DAIDALUS: Detect and Avoid Alerting Logic for Unmanned Systems

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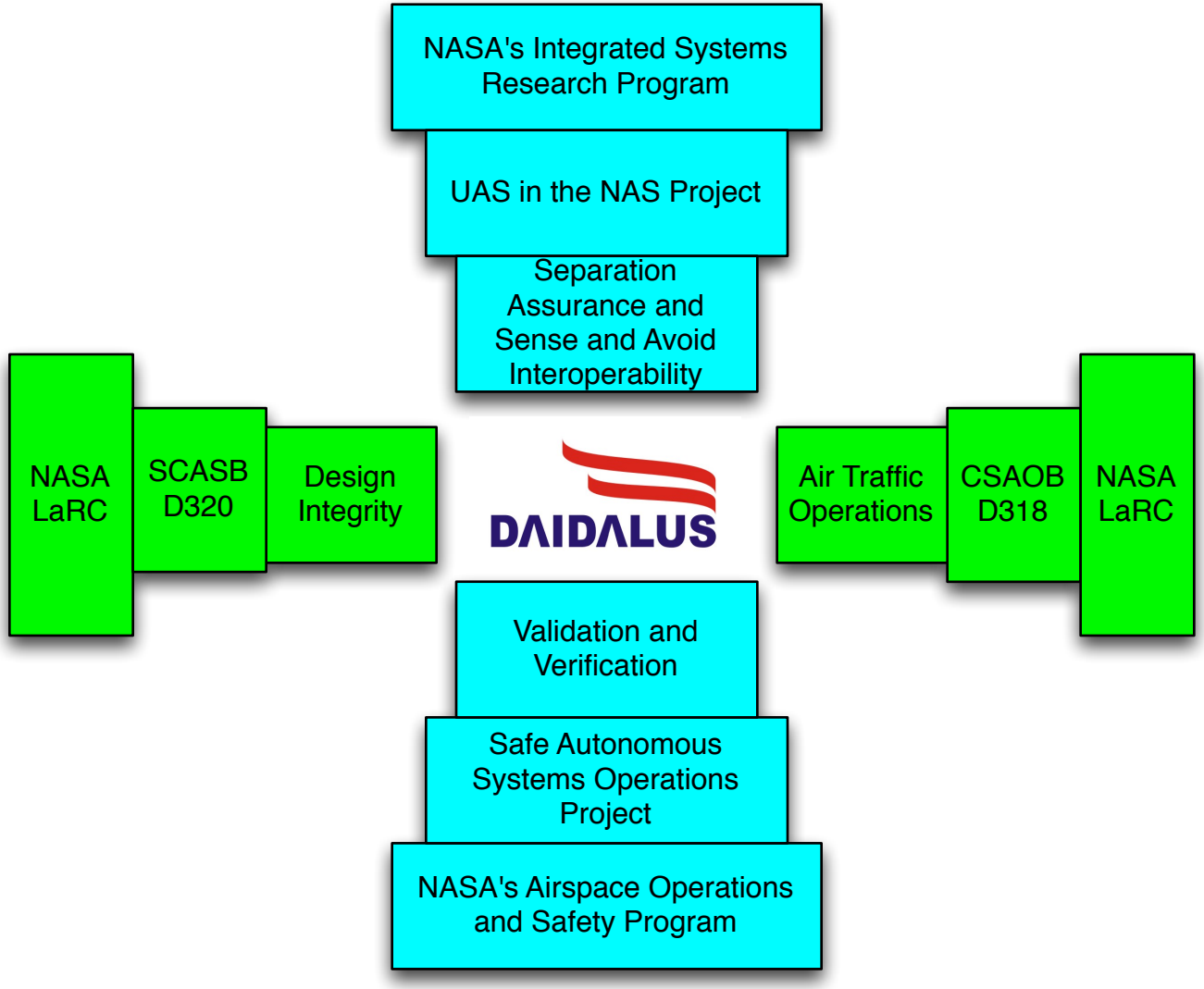
DAIDALUS

