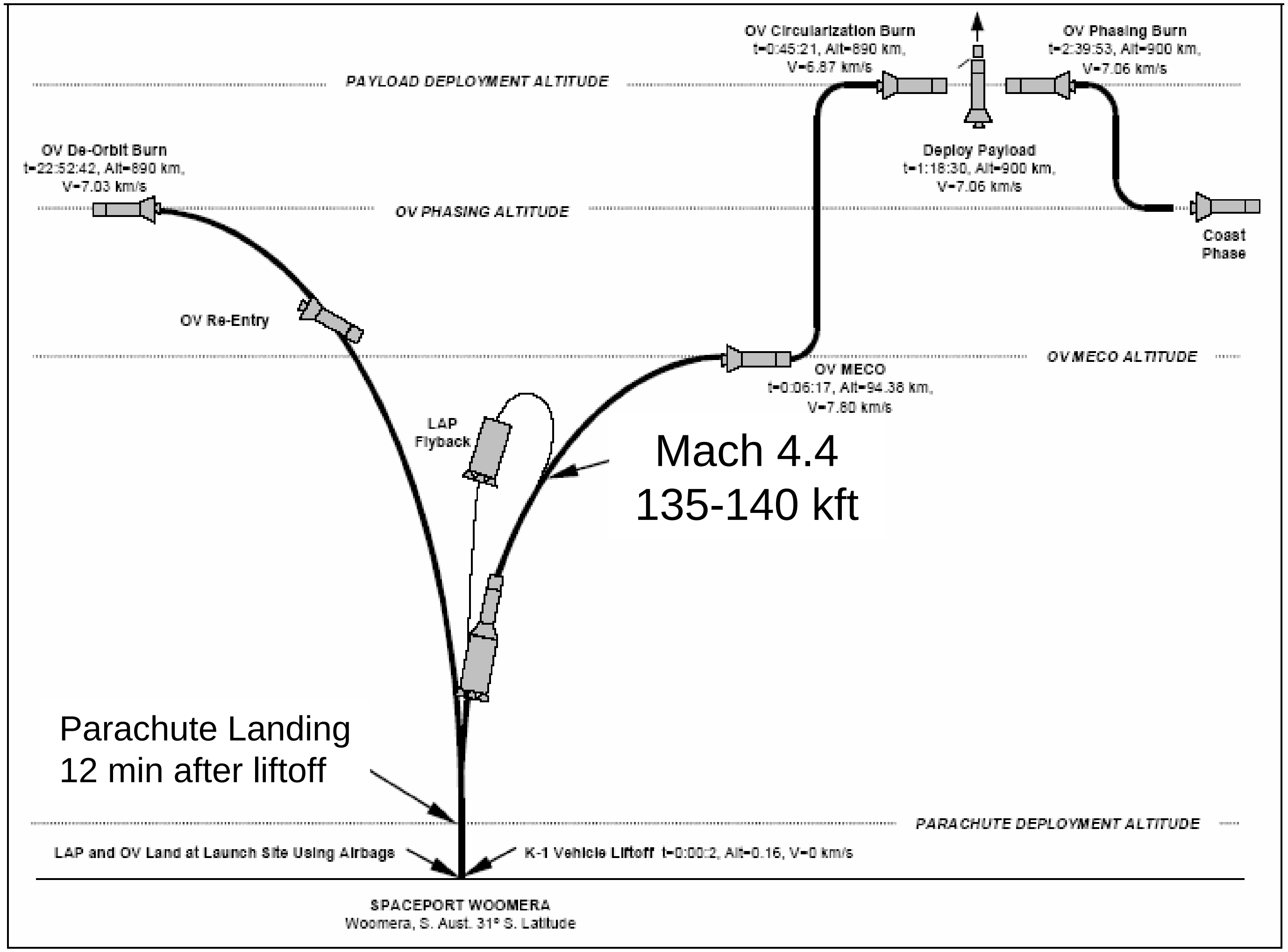
# Previously Studied RTLS Boosters

- Future Space Transportation System (Glideback)
  - Space Shuttle Replacement (80's Design)
  - Stage at Mach 3
- Liquid Flyback Space Shuttle Boosters (Flyback)
  - Stage at Mach 5.2 at 163,000 ft
  - Coast to apogee of 270,000 ft
  - Cruise at 18,500 ft and Mach 0.48



