Federal Aviation Administration

Session 139-GNC-49: “Innovations and Support of the NAS at the FAA”

Paper AIAA-2007-7145: “A Demonstration of an Aircraft Intent Interchange Specification for Facilitating Trajectory-Based Operations in the National Airspace System”

Presented to: AIAA GNC, Honolulu, HI

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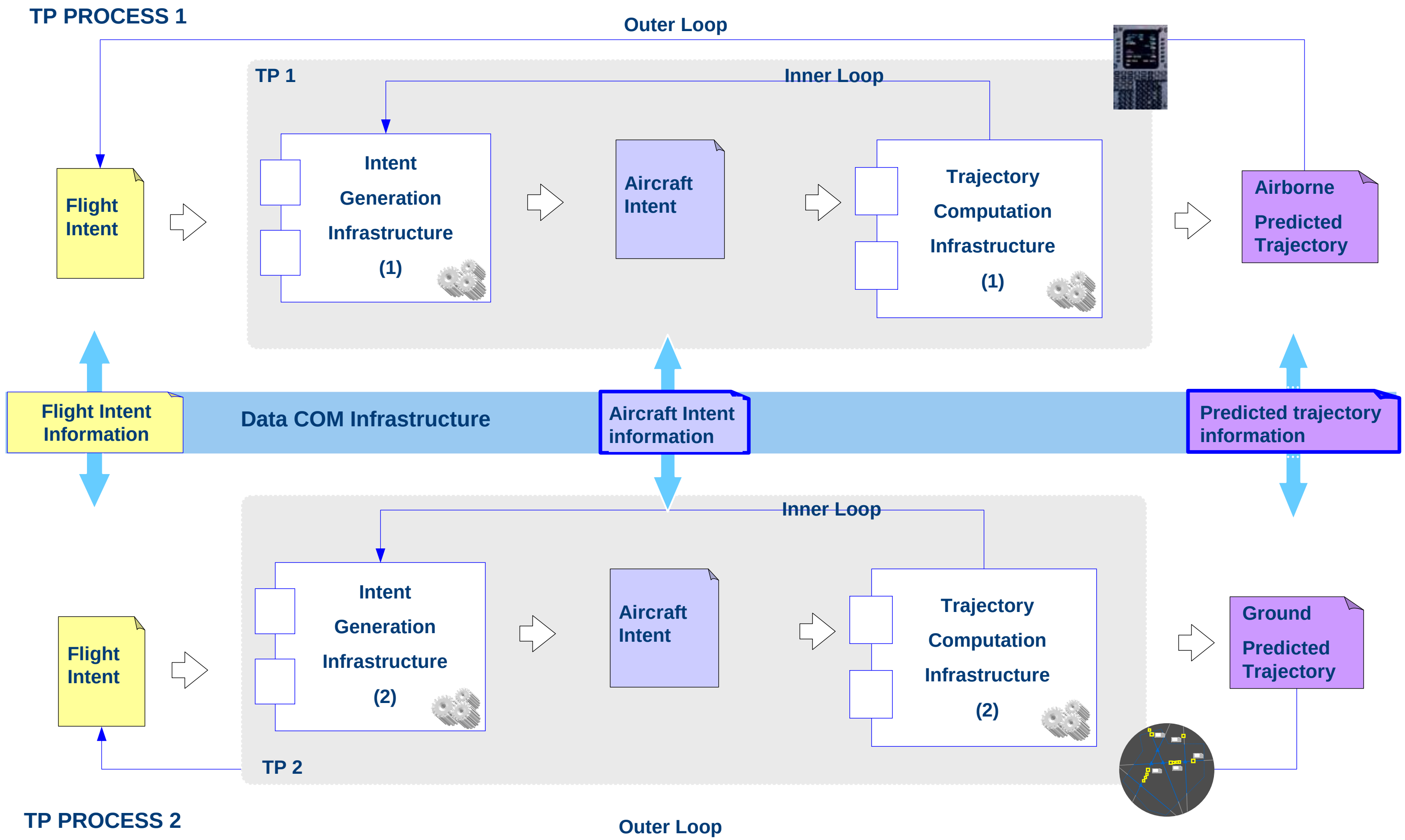
Overview

- **Motivation**
- **Background**
  - Aircraft Intent Description Language (AIDL)
  - Target Generation Facility (TGF)
    - TGF Simulator
    - TGF Trajectory Predictor (TP)
  - Mapping AIDL to TGF
- **Demonstrating TGF/AIDL Interface**
- **Results**
  - Common TP Metrics Put to Use
- **Conclusion**
  - AIDL is well-suited to communication of aircraft intent, ATM restrictions, and 4DT's

Motivation

- **Supporting the *FAA's NextGen Implementation Plan***
  - outlines a "…combination of new procedures and advances in technology to meet the need for increased capacity and efficiency while maintaining safety, their vision of the National Airspace System in 2025."
- **Trend of Cooperative Research**
  - standardizing developing technologies.
  - FAA, NASA, and EUROCONTROL & commercial partners
- **FAA/Boeing Cooperative Research & Development Agreement (CRDA)**
  - Facilitate Development in Trajectory-Based Operations (TBO)
  - This is the initial study under the CRDA
  - UAS in the NAS
- **Investigation of DATACOM between TP Processes**
  - Evaluating the effectiveness of the Boeing-Developed AIDL

