

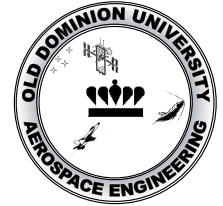
# **Selected Research at Old Dominion University**

**Brett Newman  
Dept. of Aerospace Engineering  
Old Dominion University  
Norfolk, Virginia**

**Supported By  
Near Space Systems  
NASA Wallops Flight Facility  
NASA Langley Research Center  
National Consortium for Aviation Mobility**



## Highlighted Topics

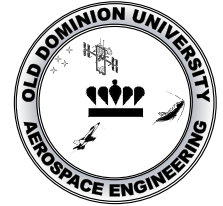


- **Propeller Analysis and Synthesis for  
Ultra-Long Duration Balloon Trajectory Steering**
- **Trajectory Management Concepts for  
Future Small Aircraft Transportation Systems**

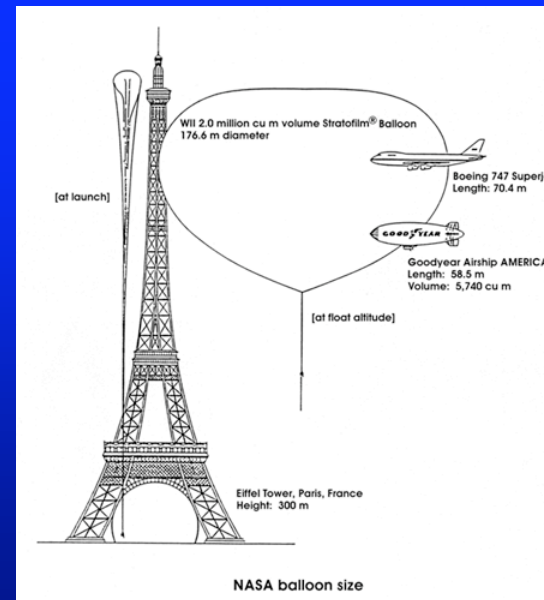


# Problem Motivation

## Balloon Types



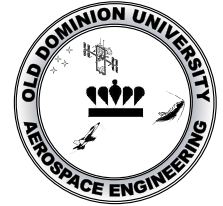
- High Altitude Balloon Used As Low Cost Platform
- Terrestrial, Atmospheric, Weather, Space Measurement & Observation
- 100,000 - 120,000 ft Altitude
- Long Duration Balloon (LDB) - Constant Pressure Configuration
- Gas Venting & Ballast Unloading Limits Flight Time < 3 Weeks
- Ultra-Long Duration Balloon (ULDB) - Constant Volume Configuration
- Composite Fabrics & Tendons, Lobed Oblate Spheroid Shape
- Inherent Constant Altitude, Flight Time  $\approx$  3 Months Or Higher



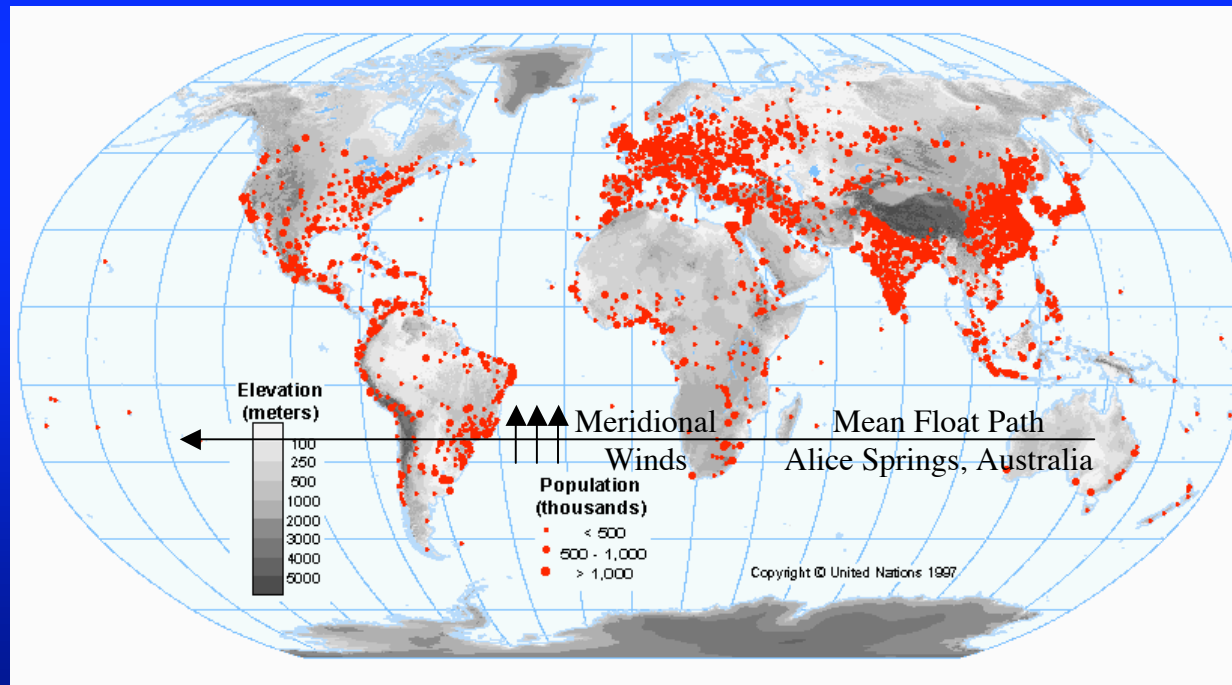


# Problem Motivation

## ULDB Mission Characteristics



- Winter Launch @ Alice Springs, Australia
- Fractional-Integer West Circumnavigations @ Constant Altitude-Latitude
- Ground Tracks Over Dense Population Centers Unacceptable
- Premature Mission Termination To Avoid Over Flight Undesirable
- Meridional Winds Push Vehicle North: Problem For Over Flight & Recovery
- Horizontal Float Path Controllability Required For Course Trajectory Guidance



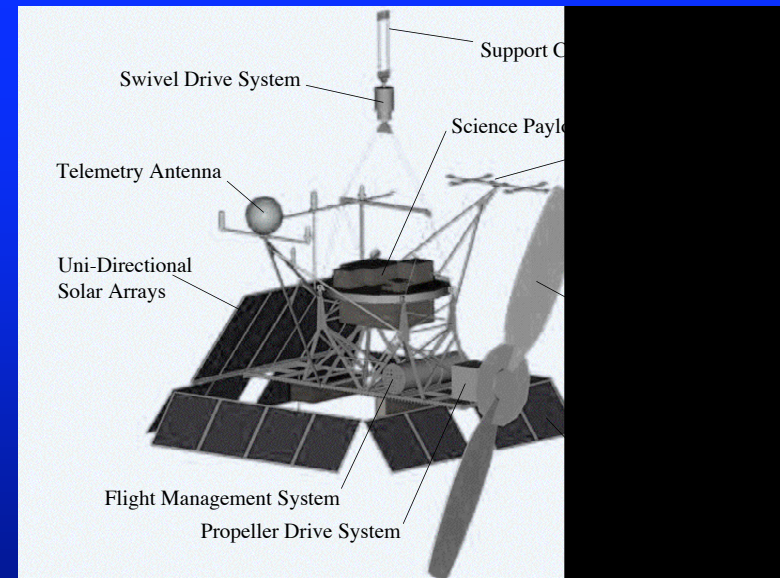


# Preliminary WFF Studies

## Selection - Feasibility - Performance



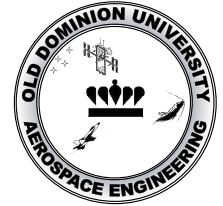
- Early Propulsion Options Assessment
- Prop, Tether, Tow, Sail, Flying Wing, Gas Vent-Regeneration Jet, ...
- Conventional Prop With Gondola Mount Preferred: Low Cost-Risk, Near Term
- Further Study On Conventional Prop Operational Concept & Performance
- Blade Element Theory With Tip Loss Utilized
- Requirements: Thrust  $\geq$  Drag (Wind, Altitude, Balloon Size-Shape Dependent)  
Power  $\leq$  300 W (Desirable),  $\leq$  500 W (Acceptable)  
Diameter  $\leq$  25 ft  
Simple Mechanization
- Freedoms: Airfoil Shape  
Twist Profile  
Turn Rate  
Number Of Blades  
Diameter  
Aspect Ratio
- Parameters: Altitude  
Wind  
Balloon Size-Shape