# Previously Studied RTLS Boosters

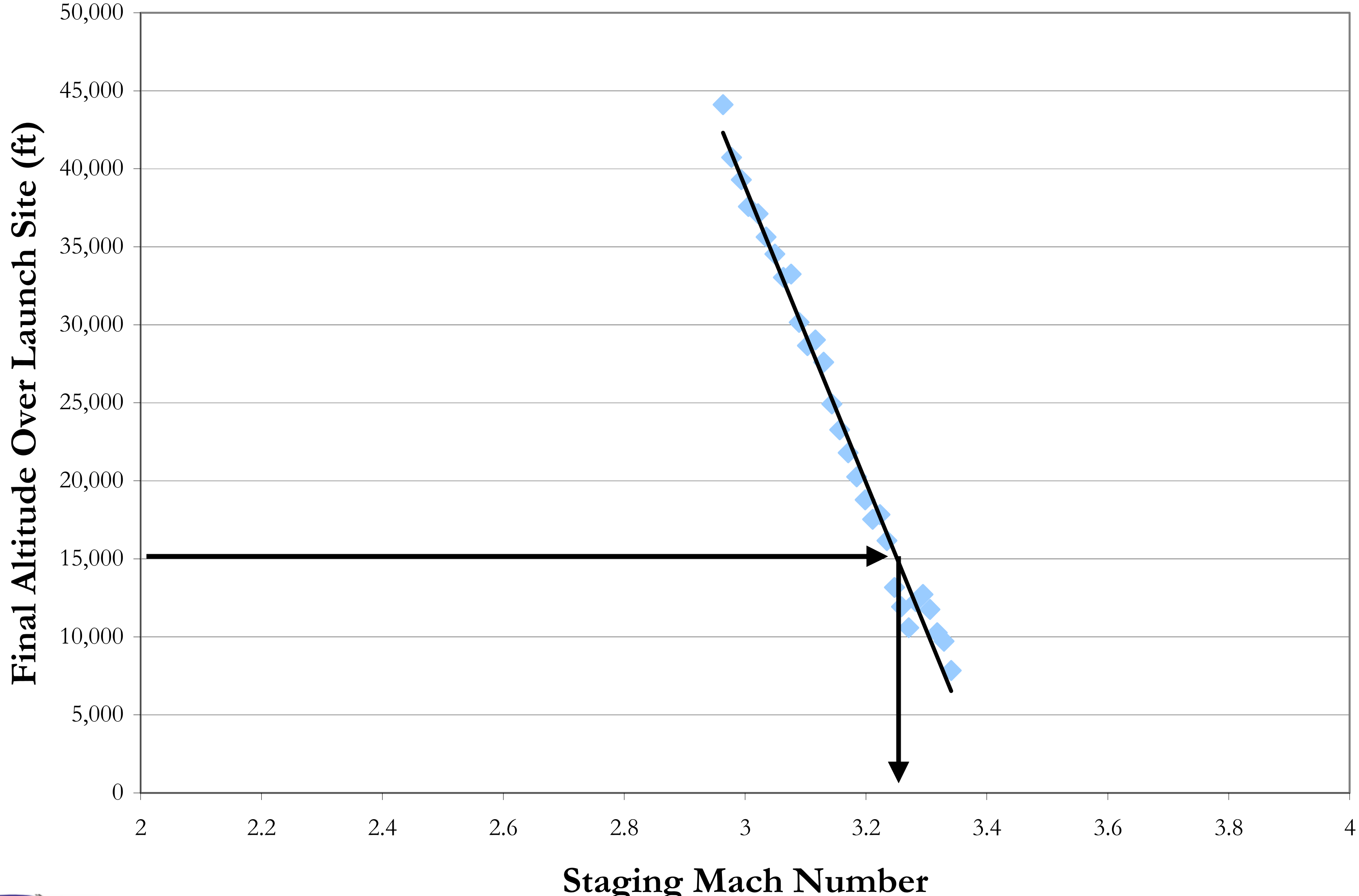
# Kistler K-1 (Boostback)