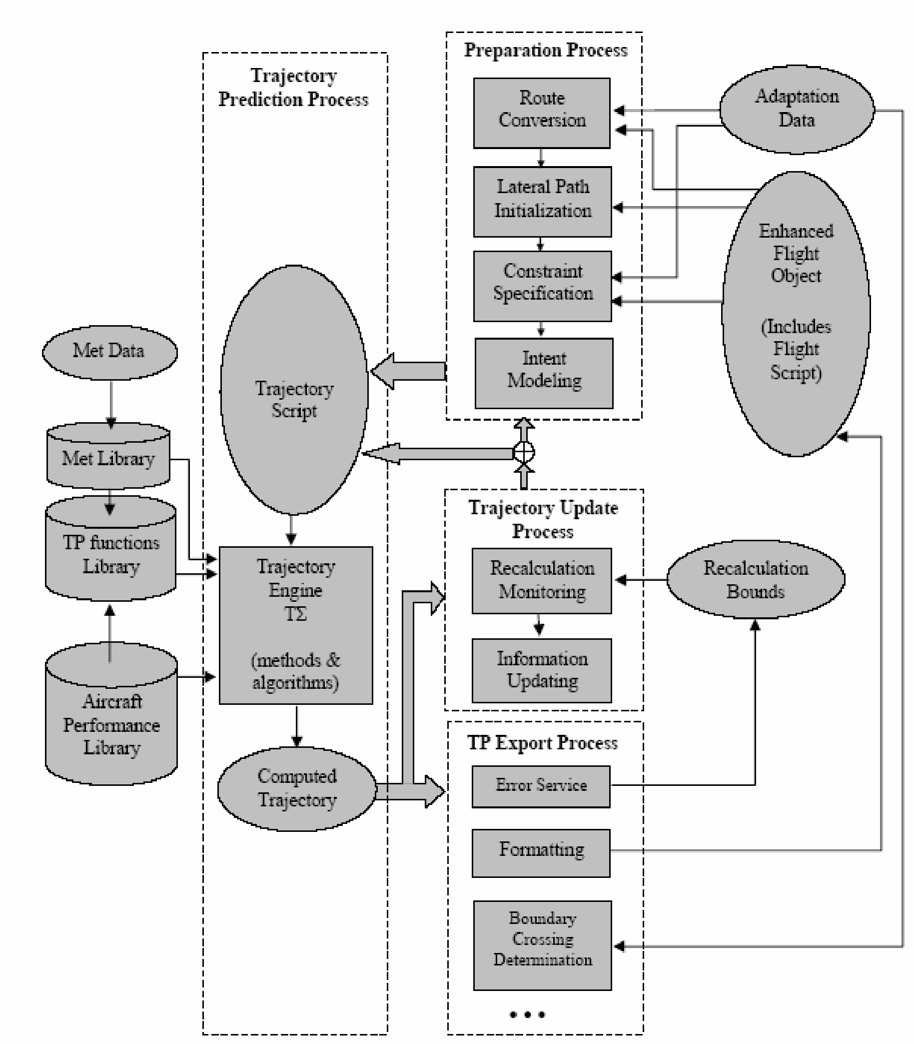
Trajectory Related Information Exchange



Aircraft Intent – Clearing Ambiguity?

- *#1 – "…Enable 'What If' Scenarios…"*
- *#2 – "…Unambiguous mathematical description of a perfectly constrained trajectory."*

TP Structure



Source:

Flight Object -
A Recommendation for Flight Script and Trajectory Description

FAA / EUROCONTROL
Action Plan 16
Common Trajectory Prediction Capabilities

October 30, 2006

AIDL Objectives

- **A common exchange language that can support trajectory synchronization in future Trajectory-Based Operations (TBO)**
- **This common AIDL has to**
  - be application independent
  - serve to encode aircraft intent information for both air or ground trajectory-based automation systems
  - support air-air, air-ground and ground-ground interoperability
  - cover any level of detail demanded by trajectory-based applications
  - serve to express the input to any trajectory computation infrastructure in ATM
- **The AIDL shall contain formal / mathematical structures to define all the possible ways in which different TPs model flight commands / guidance modes and standard procedures in ATM (the instructions)**

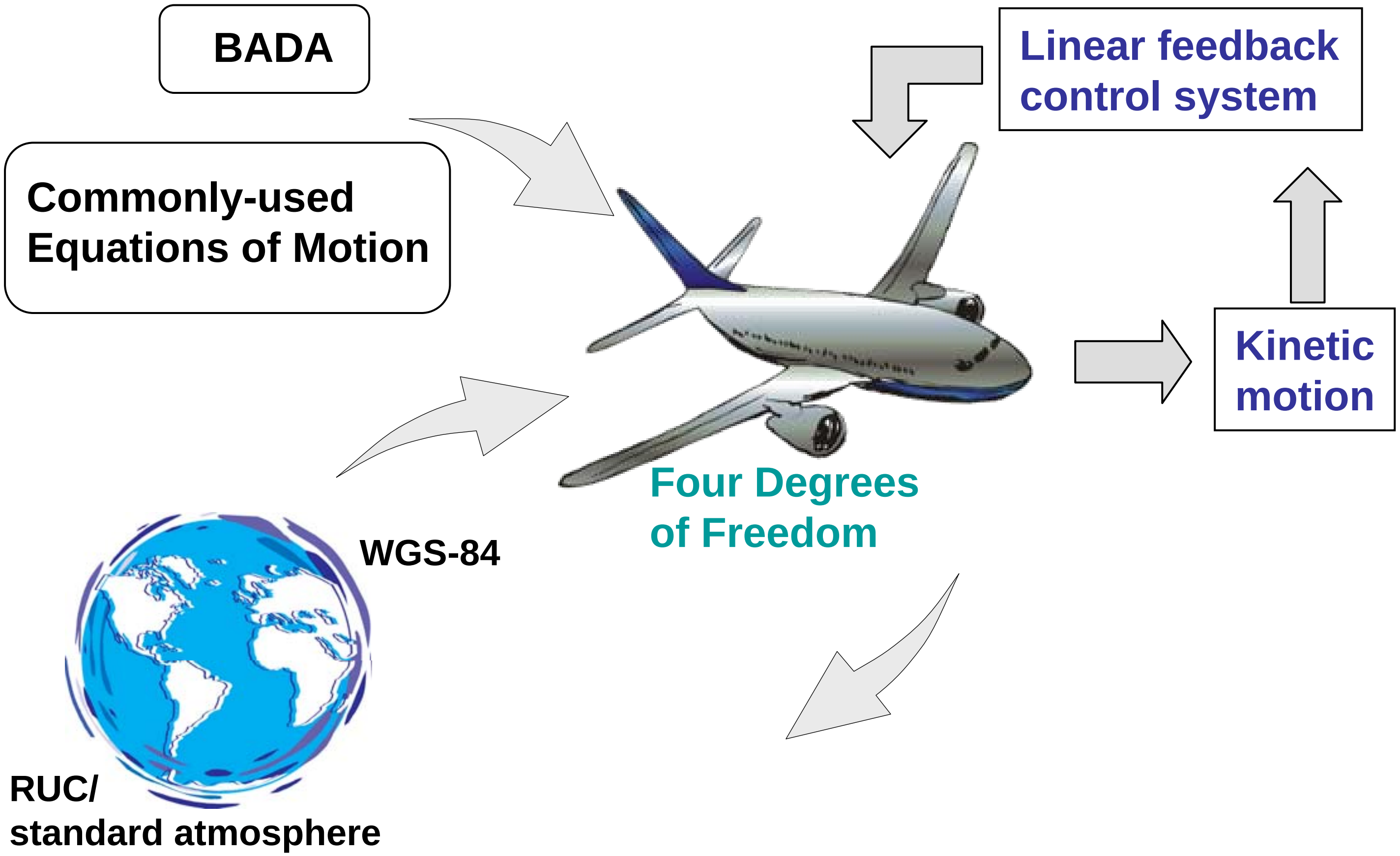
What is the AIDL?

