Java Architecture for Detect-and-Avoid (DAA) Extensibility and Modeling (JADEM) and its applications

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Background

- The U.S. Congress mandates the “safe integration” of Unmanned Aerial Systems (UAS) in the National Air Space (NAS) beginning in September 2015.
- The FAA aviation rulemaking committee is looking into amending Part 91.113 that prescribes aircraft right-of-way rules, to allow for an electronic “Detect-and-Avoid” (DAA) system enabling UAS to steer clear of potential collisions with other aircraft.
- Radio Technical Commission for Aeronautics (RTCA) is developing the technological requirements and Minimum Operational Performance Standards (MOPS) for a UAS DAA System.

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Background

UAS Integration in the NAS Project

- FAA
- NASA
  - NASA Ames Research Center: simulations
    - Separation Assurance / SAA Interoperability (SSI) - research & algorithms
    - Human Systems Integration (HSI)
    - Integrated Test and Evaluation
  - NASA Langley and Armstrong Centers
- Air Force
- MIT
- Others

JADEM

Java Architecture for Detect-and-Avoid (DAA) Extensibility and Modeling (JADEM)

DAA algorithms and simulation platform for:

- Close-loop sims for NAS-wide and parametric studies
  - JADEM simulator
- Human-in-the-Loop (HitL) sims and flight tests
  - interface with NASA Live Virtual Constructive – Distributed Environment (LVC-DE)

GRACE

Generic Resolution Advisor and Conflict Evaluator (GRACE) is needed

- to research the effect of specific features of DAA algorithms (separation standards, maneuvers, right-of-way rules, resolution consistency, etc.)
- to research interoperability between different DAA subsystems and algorithms
- to evaluate different types of guidance: directive guidance, Omni-Bands, Well-Clear Recovery (WCR)
- to study the impact of aircraft modeling and trajectory prediction errors on performance of DAA system
- as a backup conflict resolver for simulations

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GRACE

Key ideas

- Open architecture
  - Use any suitable Trajectory Predictor
  - User-defined separation standards, maneuvers, and cost functions
- Grid-based mapping for conflict detection (alerting)
- Force field theory for conflict resolution (guidance)
  - Charged particles analogy

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ALERTING

Customizable threat evaluation criteria

- Horizontal separation
- Horizontal Miss Distance (HMD)
- Vertical separation
- Tau-separation
  - modified tau
  - altitude-dependent tau as defined by TCAS sensitivity levels
- Time to co-altitude (vertical tau)
- Time to separation as a filtering condition.

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ALERTING

Symbol	Name	Pilot Action	Buffered Well Clear Criteria	Alerting Time Threshold	Aural Alert Verbiage
	TCAS RA	• **Immediate action required** • Comply with RA sense and vertical rate • Notify ATC as soon as practicable after taking action	(Driven by TCAS-II)	x	"Climb/Descend"
	DAA Warning Alert	• ***Immediate action required*** • Notify ATC as soon as practicable after taking action	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	25 sec (TCPA approximate: 60 sec)	"Traffic, Maneuver Now"
	DAA Corrective Alert	• On current course, ***corrective action required*** • Coordinate with ATC to determine an appropriate maneuver	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Avoid"
	DAA Preventive Alert	• On current course, corrective action ***should not be required*** • Monitor for intruder course changes • Talk with ATC if desired	DMOD = 1.0 nmi HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Monitor"
	Remaining Traffic	• No action expected	Within surveillance field of regard	X	N/A

* These values show the Protection Volume (well clear volume) at MSL 5000-10000ft (TCAS Sensitivity Level 5)

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DIRECTIVE GUIDANCE

Standard Maneuvers (SM)

1. Right turn
2. Left turn
3. Increased vertical speed / pitch (faster climb or slower descent)
4. Reduced vertical speed / pitch (slower climb or faster descent)
5. Reduced speed (decelerate / slow down)
6. Increased speed (accelerate / speed up)

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DIRECTIVE GUIDANCE

Solution costs

- Rank cost (right turn has the lowest cost)
  - favors right-of-way compliant maneuvers
- Maneuver cost
  - penalizes too aggressive maneuvers
- Maneuver change cost
  - penalizes frequent changes of maneuvers
- Collision threat cost
  - naturally dominates over others when close to collision
  - rapidly decreases as a function of distance to intruder at CPA relative to NMAC limit

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OMNI-BANDS

Omni-directional suggestive guidance for all intruders shown as the color-coded “bands”

Three-step algorithm powered by GRACE (heading bands)

1. Determine potential threats by finding the intruders that can be reached (intercepted) by ownship;
2. Find bands for each of these threats from GRACE maneuvers for right and left turns;
3. Assemble the OmniBands for all intruders using set-theoretic operations over bands for individual threats.

