STEReO/SAFE50 : Advanced Airborne Autonomy For Urban Operations

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Goals

• Enable High-Density Low-Altitude UTM Operations over Densely-Populated Urban Environments through Advanced Vehicle Autonomy
• Vary the vehicle and autonomy
• Assumes today’s technology and infrastructure (fix everything else)
• Evolve the UTM TCL 4 framework as necessary to meet derived requirements

Technical Objectives

• SAFE50 Reference Design Study
• Reference Architectures
• Flight and Simulation Experimentation
  • Feasibility, Characterization, Requirements Derivation, and Validation
SAFE50 ConOps

Use case 1: point-to-point

Store (Operator)
Take-off
Climb out

Cruise

Emergency Landing

Park

Pull-outs

Use case 2: Emergency (High-priority Flight)

Fire dept.

Approach
Descent
Landing

Theater (customer)

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Requirements for Autonomous Operations

Environment Challenges

Atmospheric Uncertainty

Failures and Contingencies

Ground Operators and UTM System

C3 and Surveillance Requirements

Do not interfere

Manned Aircraft

Input:
High-Level Mission Goal and Constraints

Detect and Operate-Near

Detect, Operate-Near, and Avoid-Endangering DGOs

Hazard Footprint Awareness, Risk Minimization/Avoidance, Health Monitoring

Static Ground Objects

Dynamic Ground Objects

Other Aircraft

UAS

Detect and Operate-Near

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SAFE50 Reference Autonomy System - Conceptual View

Input:
High-Level Mission Goal and Constraints

SAFE50 Vehicle Autonomy System
(Vehicle Agnostic)

- High-Level Planner (Mission Planning and Decision Making)
- Path/Trajectory Planning
- Sensor Processing Modules
  - Navigation Modules (SLAM, INS, ADHRS, Filters/Fusion, etc.)
  - Environment Processing Modules (Mapping, Object Detection/Tracking, etc.)
  - IVHM Modules

Execution and Communication Layer

- Actuation and Propulsion Systems
- Flight Displays and User Interfaces
- Communication Systems (LOS, ELOS/OTH, V2V, etc.)
- Flight Management System (FMS)
- Low-Level Flight Control System (FCS) (Inner-Loops, Platform Specific)
- High-Level Flight Control System (FCS) (Outer-Loop, Platform Agnostic)

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Reflection Simulation Architecture

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Reference Design Vehicles and Payloads

SAFE50 Gen-2.5 Autonomy Avionics Payload

Gen-2 on SAFE50 Multicopter

SAFE50 Vehicles (top)
SAFE50 Gen-1 Vehicle System (bottom)
GPS-Free Navigation and Mapping in Constrained Spaces

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Power Line Identification and Reconstruction through ML/AI - Flight Test Verification Results
Raw LiDAR point clouds (left), voxel processing (middle), reconstructed powerlines at 75m (right).
Real-Time Constrained Trajectory Optimization – Low-Level Planner

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Real-Time Constrained Trajectory Optimization – High-Level Planner

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Real-Time Constrained Trajectory Optimization – Volume Conformance

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Questions?
Flight Tests

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Goal

• Enable High-Density Low-Altitude UTM Operations over Densely-Populated Urban Environments through Advanced Vehicle Autonomy

Technical Objectives

• SAFE50 Reference Design Study
  o Comprehensive system-wide design study for autonomous UAS operations (from UTM down to vehicle subsystem level)
  o Design for future generation vehicles and avionics (vary the vehicle system)
  o Assumes today’s technology and infrastructure (fix everything else)
  o Extend UTM TCL-4 framework as necessary to meet requirements and achieve objectives

• SAFE50 Reference Architectures (Vehicle, Avionics, and Flight Autonomy)
  o Software Implementation and Flight Hardware Prototypes

• Feasibility and Validation
  • Modeling and Simulation
  • Simulation and flight test experimental validation
Safely Enabling Routine High-Density Low-Altitude UAS Operations over Densely-Populated Urban Environments

- Unmanned Aircraft Systems (UAS) Traffic Management (UTM) project seeks to advance concepts towards higher-density operations over densely-populated areas.
- UAM and UTM industry partners are actively seeking access to this space.
- Anticipated high-demand market with significant economic growth potential.
- Non-trivial shift from UTM TCL 4 to high-density urban UAS operations.
Challenges for High-Density Urban Flight Operations

- Flight over people, property, and critical urban infrastructure
- Highly constrained spaces within urban canyons
- Operations almost entirely beyond visual and communication line-of-site
- Concurrent operations in high-density air traffic
- Mission designs drive towards larger more-capable vehicles in higher risk categories
- Cluttered and challenging RF environment and GPS degraded/denied
- Urban environment is unpredictable and dynamic
- Complex hazardous atmospheric conditions that are poorly understood
- Many stakeholders with competing needs and desires
Enabling Safe Autonomous UAS Urban Operations

Gaps

Concepts and Standards Gap
- Lack of guidance for FAA rulemaking
- Disparate technologies, assumptions, capabilities
- Lack of industry standards and requirements
- No clear certification path

Knowledge Gap
- Lack of validated system-wide studies
- Poor understanding of vehicle behavior and environmental conditions

Technology Gap
- Current industry platforms in state-of-the-art lack functionality, performance, capabilities and robustness
- Gap between academic research and industry
- Low-TRL research literature technologies for this application

Approach

Perform systems-wide studies to show path towards urban access for UTM through onboard autonomy.

Identify gaps and advance the state of the art in fundamental understanding.

Develop feasible validated reference architectures for advanced vehicles.

Technical Objectives (Vehicle Autonomy Focus)

Conduct system-wide/systems-level reference design study.

Develop high-fidelity environment models. Develop validated flight dynamics models from wind-tunnel experimental data.

Develop and validate SAFE50 reference design vehicle and autonomy architectures.

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SAFE50 Design Process

Concept of Operations (Con-Ops) → Scenarios and Use Cases: Nominal, Off-Nominal, Contingency Requirements → Stakeholder Needs and Desires → Reference Design Architectures → Requirements Architecture

- Functional Decomposition Architecture
  - Flight Phases
  - FFBD
  - Functional Requirements

- Physical Decomposition Architecture
  - UTM Arch.
  - H/W Arch.
  - Autonomy Architecture
  - S/W Arch.

Reference Design Study
- Functional Requirements
- Performance Requirements
- Equipage Requirements
- KPPs & MPPs
- Risks/Hazards Analysis

- Verification and Validation

Research Focus
- Vehicle/Avionics Design
- Flight H/W Prototypes
- Flight Software
- Analysis & Publications
- Experiment Data

Validated Deliverables
- Scenarios and Use Cases: Nominal, Off-Nominal, Contingency Requirements
- Reference Design Architectures
- Reference Vehicle Architecture
- Reference Avionics Architecture
- Reference Autonomy Flight S/W Architecture
- Simulation
  - Standalone
  - HILS
  - Batch
  - AOL Intgrn.