- The Aircraft Intent Description Language (AIDL), developed at Boeing Research & Technology Europe (BR&TE), is a formal language designed to describe aircraft intent information in a rigorous but flexible manner
- AIDL is comprised of an alphabet and a grammar (lexical and syntactical)
- AIDL alphabet contains a set of instructions that define all the possible ways in which different TPs model flight commands and guidance modes in ATM
- Lexical grammar contains a set of rules (lexicon) to define valid simultaneous combination of the instructions to express elemental behaviors of the aircraft (operations)
- Syntactical grammar contains a set of rules (syntax) to define valid sequential combination of instructions to express the sequence of operations that give rise to the trajectory

TGF Aircraft Dynamic Simulator

- **Real-time Air Traffic Simulator for Fixed Wing Aircraft**
- **Functions**
  - Operational Test & Evaluation
  - Research & Development
  - ATM procedure development and validation
- **Tested ATM Technologies**
  - Separation procedures
  - Controller displays
  - Data communication technologies
  - Traffic routing procedures

TGF Aircraft Dynamic Simulator



Mapping AIDL Set Instructions to TGF

AIDL	TGF
Set Path Angle	**(lift coefficient variation)**
Set Throttle	**Spooling Lag**
Set Bank Angle	**Bank Angle Dynamics**
Set High Lift Devices	
Set Speed Brakes	
Set Landing Gear	

TGF Trajectory Predictor

- **Same equations of motion as the TGF simulator**
- **No control system - assumes that the vertical, lateral, and speed profiles are followed exactly**
- **Perfectly suited for interfacing with AIDL**
  - Designed to interface with AIDL
  - Identical instructions, identical instruction intervals
- **Variable integrator**
  - First-order to fourth-order integrator
  - Time step varies according to the needs of the dynamics, from 10 seconds to 500 seconds
- **Extremely fast trajectory computations**

TGF/ AIDL Interface

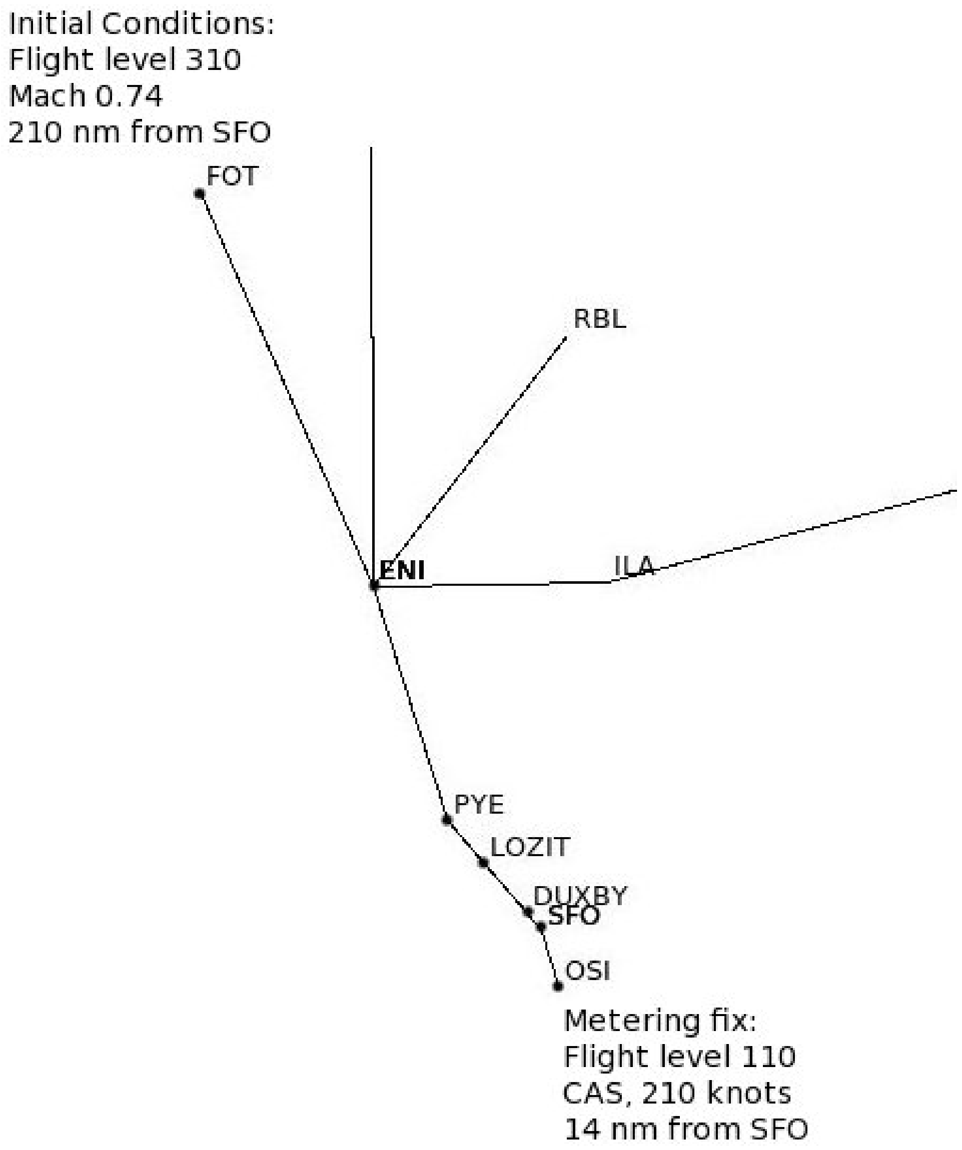
- **TGF's AIDL Reader translates AIDL to TGF Lateral and Speed/Alt Maneuvers**
- **The Reader is insufficient for AIDL "Auto-Parameters"**
  - These are the parameters which are left as unknown or unspecified
    - **Implicit AIDL**
  - The aircraft intent is still unambiguous, as proven by AIDL developers