DAIDALUS @ NASA



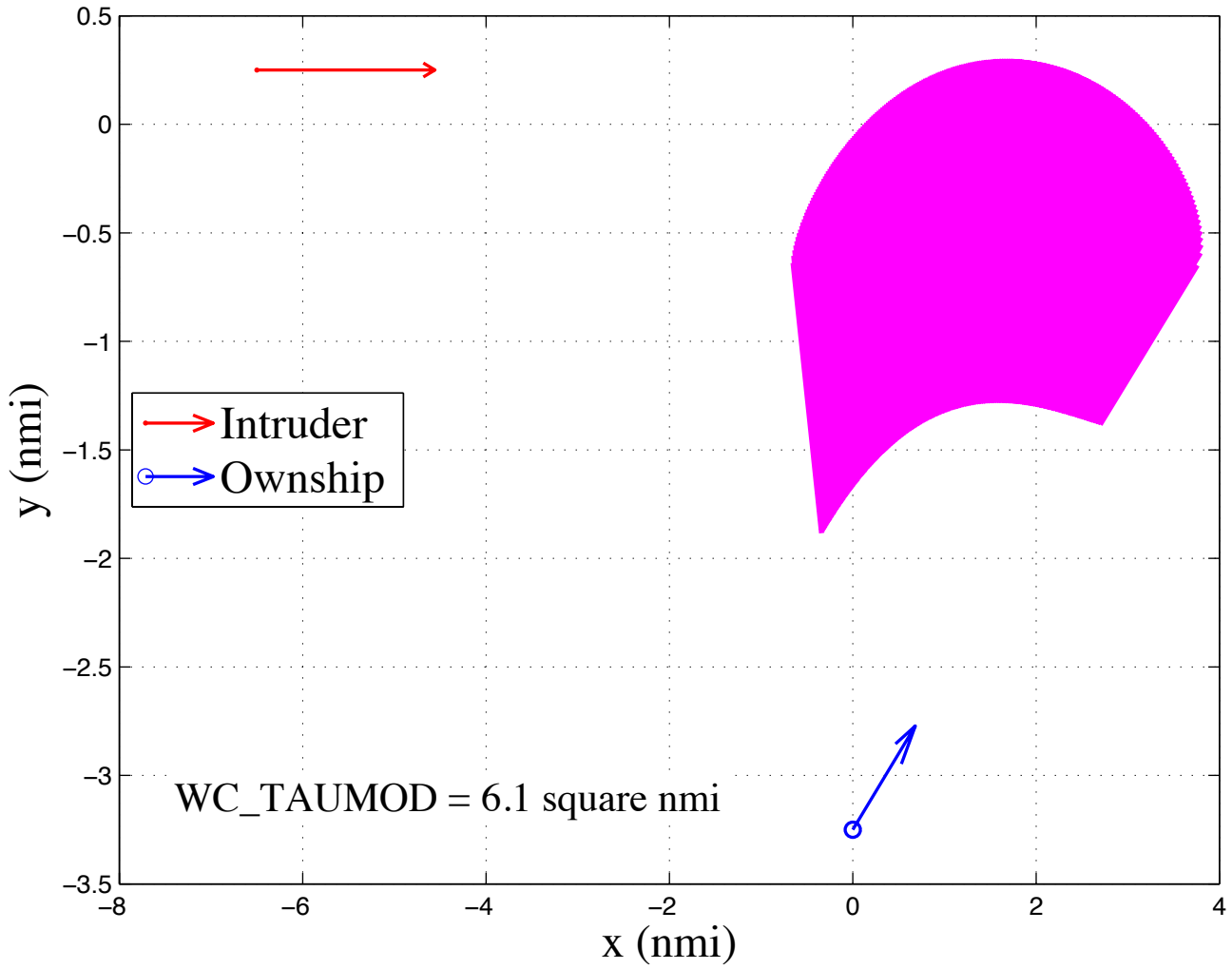
DAIDALUS Highlights

- Reference implementation of NASA's **detect and avoid** concept for the integration of **Unmanned Aircraft Systems** into civil airspace
- Based on a mathematical definition of the **Well-Clear** boundary.
- Provides algorithms that:
  - Determine the current pairwise well-clear status (Detection Logic).
  - Compute maneuver guidance to maintain or regain well-clear status (Determine Processing Logic).
  - Determine alert type (Alerting Logic).