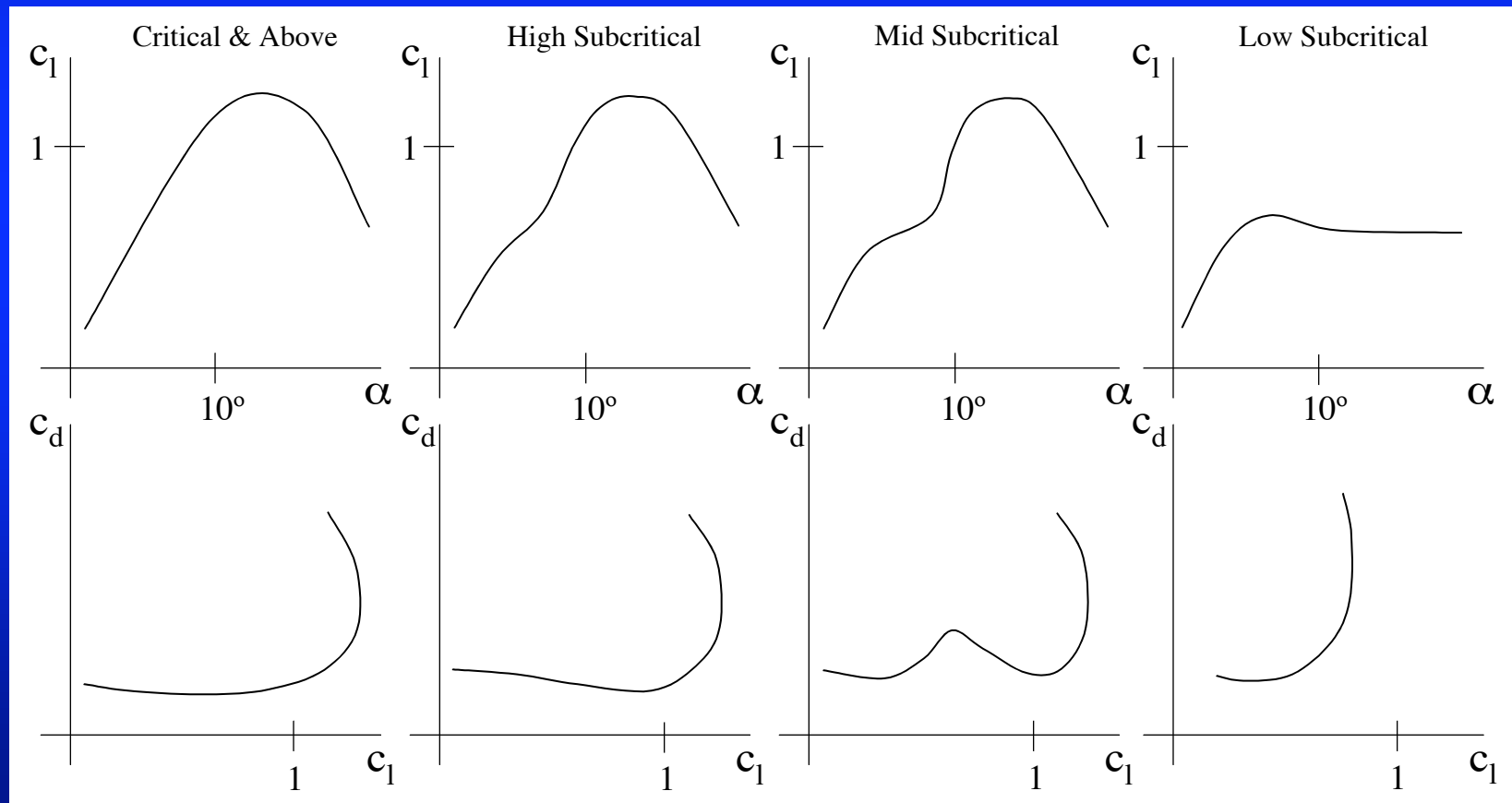


# Low Reynolds Number Airfoil Behavior

## Qualitative Lift-Drag

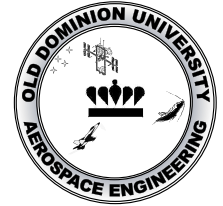


- Predominately Laminar Boundary Layer, Non-Conventional Stall Behavior
- Separation Bubble, Bubble Burst, Flow Separation-Reattachment, Off-Surface Transition, Hysteresis, ...
- Gradual-Abrupt Re Dependent Flow Separation From Nose As Attack Angle Increases





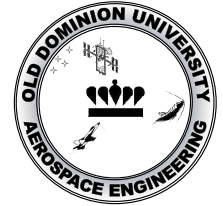
# Propeller Thrust-Power Results Investigation Strategy



- **Requirements:** Thrust  $\geq$  Drag @ 3.25 ft/s Wind, 475 ft Diameter, 0.5 Drag Coefficient  
Power  $\leq$  300 W (Desirable),  $\leq$  500 W (Acceptable)  
Diameter  $\leq$  25 ft  
Simple Mechanization
- **Freedoms:** Airfoil Shape  
Twist Profile  
Turn Rate  
Number Of Blades  
Diameter  
Aspect Ratio
- **Parameters:** 100,000 ft  $\leq$  Altitude  $\leq$  120,000 ft
- **For Specified Altitude,  
Optimize:**  
Airfoil Shape, Twist Profile, Turn Rate, Number Of Blades, Diameter, Aspect Ratio



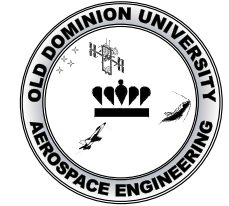
# Propeller Thrust-Power Results Investigation Strategy