Demonstrating TGF/AIDL Interface

- **Revisiting a 17-Year-Old Study**
  - Williams, D. H., Green, S. M., "Airborne Four-Dimensional Flight Management in a Time-Based Air Traffic Control Environment," NASA TM 4249, 1991
  - Approaches into the Denver area for two Boeing 737-100 aircraft
  - 210 nm out of Denver at 31,000 ft and Mach 0.74
  - 80 seconds of separation
  - RTA to the metering fix at 80 seconds apart
  - 11,000 ft and 210 knots
  - Each selected a different speed strategy to meet the RTA, resulting in as much as 8 nm of along-track error in a 30-minute approach flight

Two Speed Strategies to Meet an RTA

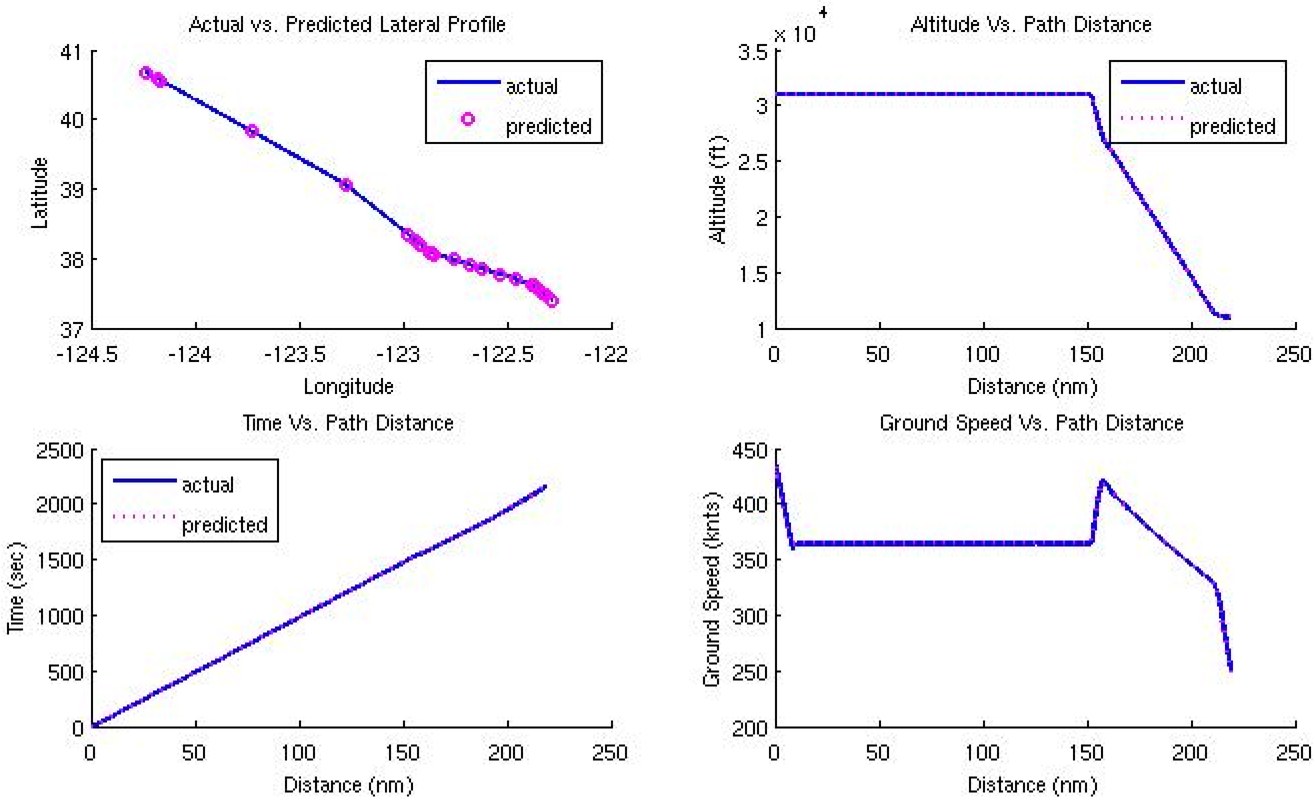
- **ATC Descent Advisor**
  - Targets a 280 kt descent into metering fix
  - Intended to provide consistent spacing between aircraft of different types
- **Minimum Fuel**
  - Intended to emulate the Cost Index of a 4D-capable FMS
  - Optimizes fuel burn and flight time


Initial Conditions:
Flight level 310
Mach 0.74
210 nm from SFO
FOT
RBL
ENI
ILA
PYE
LOZIT
DUXBY
SFO
OSI
Metering fix:
Flight level 110
CAS, 210 knots
14 nm from SFO