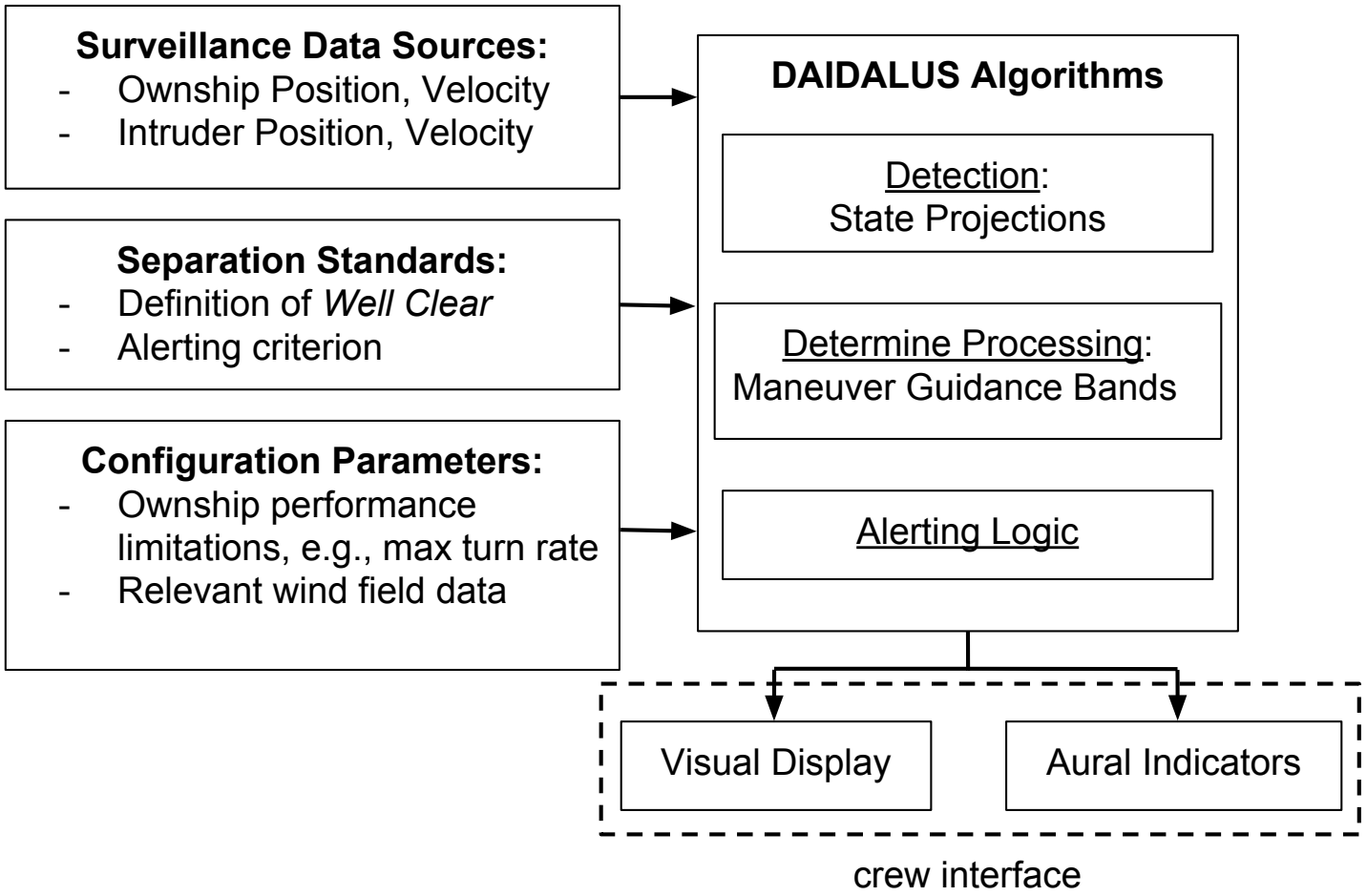
RTCA SC 228 Definition of Well Clear

- Two aircraft are **well clear** if appropriate distance and time variables determined by their states remain outside a set of predefined threshold values
- Threshold values under consideration by RTCA SC 228 DAA WG are:
  - Horizontal miss distance (HMD) = 4000 feet
  - Modified distance (DMOD) = 4000 feet
  - Time to loss of WC (TAUMOD) = 35 seconds
  - Vertical separation (ZTHR) = 450 feet
  - Time to co-altitude (TCOA) = 0 seconds (vertical closure rate not considered in current thresholds)

Well-Clear Boundary

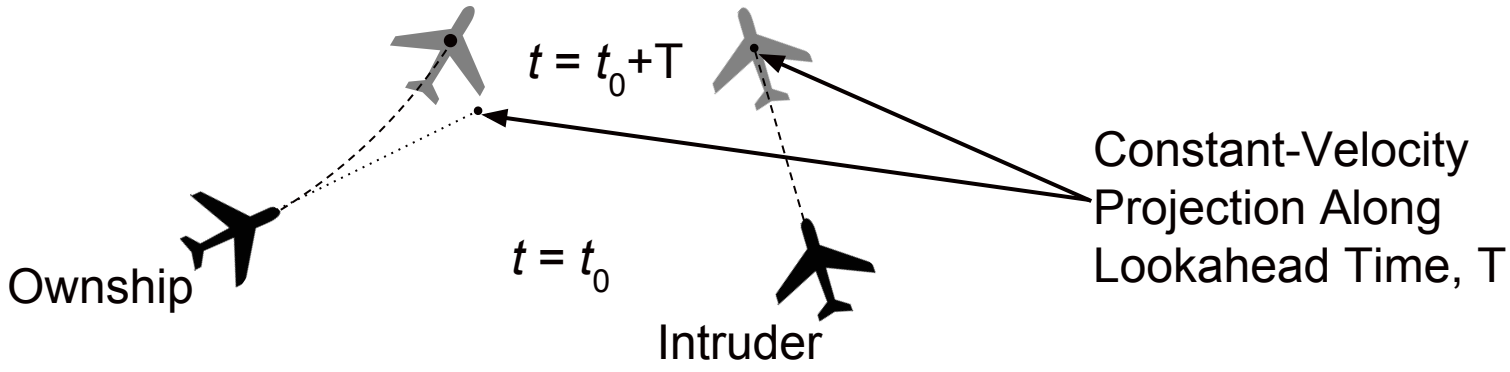


DAIDALUS High-Level Architecture



Detection Logic

- Given ownship and intruder state information and a lookahead time, detection logic provides the time interval of a **well-clear violation***.
- Logic assumes non-maneuvering trajectories for both aircraft.