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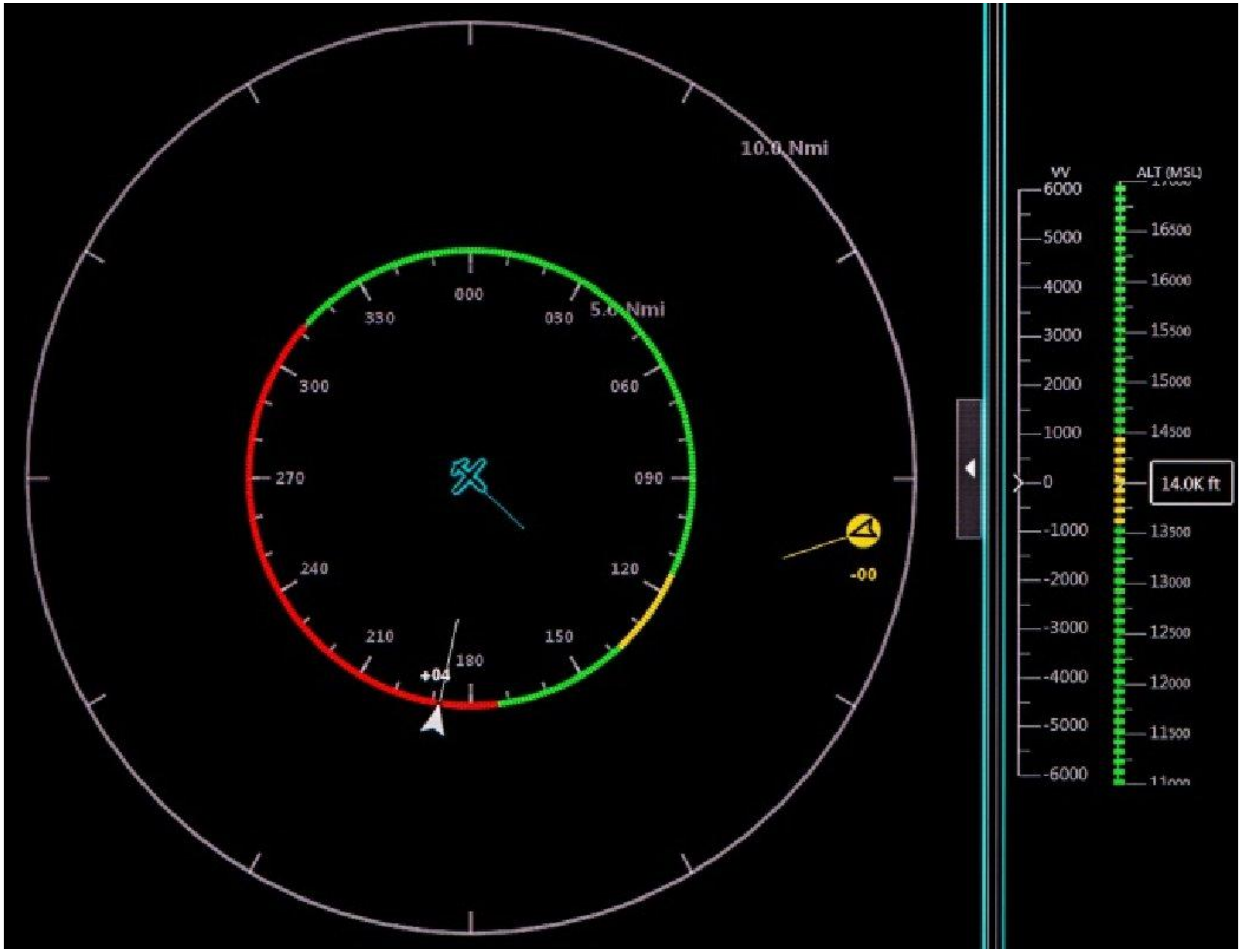
OMNI-BANDS


10.0 Nmi
5.0 Nmi
000
030
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120
150
180
210
240
270
300
330
+04
-00
VV
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
ALT (MSL)
16500
16000
15500
15000
14500
14.0K ft
13500
13000
12500
12000
11500

WELL-CLEAR RECOVERY (WCR)

- WCR guidance indicates to the pilot the "best" maneuver to restore the Well Clear
- Relies on GRACE maneuvers
- Presented as a "wedge" at pilot's display
  - the low bound is the lowest value of control variable needed for a timely recovery from loss of Well Clear
  - the high bound is GRACE maneuver limit
  - both bounds are snapped to a specified grid
  - the difference between high and low bounds cannot be smaller than a configurable minimal wedge width

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WELL-CLEAR RECOVERY (WCR)

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CURRENT STATUS

Support for Requirements of Phase 1 of UAS Integration Project

- Alerting Logic per MOPS
- Guidance:
  - directive
  - Omni-Bands / WCR
- Integrated High-Fidelity Surveillance Model with Noisy Sensors
- Integrated TCAS Module
- Support for TCAS Interoperability Requirements
- Developed Pilot Models for directive and Omni-Bands / WCR guidance

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CURRENT STATUS

Preparing for Phase 2 of UAS Integration Project

- Refactoring
- Optimization
- Data Analysis Tools

Writing a Paper on GRACE

Exploring Applications beyond MOPS

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