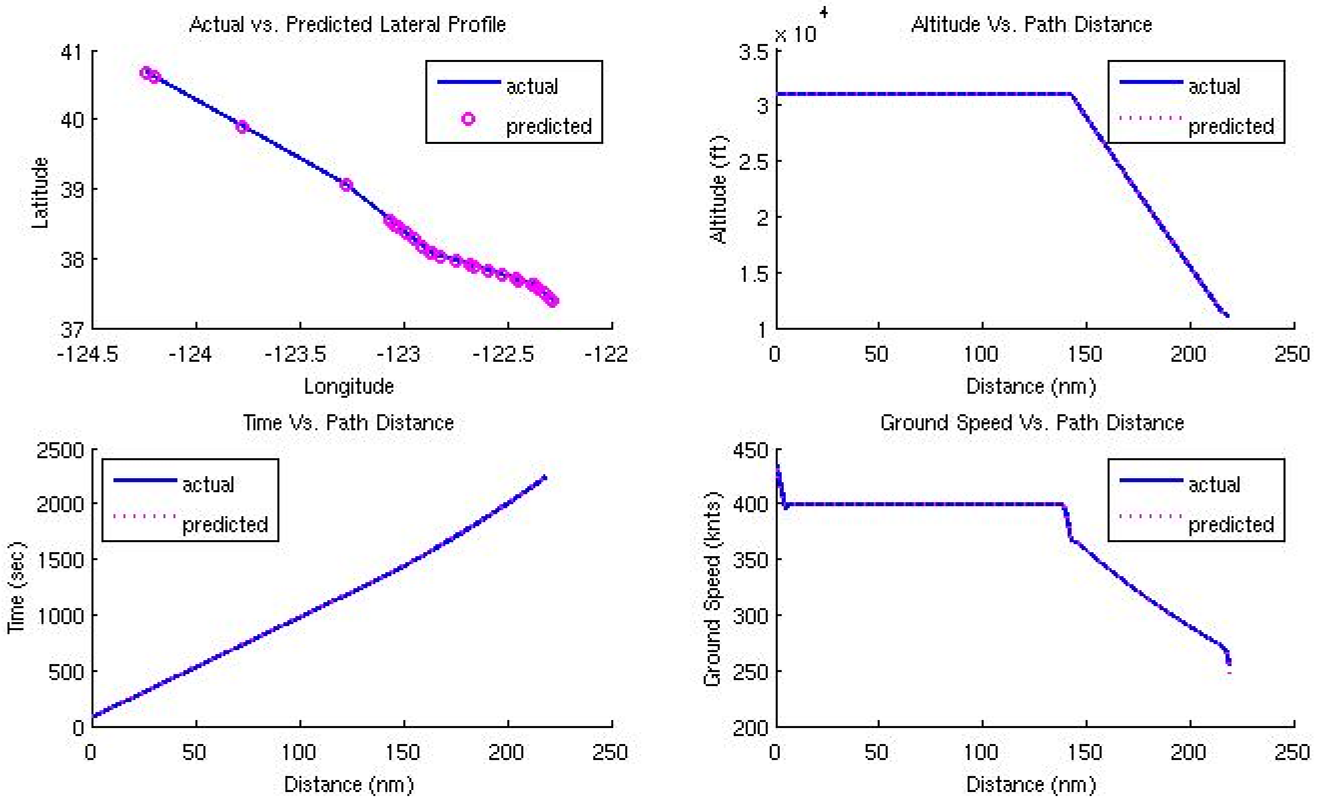
Aircraft Profiles

- **Leading aircraft selects ATC Descent Advisor program**
  - Mach 0.62 cruise for 150 nm
  - 280 KIAS descent
  - TOD about 70 nm from the metering fix
- **Trailing aircraft selects Minimum Fuel profile**
  - Mach 0.68 cruise for 140 nm
  - 230 KIAS descent
  - TOD about 80 nm from the metering fix
- **TGF TP simulates the Functions of the Airborne FMS**

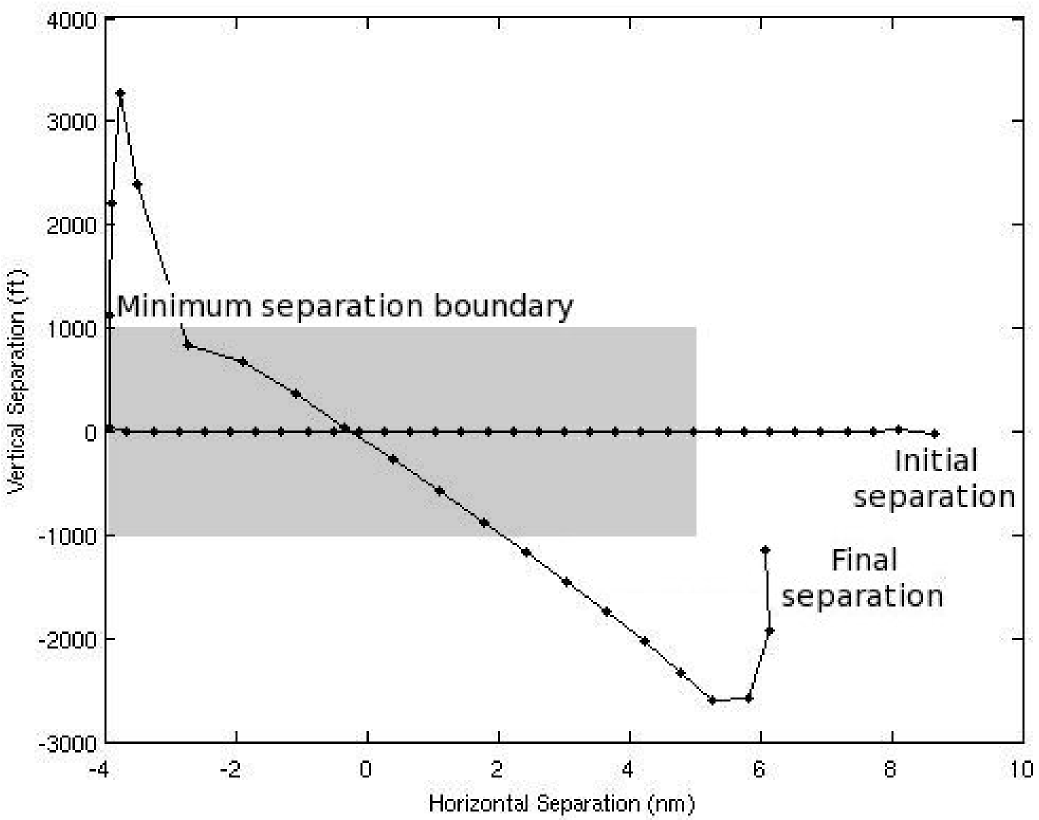
TGF TP Vs. TGF Simulator
- ATC Descent Advisor Aircraft