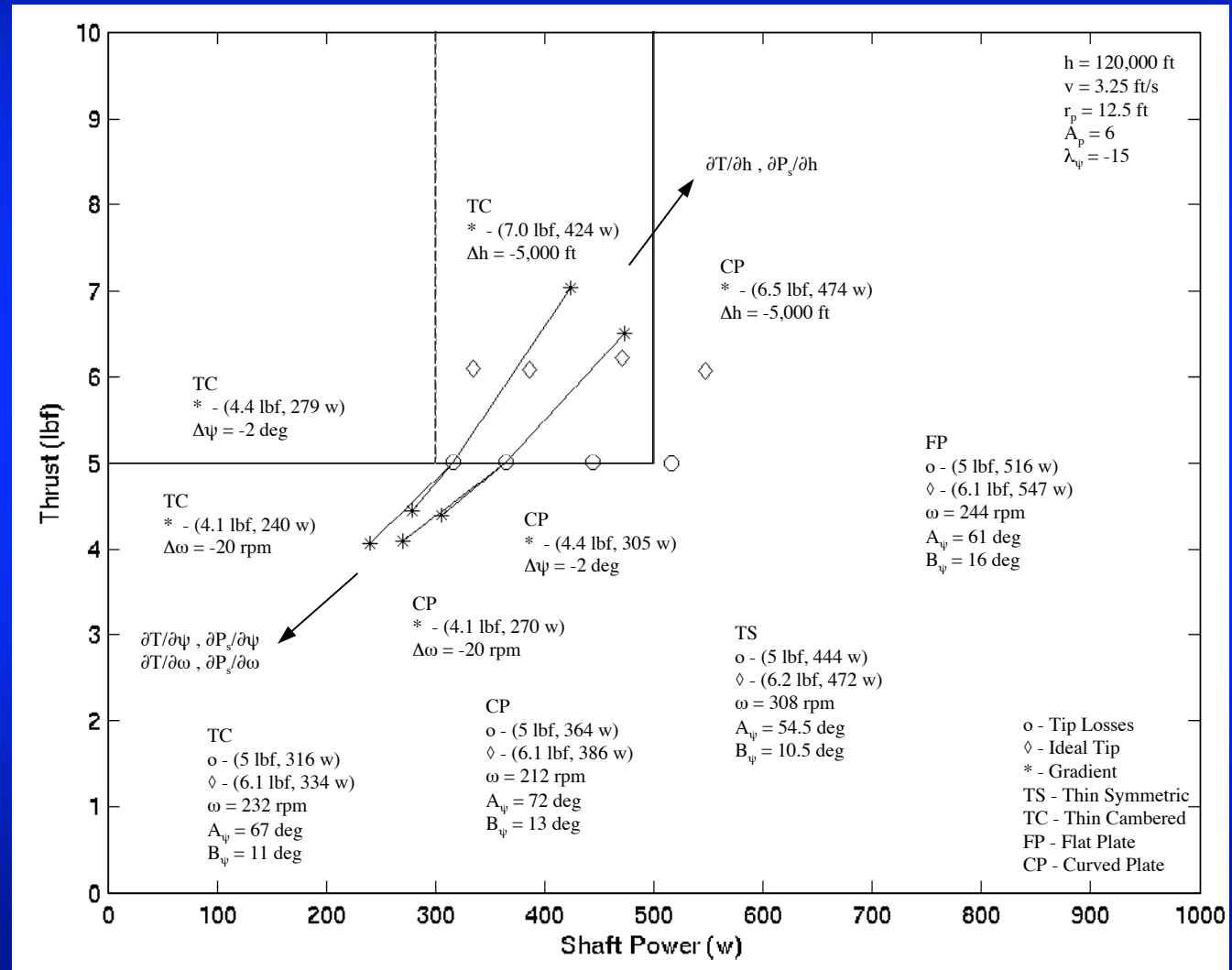
- **Quasi-Optimal Approach**
  - Specify Several Design Variables (Engineering)
  - Manually Optimize Remaining Variables (Engineering)
- **Specify: Number Of Blades = 2, Diameter = 25 ft, Aspect Ratio = 6 (Chord = 2.1 ft)**
- **Optimize: Twist Profile, Turn Rate For Each Airfoil Family**
  
- **Power Is Critical Constraint, More Difficult To Meet At Lower Altitude**
- **At 120,000 ft Altitude, Optimize Twist Profile & Turn Rate For Min Power While Just Satisfying Thrust Constraint**
- **Assess Degradation At Lower Altitudes, Determine Turn Rate Schedule**
  
- **Exponential Twist Profile Provides Nearly Constant Attack Angle**
- **Twist Profile:  $\psi = A_{\psi} e^{\lambda_{\psi} r/r_p} + B_{\psi}$  ,  $\lambda_{\psi} = -15$ ,  $A_{\psi}$  &  $B_{\psi}$  Are Design Variables**



# Propeller Thrust-Power Results Minimum Power Design Points

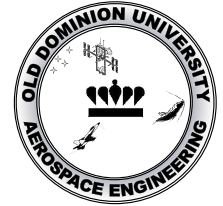


- Thin Cambered Best
- Flat Plate Worst
- Conservative Tip Loss
- Gradients
- Optimum Condition
  
- Thin Cambered & Curved Plate Studied Further

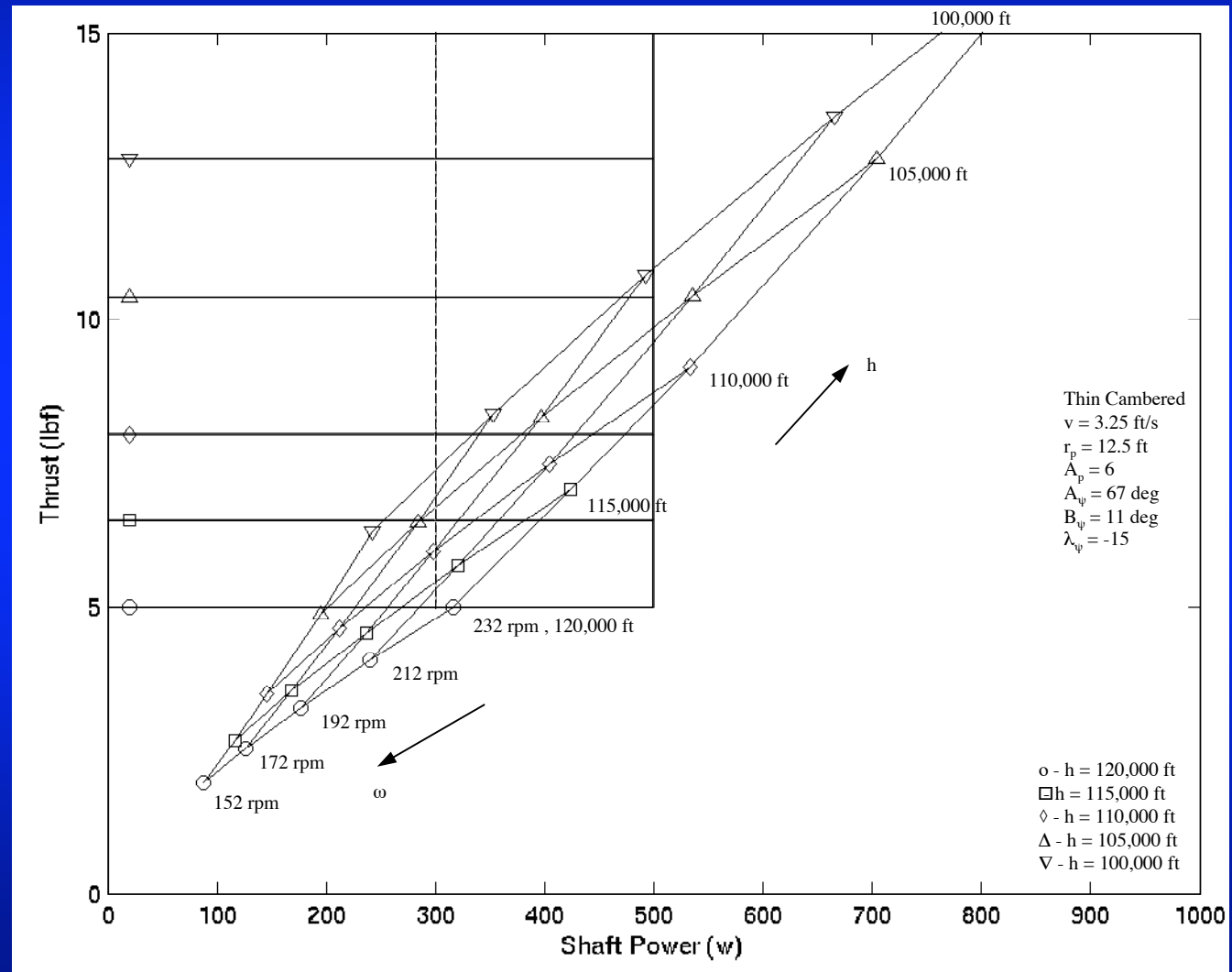




# Propeller Thrust-Power Results Thin Cambered Parameter Space

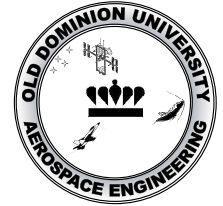


- Fixed Twist Profile
- Altitude-Turn Rate Parameter Space
- Altitude Dependent Thrust
- Turn Rate Schedule
- Requirements Meet Over Portion Of Float Envelope