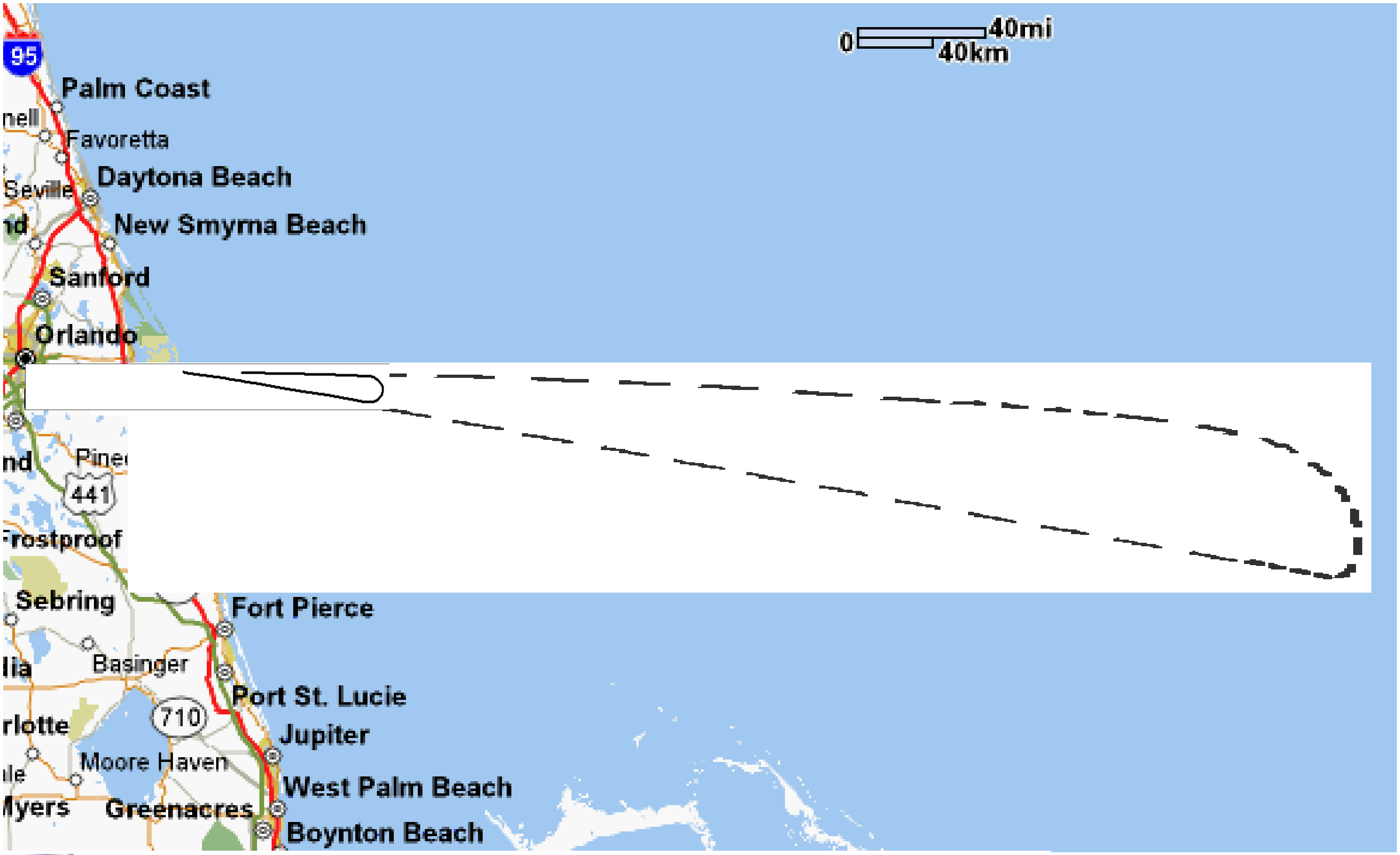
# Technical Approach
## Contributing Analyses

- Aerodynamics
  - APAS
- Airbreathing Propulsion
  - Isp ~ 3600 sec SFC ~ 1/hr
- Rocket Propulsion
  - Spaceworks Engineering Inc.'s REDTOP 2
  - LOX/RP, Gas-Generator, 2500 psi
- Weights & Sizing
  - Booster weights based on MER from Dr. Ted Talay
    - NASA LARC
- Trajectory
  - POST 3D

# Glideback Final Altitude



# Ground Track



# Boostback Booster and Upper