TGF TP Vs. TGF Simulator - Minimum Fuel Aircraft

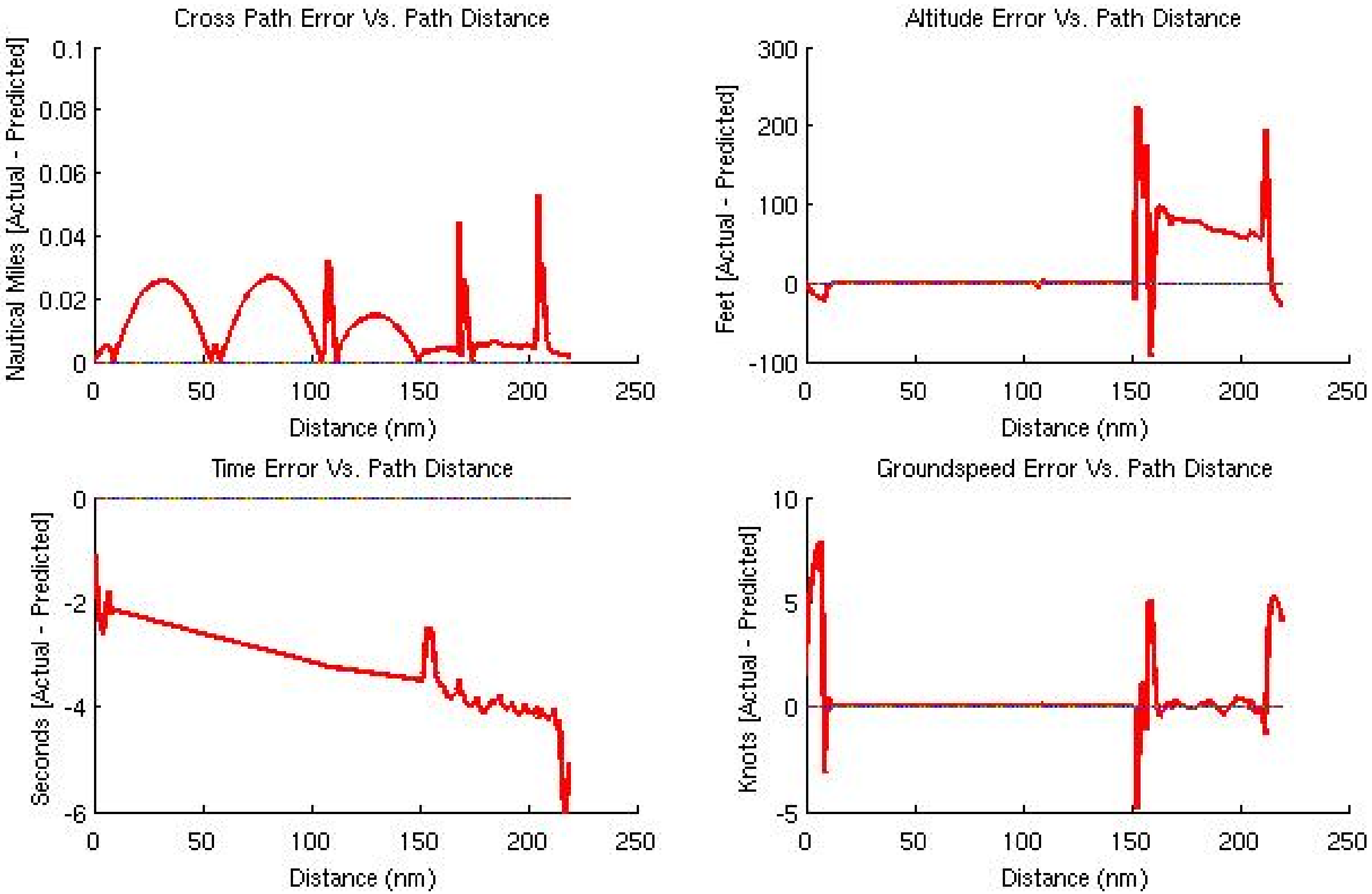


Separation Conflict Induced by Different Speed Strategies

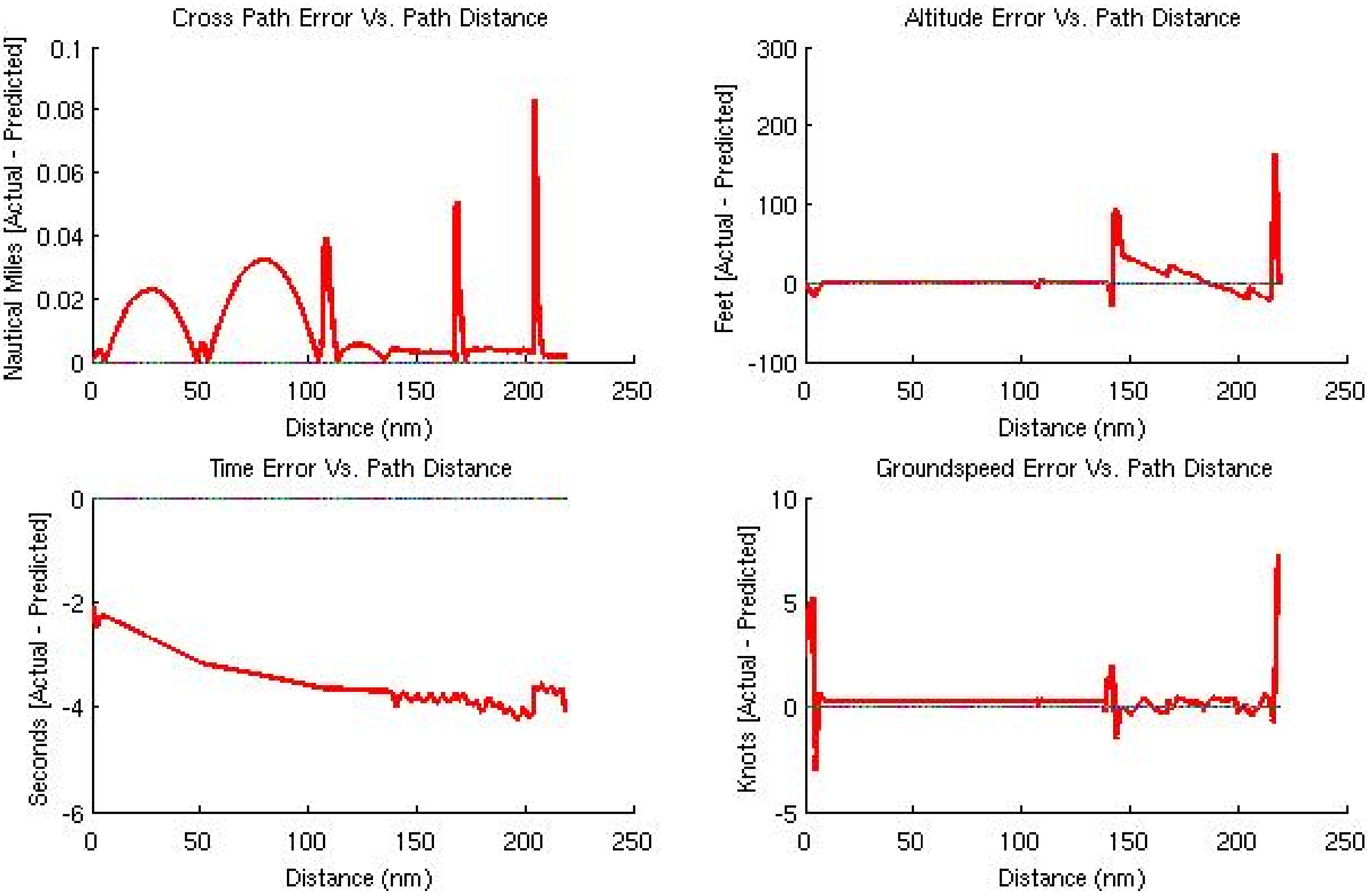


Similar to results of Williams and Green

TP Error Metrics for Boeing 737-200 using ATC Descent Advisor Profile

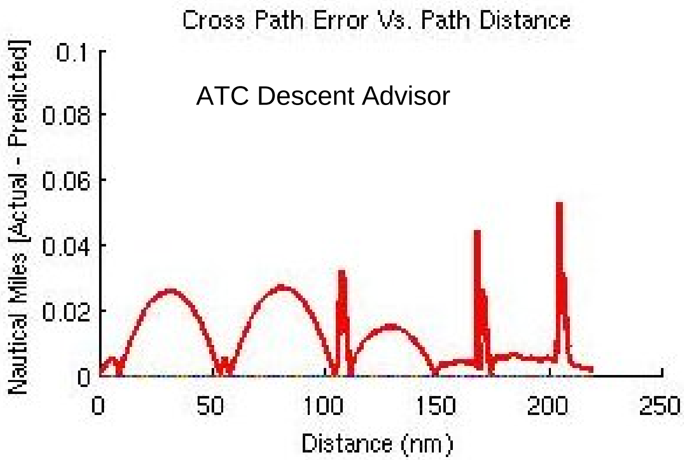


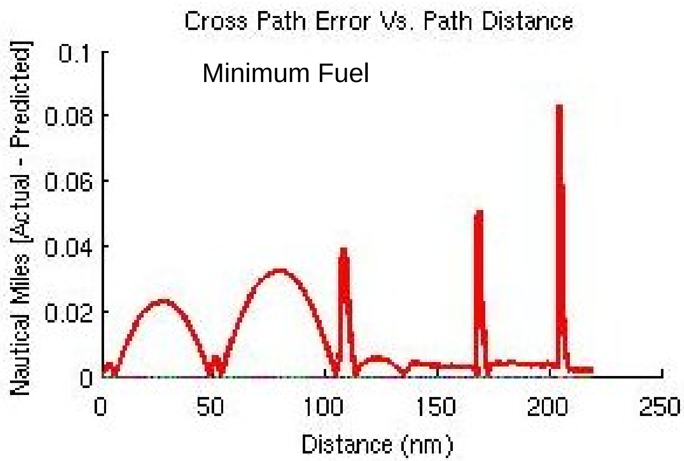
TP Error Metrics for Boeing 737-200 using Minimum Fuel Profile



Cross-Path Error

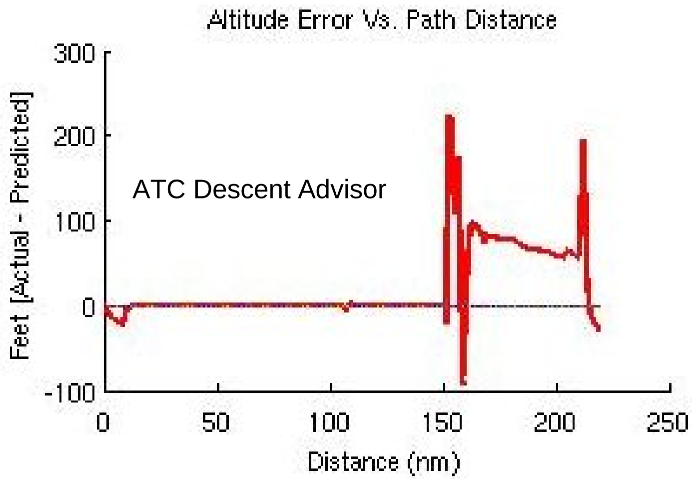
- **Always positive**
- **Never more than 0.08 nm or about 500 ft**
- **Mean cross-path error is on the order of 100 ft**
- **Source of Error**