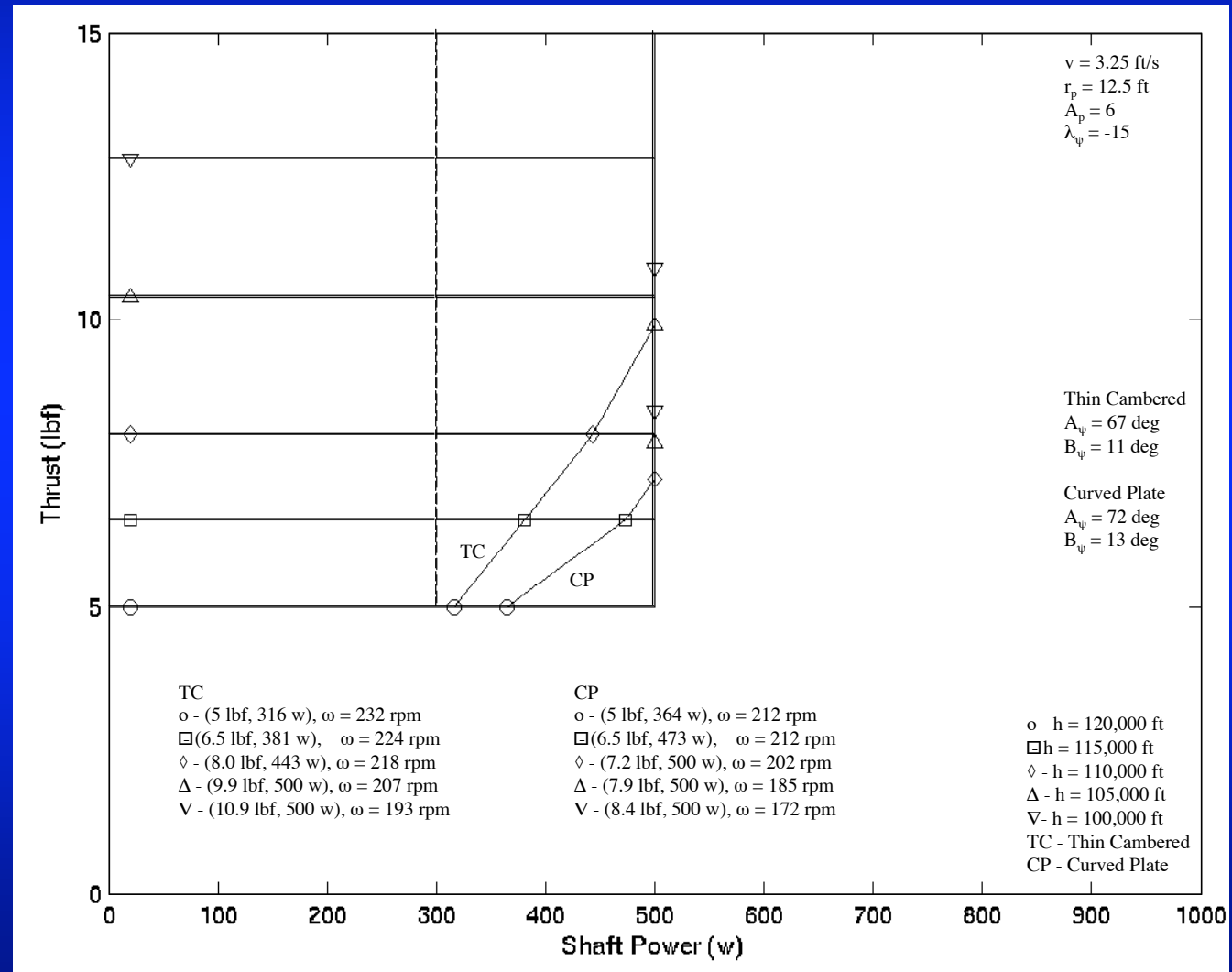




# Propeller Thrust-Power Results Thin Cambered & Curved Plate Float Envelope

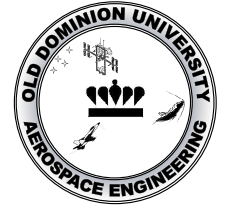


- Thin Cambered 1st  
• 107 kft  $\leq H \leq 120$  kft  
Float Envelope
- Curved Plate 2nd  
• 113 kft  $\leq H \leq 120$  kft  
Float Envelope





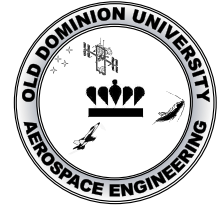
## Highlighted Topics



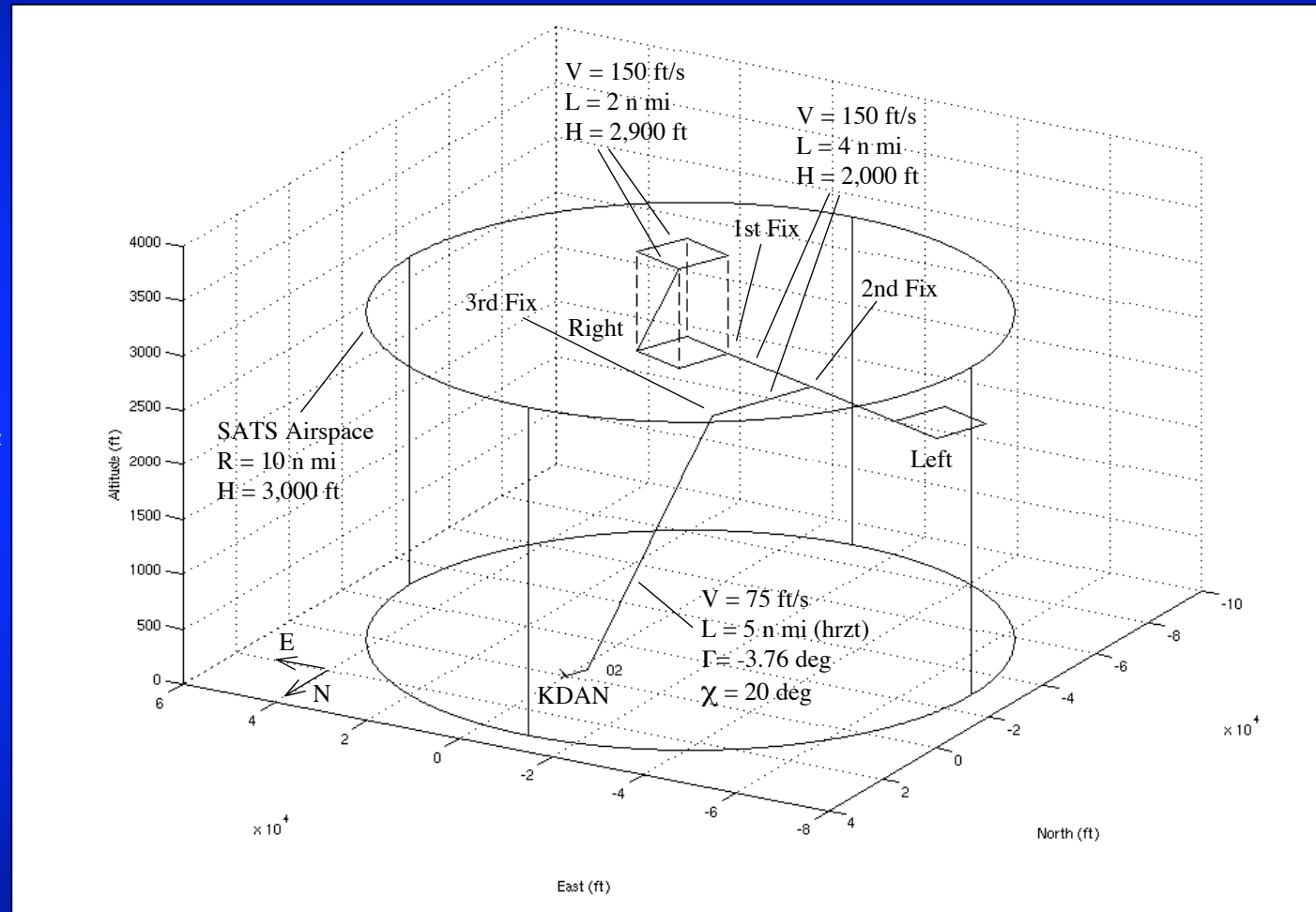
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# Operation In SATS Airspace Description