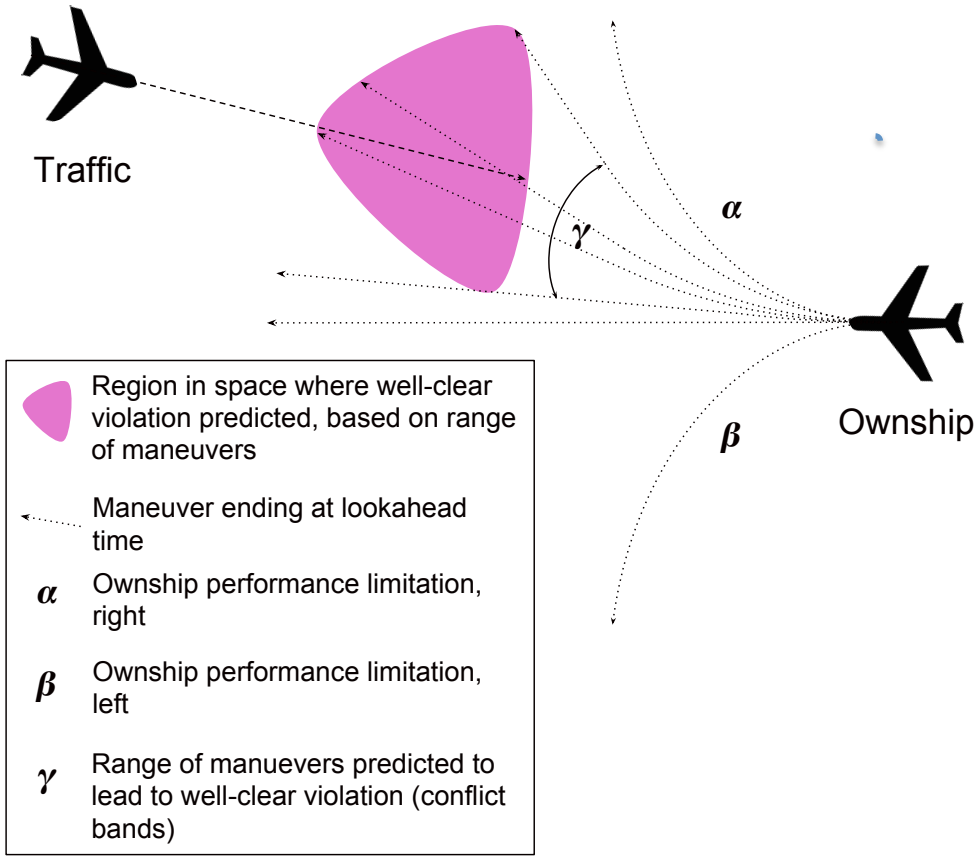
(*) RTCA now refers to it as “loss of well clear” LoWC

Determine Processing Logic

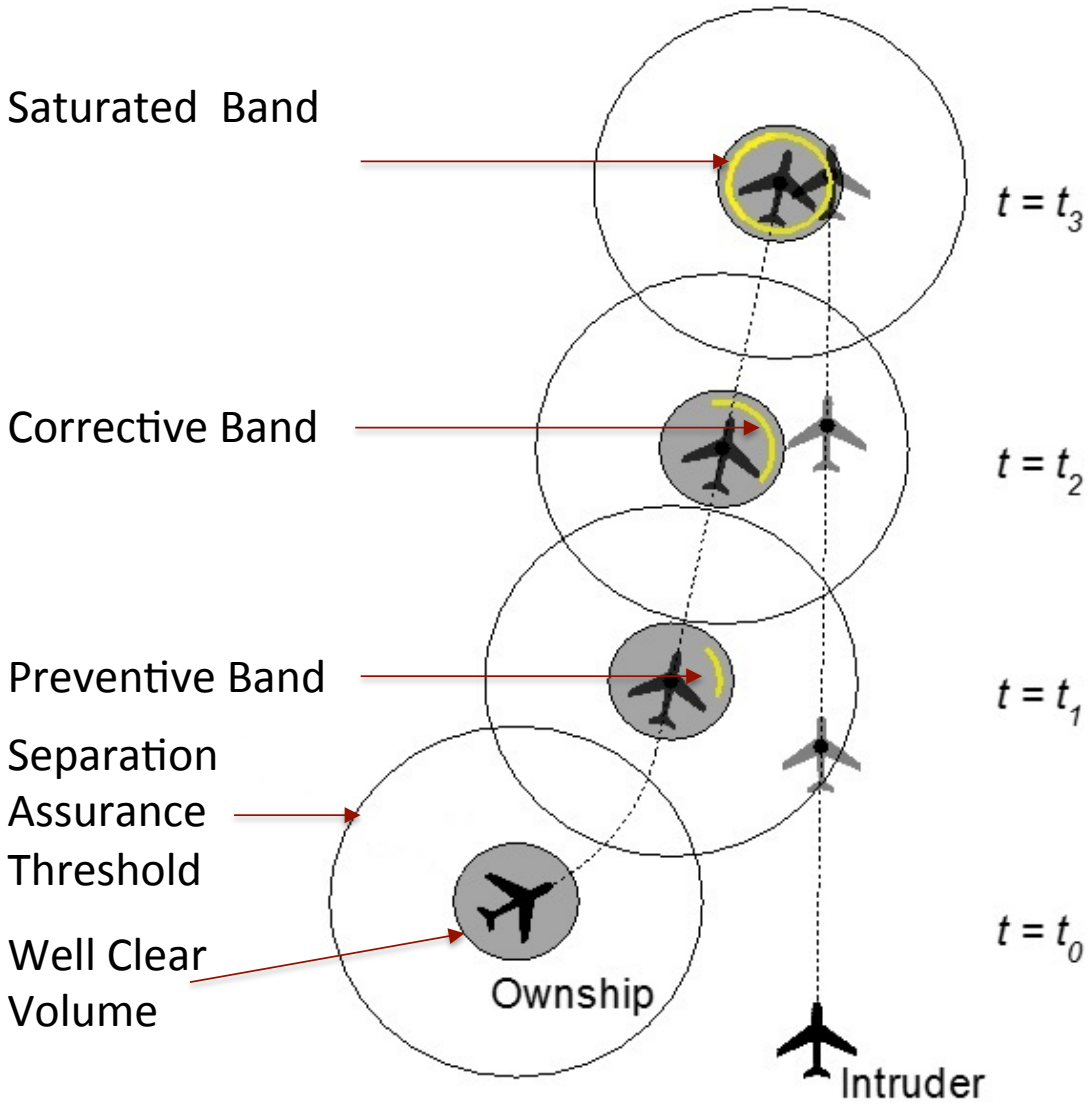
- Determine processing logic provides maneuver guidance to remote pilots.
- Ownship state is projected assuming constant acceleration and constant turn rate.
- Intruder state is projected assuming constant velocity.
- Maneuver guidance can be:
  - **Corrective**: Well-clear will be lost if the ownship does not maneuver.
  - **Preventive**: Well-clear will be lost if the ownship maneuvers into a bands.