  - TGF TP does not model flight technical error (it assumes the lateral path is held exactly)
  - TGF TP does not model roll-in and roll-out when turning (it assumes constant radius turns)

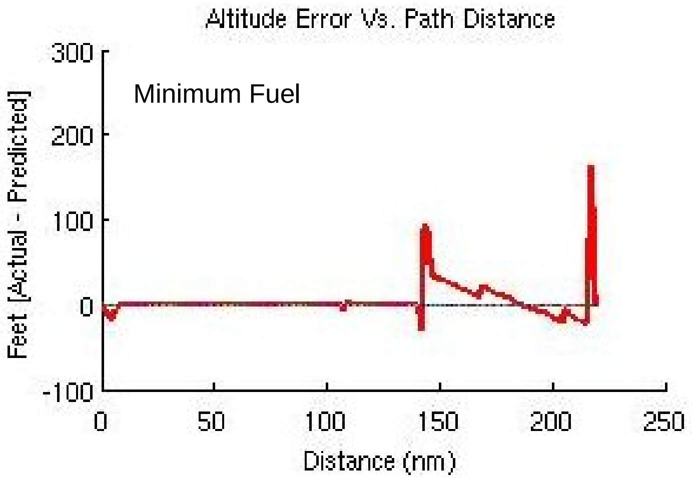




Altitude Error

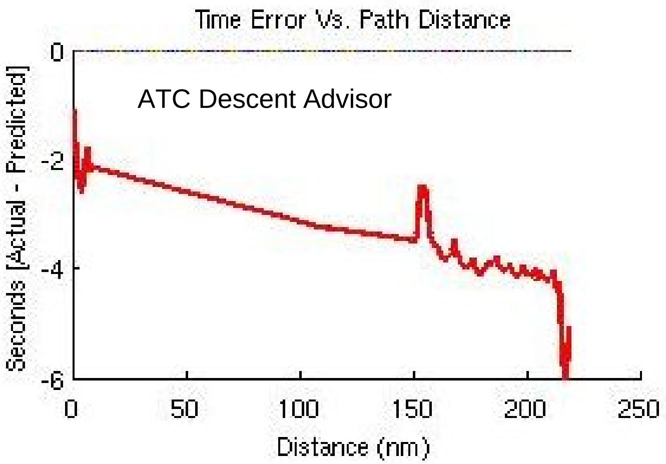
- **Small during cruise**
- **Highest at transitions**
- **ATC Descent Advisor**
  - Descent phase errors too big for effective CD&R
  - suitable for use in current TGF applications
  - Descent transitions not modeled
- **Minimum Fuel**
  - Error is smaller during descent transition and during the descent
  - Minimum Fuel AIDL is modeling the descent transition with a HE (Hold Energy) instruction which is a more accurate transition model.