- KDAN, Runway 02
- HP SATS Vehicle
- Multiple Slow Traffic
- Interface To Land
- $\approx$  HVO ConOps
- Possible Hold Up

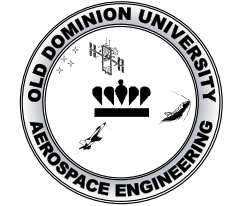


- **Managed Variable Curvilinear Trajectory Is Sought**
- **Time Adjustable To Supcede Traffic Or Sequence Behind Traffic**

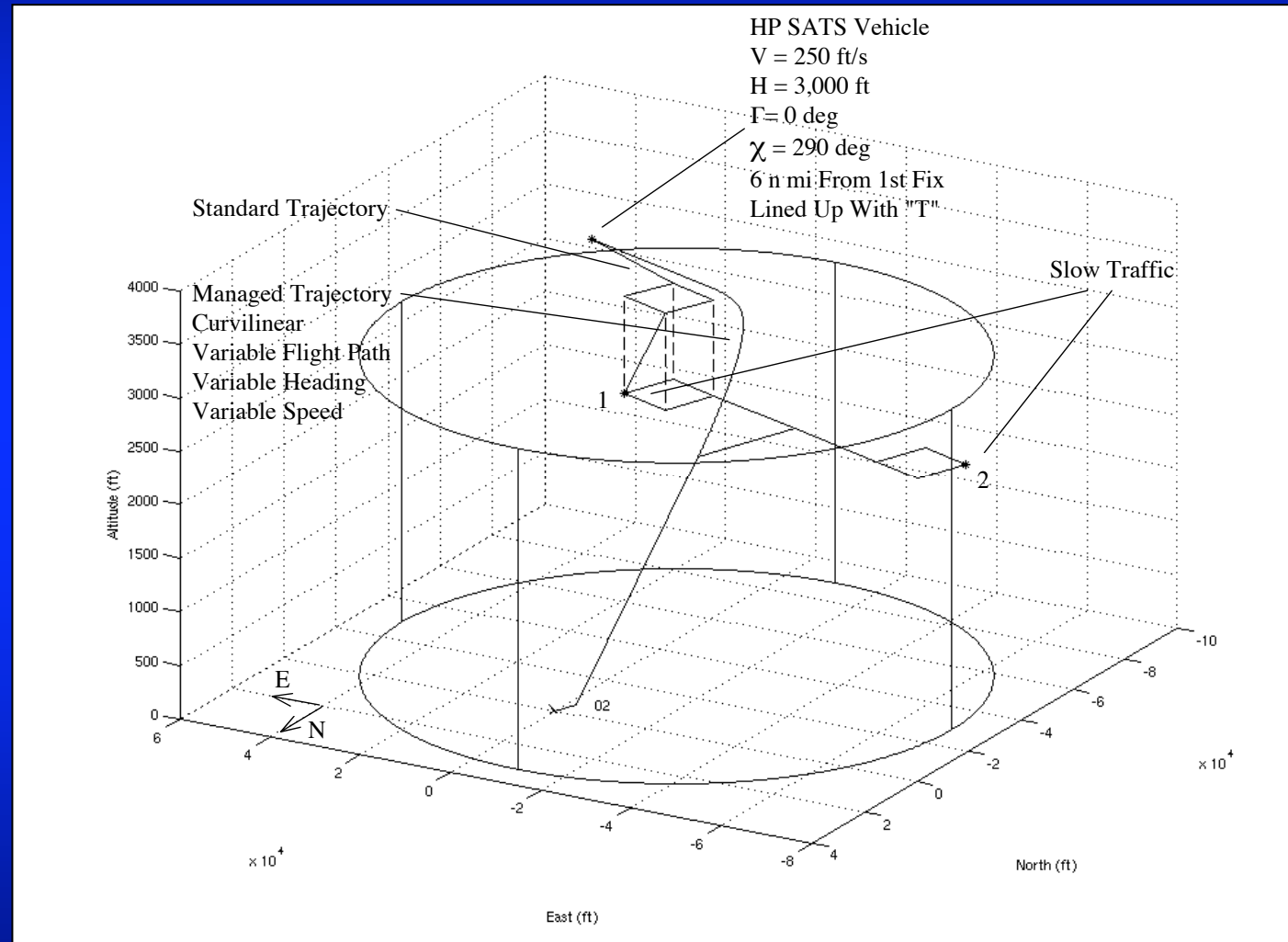


# Operation In SATS Airspace

## Right Turn Example - Unconstrained



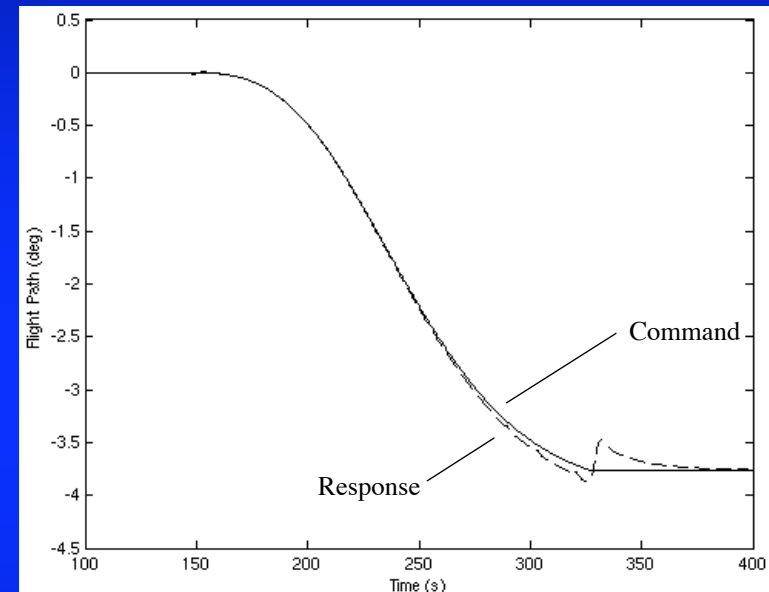
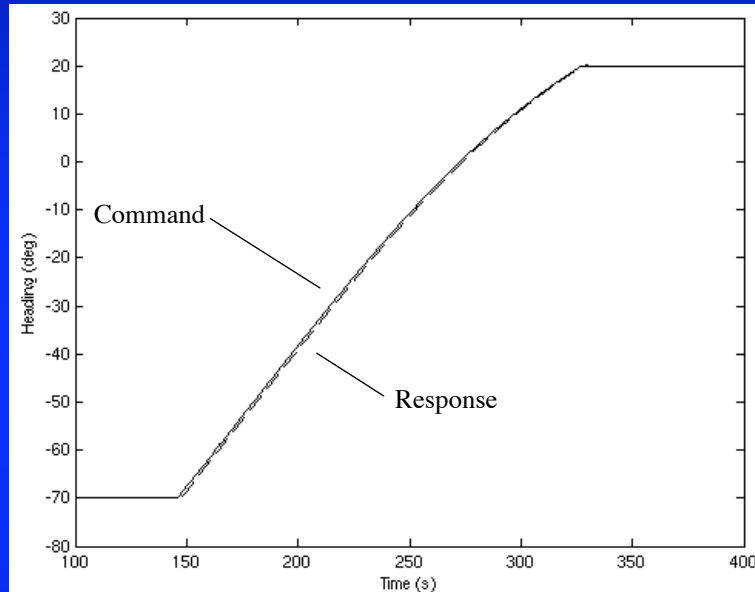
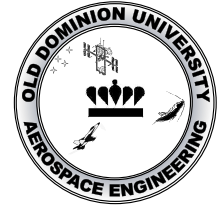
- Standard Trajectory
- HVO ConOps
- HP SATS Is 3rd
- Managed Trajectory
- HP SATS Is 1st
- Maintain Energy
- Helical: F1+ → F3
- F3: 125 ft/s