Separation Assurance Bands

- Maneuver guidance is provided in the form of **separation assurance of bands**, i.e., ranges of track, ground speed, vertical speed, and altitude that lead to loss of well clear.



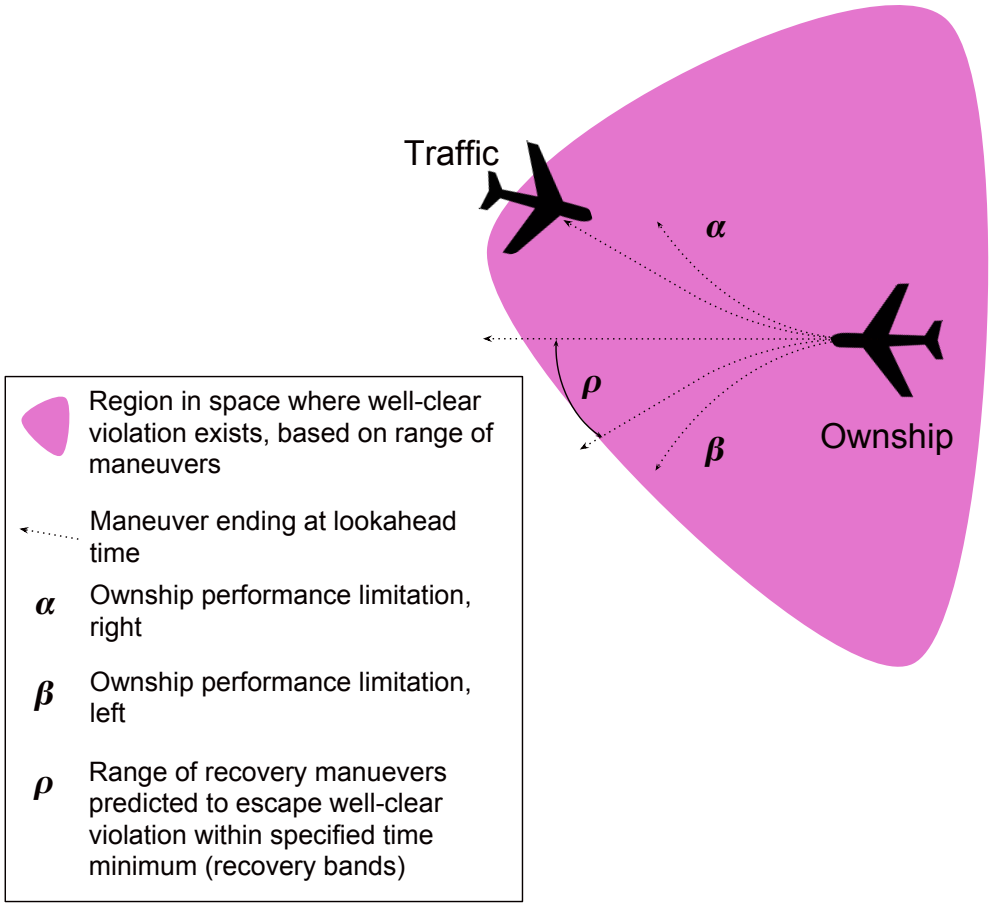
Bands Progression*



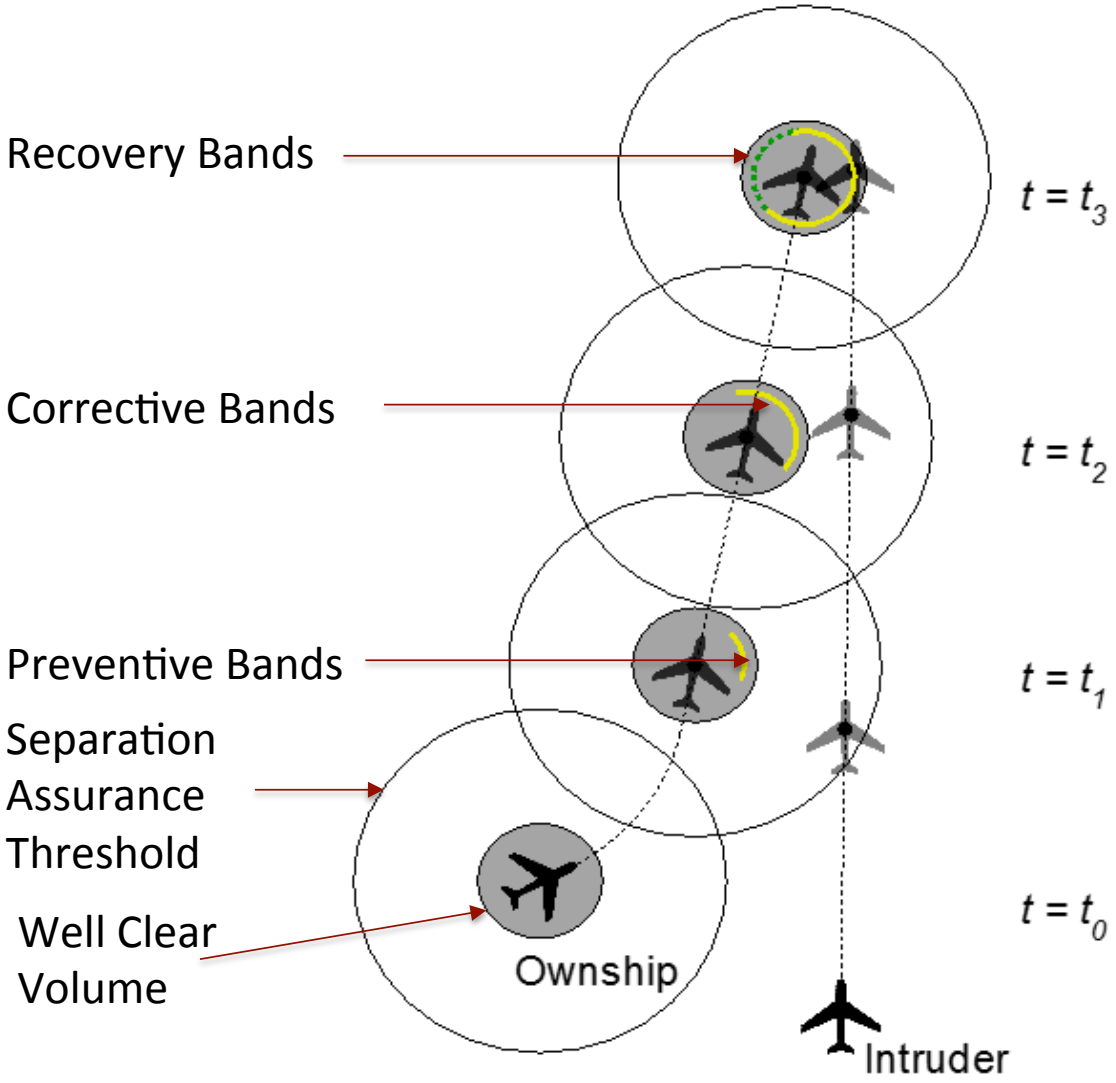
(*) Notional figure. Separation assurance and well-clear boundaries are not circular.

Recovery Bands

- **Recovery bands** are ranges of track, ground speed, and vertical speed that lead to regaining well-clear status when a well-clear violation has already happened or is unavoidable.



Preventive, Corrective, and Recovery Bands*



(*) Notional figure. Separation assurance and well-clear boundaries are not circular.

Alerting Logic

- Given ownship and intruder state information, alerting logic computes a numerical alert level indicating severity of potential loss of well clear.
- Alert level is based on predicted loss of well-clear with respect to well-clear violation volumes of different size.
- The smaller the volume the greater the alert level.