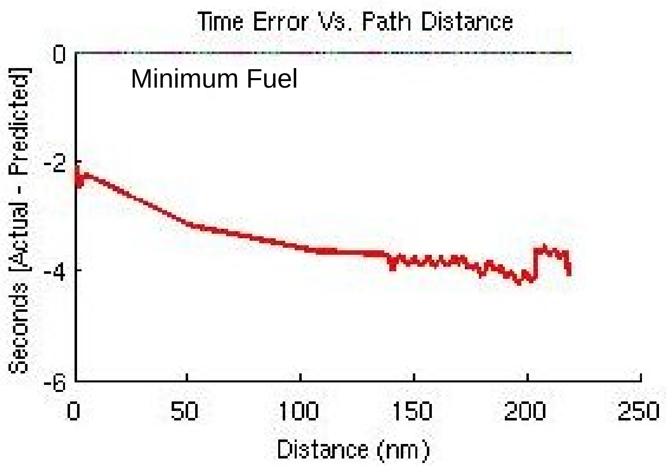




Time Error

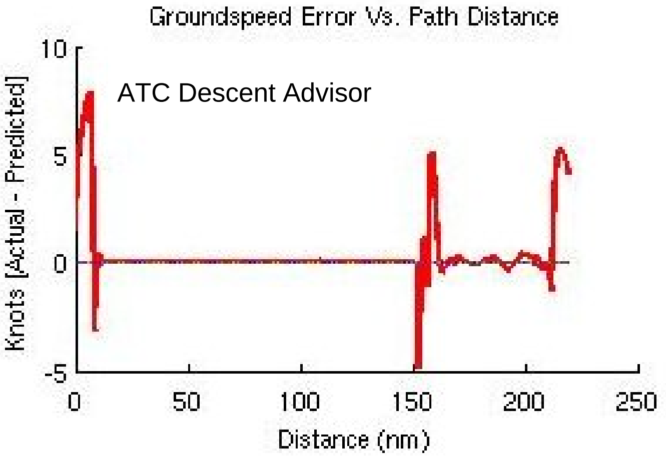
- **Gets worse with simulation time, a common problem with TP tools**
  - Grows to about 6 seconds
  - Insufficient for reliable CD&R
  - Suitable for currently proposed TGF applications
- **Reliable ground-based CD&R**
  - Requires TP accuracy within about two seconds over a 20-minute trajectory
  - Both of these flights have a four-second error in 20-minute
  - Improvement on the accuracy of the TGF TP would require accurate modeling of turn and descent transitions
  - The mass of the aircraft (as affected by the fuel burn model) has a large effect on the 20-minute trajectories and needs to be carefully modeled

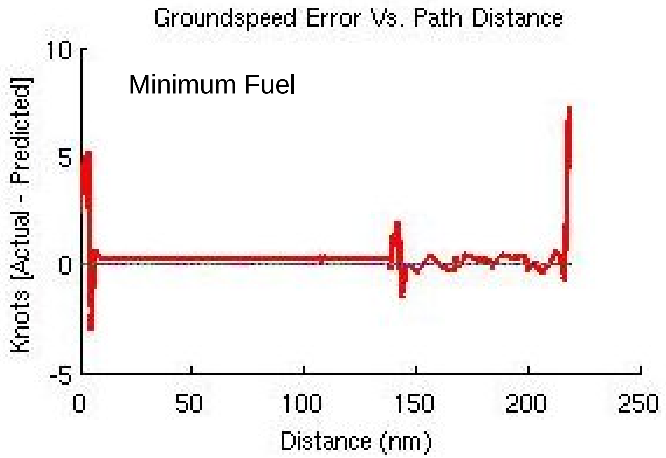




Speed Error

- **Overall very low**
- **Spikes just above 5 knots during transitions**
- **Minimum Fuel Aircraft**
  - Modeling of the descent transition via an AIDL HE instruction creates a more accurate representation of the transition
- **5-knot error is well within the acceptable range of current TGF applications**





Conclusions

- **AIDL effective and reliable; and easily extensible to 4D trajectories and constraints at the flight script level**
- **A 4DT alone is insufficient for a ground-based CD&R tool to perform effective conflict resolution because the aircraft's intent cannot be extracted**
  - Communication of aircraft intent is necessary for ground-based CD&R tools to perform a conflict resolution function
- **An RTA is insufficient for ensuring conflict-free trajectories**
- **TGF TP was able to predict the simulated aircraft trajectory with**
  - maximum along-track error of 6 seconds
  - maximum cross-track error of 0.08 nm
  - maximum vertical error of 300 ft
  - maximum absolute position error of 8 nm

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Mapping AIDL Law Instructions to TGF

AIDL	TGF
Speed Law	**discrete speed-alt profiles**
Horizontal Speed Law	
Energy Law	
Vertical Speed Law	**landing flare law**
Path Angle Law	
Altitude Law	**ILS following**
Throttle Law	**spooling lag**
Bank Angle Law	**Relationship with desired heading**
Course Law	**GroundTrack, FollowTrack, and RouteOffset Maneuvers**
High Lift Devices Law	**ILS procedures**
Speed Brakes Law	**Crossing and Landing Urgency**

Mapping AIDL Hold Instructions to TGF

AIDL	TGF
Hold Speed	**climb/descent & level flight**
Hold Horizontal Speed	**implemented via airspeed**
Hold Energy	**Region 1&4 energy share**
Hold Vertical Speed	**CVS (const. vert. speed)**
Hold Path Angle	**FPA climb/descent**
Hold Altitude	**level decel/accel & level flight**
Hold Throttle	**thrust coef. (eg, idle & max)**
Hold Bank Angle	**via heading capture**
Hold Course	**vector & route following**
Hold High Lift Devices	***flaps* = {0,4}**
Hold Speed Brakes	***speedBrakesOn* Boolean**
Hold Landing Gear	***landingGearOn* Boolean**

AIDL Open Loop Instructions

- **Open Loop instructions for flight path angle, throttle, bank angle, and speed brakes are not currently used**

Mapping AIDL Track Instructions to TGF

AIDL	TGF
Track Vertical Path	**follow track**
Track Lateral Path	**route following, follow track, ground track, holding patterns**