- Time Difference Of 13.73 min
- Airspace Throughput Increased



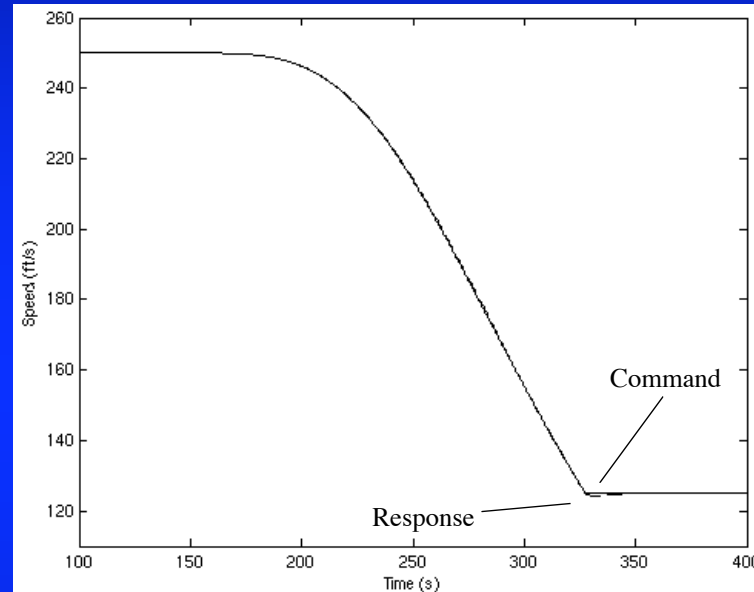
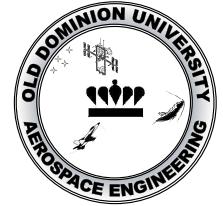
# Auto Flight Mode Right Turn Results - Unconstrained



- **Managed Trajectory Is Command Motion**
- **Commands Are  $C^1$  Functions, Not  $C^2$**
- **Speed Brake Crucial For High Deceleration Profile**
- **Trajectory Correction Signals Turned Off**
- **Horizontal Threshold Error  $\approx 20$  ft, Many Refinements Possible**
- **Heading, Flight Path & Speed Response Exhibit Acceptable Behavior**
- **Managed Trajectory Executed By SATS Vehicle Feasible**



# Auto Flight Mode Right Turn Results - Unconstrained



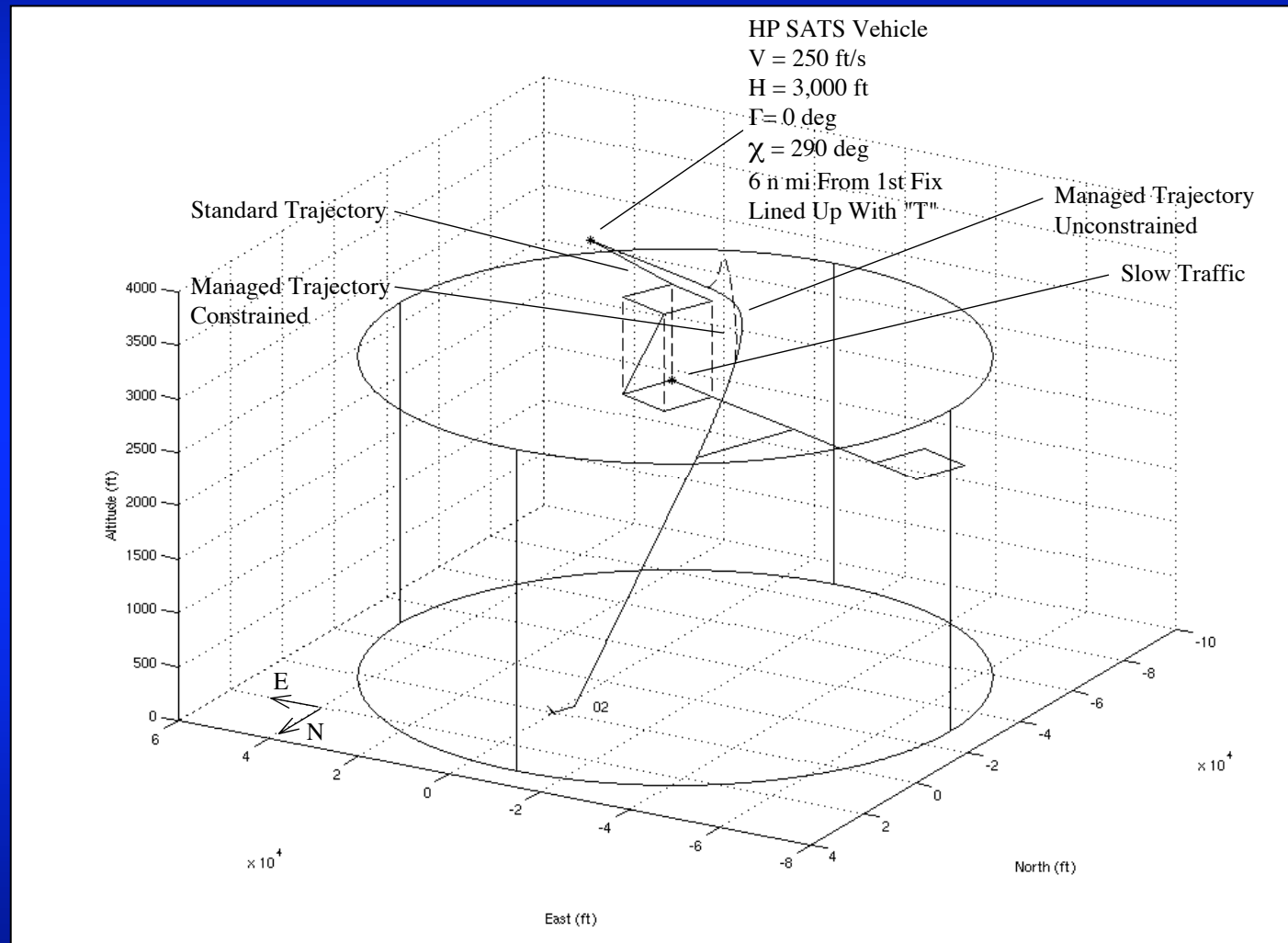
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# Operation In SATS Airspace Right Turn Example - Constrained