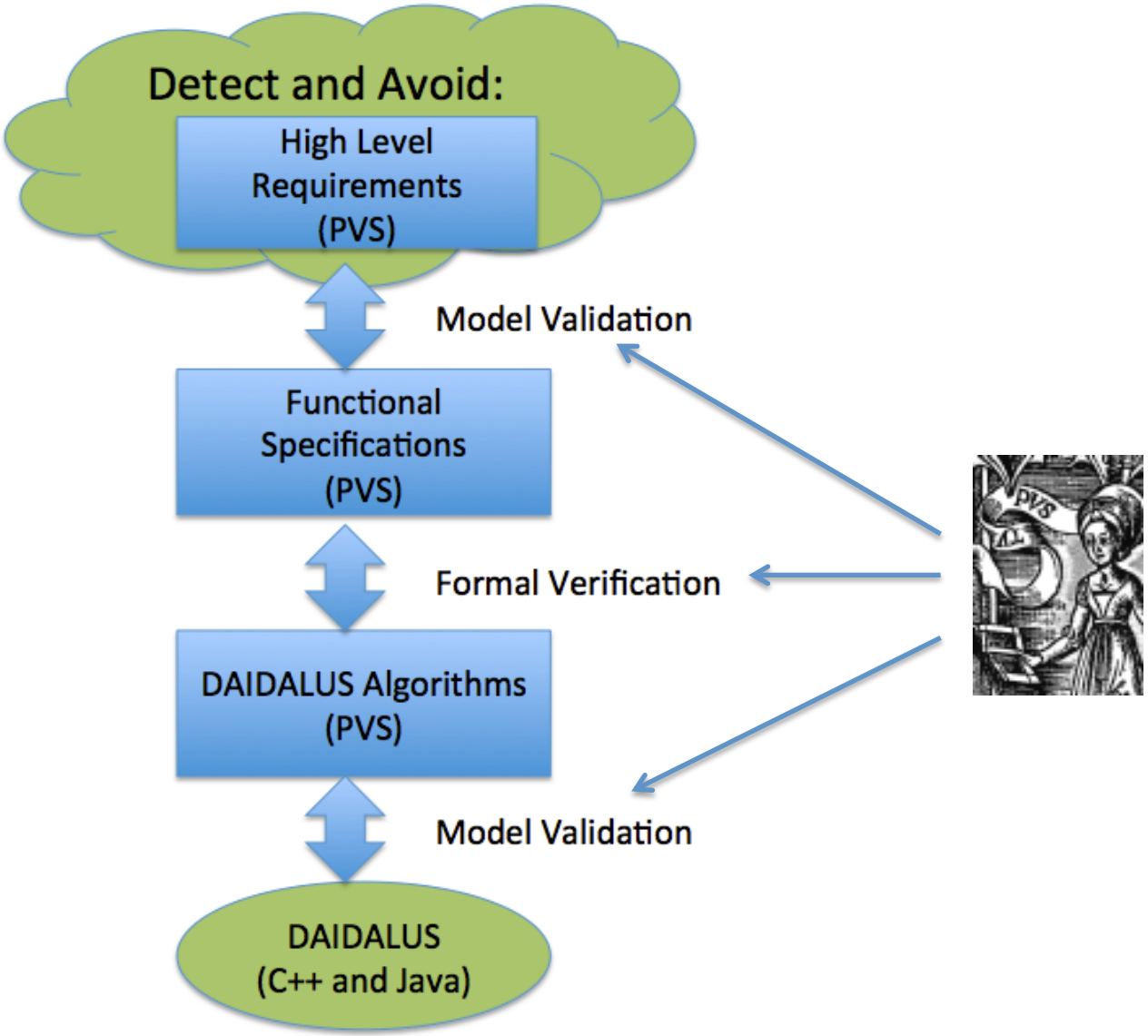
Prototype Implementations

- DAIDALUS core algorithms have been implemented as an Application Programming Interface (API) library in Java and C++.
- Highly configurable interface:
  - Aircraft performance limits (acceleration, turn rate, etc.)
  - Wind information (simple wind-field model)
  - Threshold values
- Code is released under NASA Open Source Agreement (Invention Disclosures LAR-17785-1, LAR-17878-1, LAR-18464-1): http://github.com/nasa/wellclear.

Formal Verification in PVS

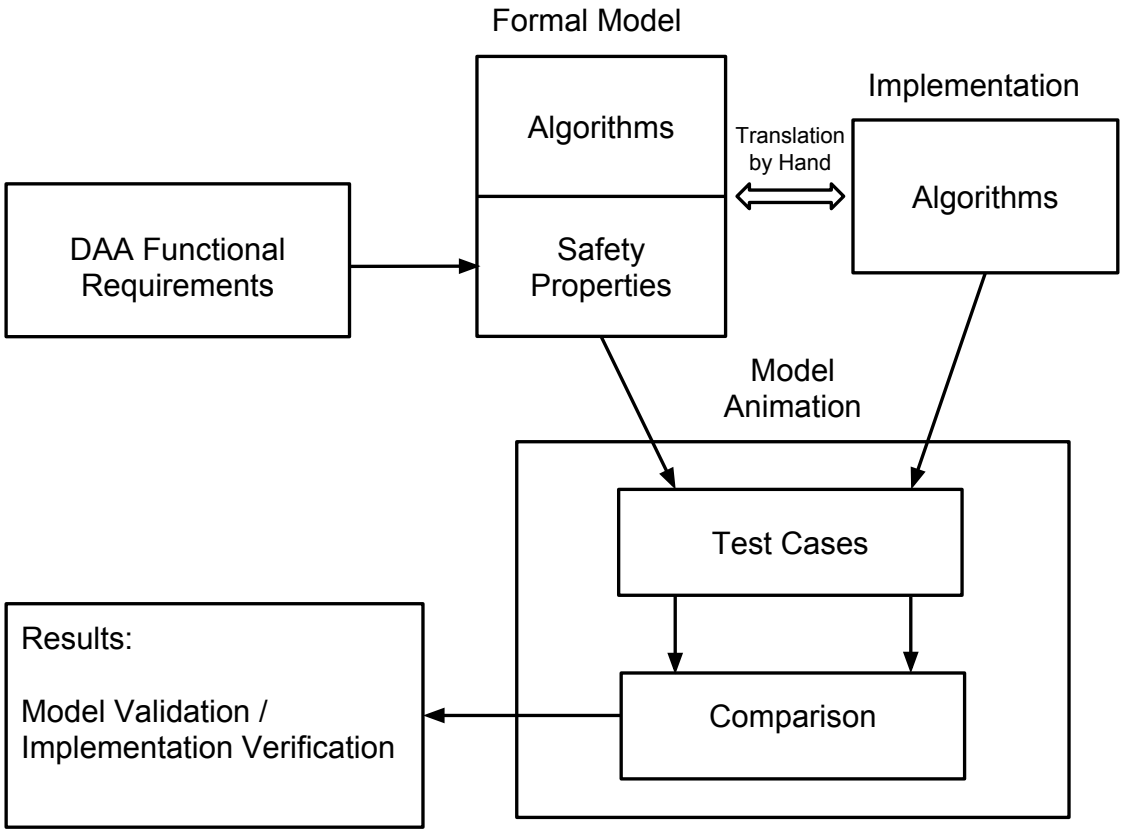
- Well-clear concept and DAIDALUS core algorithms have been formally specified and verified for functional correctness in the *Prototype Verification System* (PVS) (http://github.com/nasa/pvslib).
- PVS is both a specification language and an interactive theorem prover developed by SRI International (http://pvs.csl.sri.com).