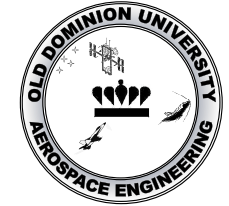
- Managed Trajectory
- HP SATS Is 1st
- Maintain Energy
- Helical: F1+ → F3
- F3: 125 ft/s
  
- Distorted Trajectory
- Mild Swell
- Gradual Right-Left "S" Turn
- Time Synchronized @ Initial-Final Distortion Points



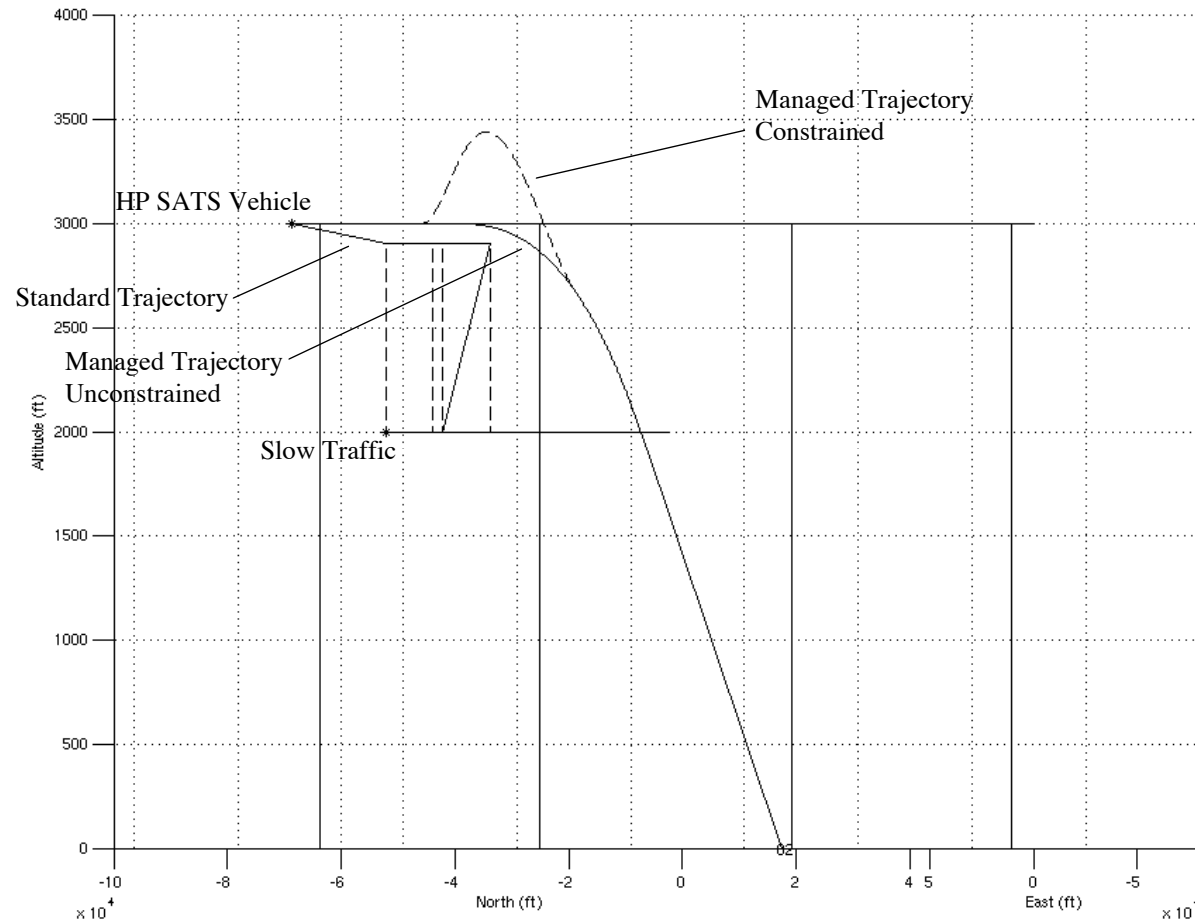
- No Change To Time Difference: 8.33 min
- Trajectory Smoothly Distorted Away From Traffic