Validation and Verification

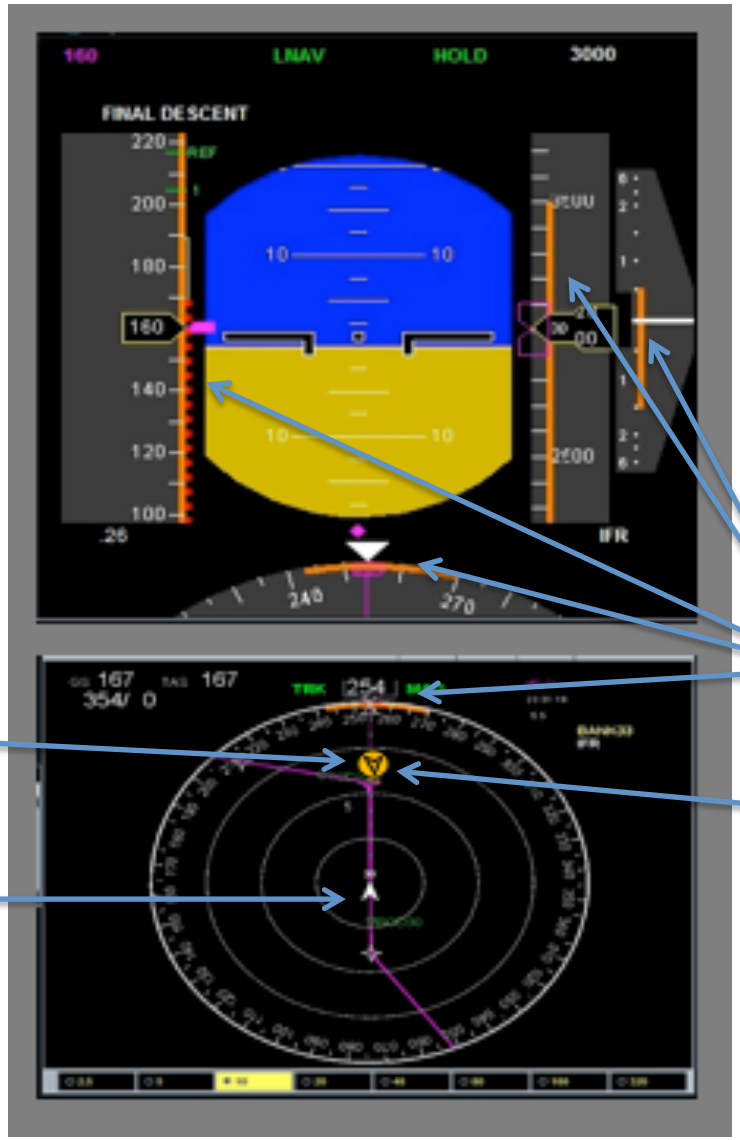


Model-Based Validation

- Prototype implementations (Java, C++) have been validated against formal models (PVS) using stressing case scenarios.



Multi Aircraft Control System (MACS)



Future Work and Activities

- Validation and verification of DAIDALUS with respect to Minimum Operational Requirements being defined by RTCA SC-222.
- Mitigation of sensor uncertainty and communication delay.
- Research on recovery bands and interoperability with collision avoidance systems, e.g., TCAS II, ACASX.
- Extension to small UAS:
  - Autonomous guidance.
  - Obstacle detection and resolution.
  - Geofencing and geographic containment.

Concluding Remarks

- DAIDALUS is a reference implementation of NASA's detect and avoid concept for the integration of UAS into the NAS.
- DAIDALUS is being considered as the DAA reference implementation in Appendix "G" of the MOPS for UAS developed by RTCA SC 228.
- DAIDALUS has been integrated into NASA's Multi Aircraft Control System (MACS) and is currently used in human-in-the-loop experiments at NASA.
- DAIDALUS has been used in flight tests providing maneuver guidance to the NASA owned Ikhana UA pilots.
- DAIDALUS is currently being used by the FAA Tech Center in a human factors DAA study.

Concluding Remarks (Cont.)

- Foundational work informed the Sense and Avoid Science Research Panel (SARP) during the definition of the Well-Clear concept.
- Mathematical framework has been used in the development of SAA concept by General Atomics Aeronautical Systems (GA-ASI).
- Published algorithms have been used by NASA Ames to implement their own DAA software (JADEM).

Team Composition

- Skill Mix:
  - Air Traffic Management
  - Aviation Operation
  - Flight Operations
  - Physical & Systems Modeling
  - Algorithm Development
  - Formal Verification
  - Software Engineering
- Workforce:
  - SCASB - D320: ~2.0 FTE (George Hagen, César Muñoz, Jason Upchurch, Aaron Dutle, Anthony Narkawicz)
  - CSAOB - D318: ~1.0 FTE (María Consiglio), ~1.0 WYE (James Chamberlain)

Questions?

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