# Operation In SATS Airspace Right Turn Example - Constrained



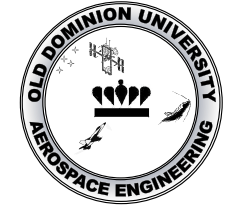
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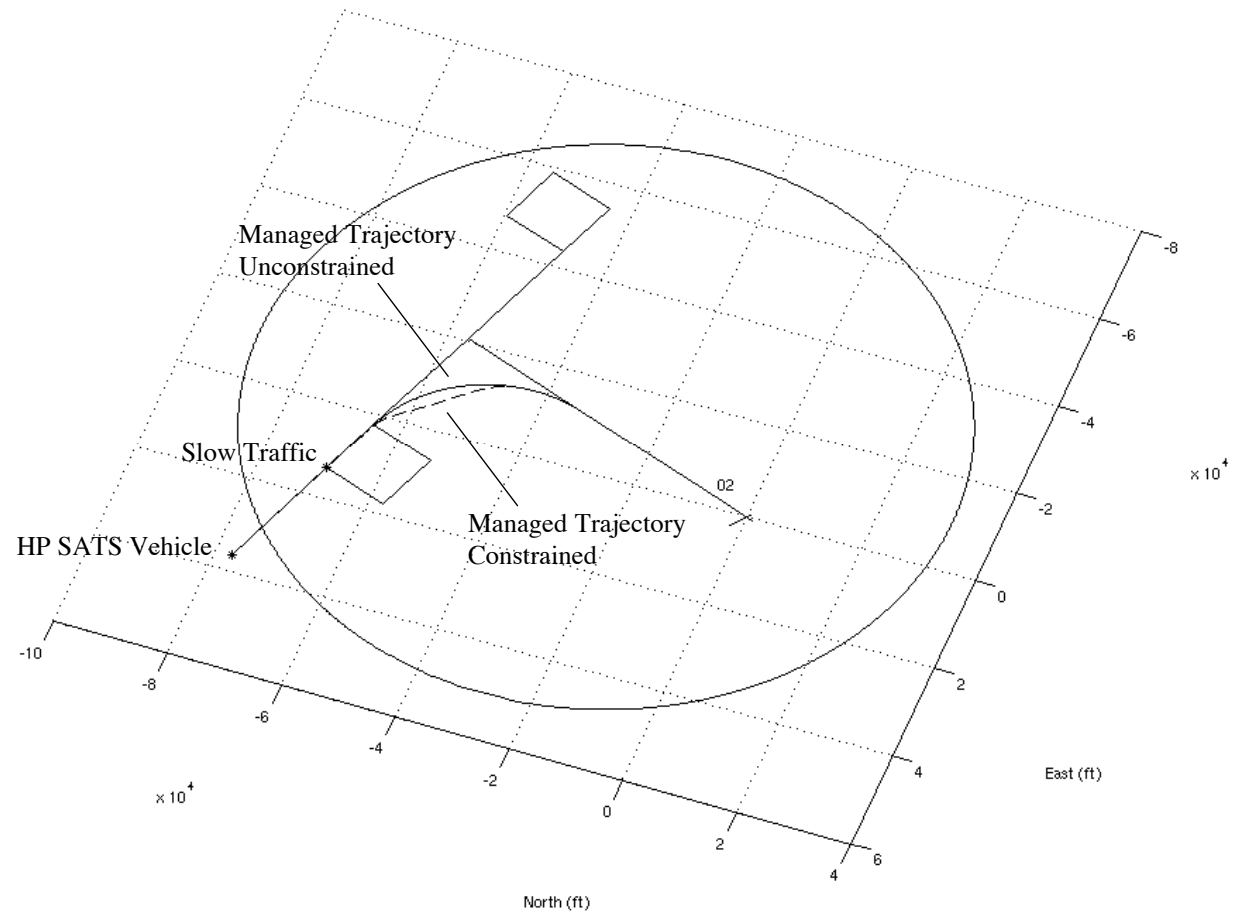
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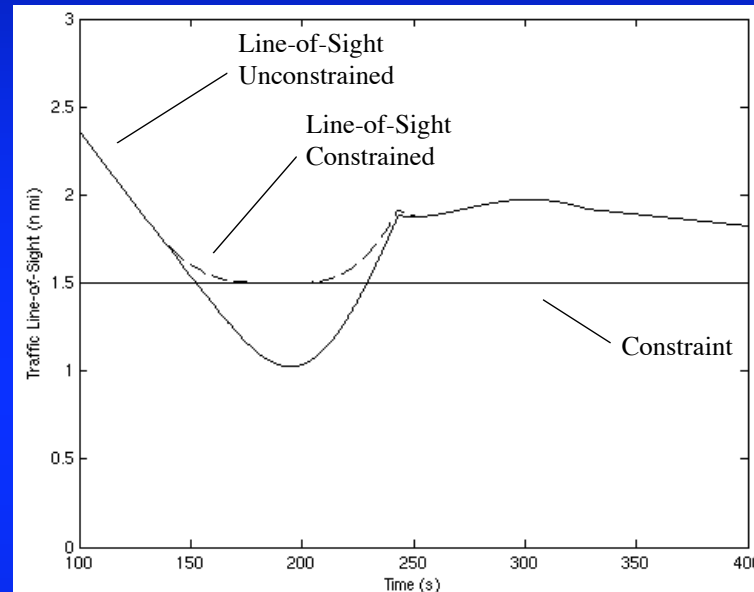
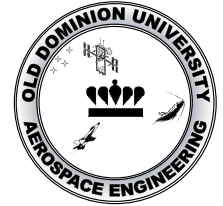
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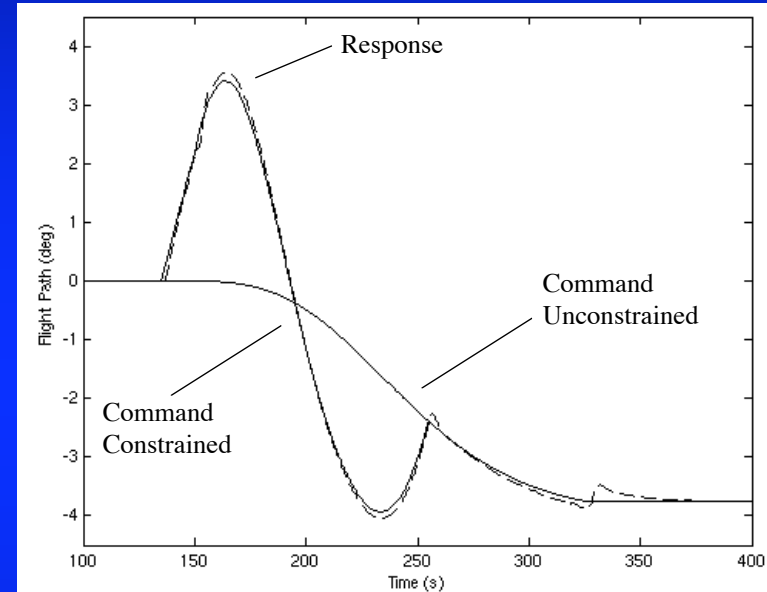
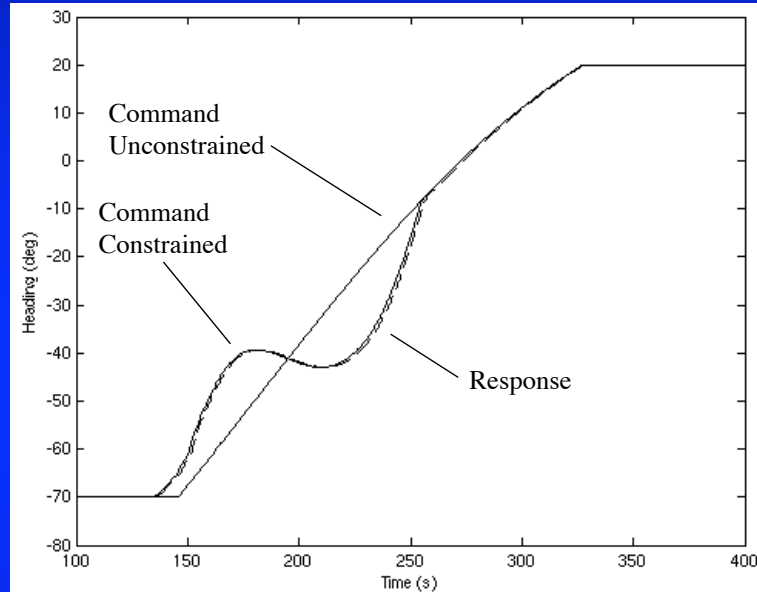
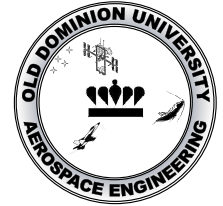
# Line-Of-Sight Distance Right Turn Example - Constrained



- **Distorted Trajectory Satisfies Line-Of-Sight Constraint  $R_{LOS}^* = 1.5$  n mi**
- **Line-Of-Sight Equals Constraint @ 195 s, Above Constraint Elsewhere**
- **Distortion Time Window Is Specified As  $\Delta t_- = \Delta t_+ = 60$  s**
- **Separation From Traffic Maintained During Descent**



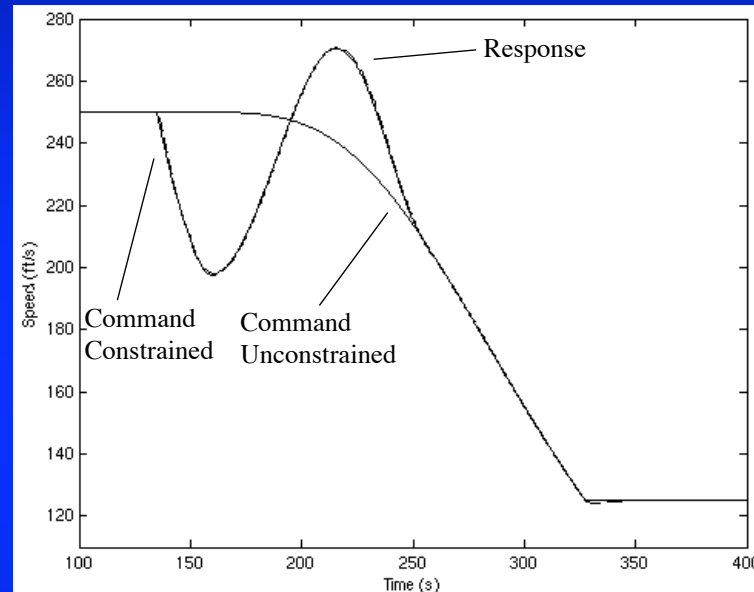
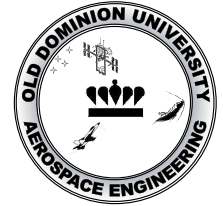
# Auto Flight Mode Right Turn Results - Constrained



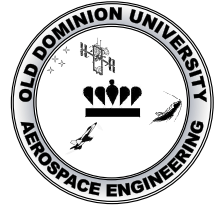
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Dept. of Aerospace Engineering  
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Norfolk, Virginia**

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National Consortium for Aviation Mobility**