Autonomous Flight: Challenges and the Path Ahead

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A Brief History of Powered Flight

• 1903: The Wright Brothers flew at Kitty Hawk.
  – Model aircraft flights prior to Kitty Hawk flight saved their lives.
• Over the next decades, manned aircraft proliferated for passenger/cargo transport, defense, and recreational uses
• The “drone” emerged in defense applications to provide target practice and deliver munitions.
• A low-key model aircraft community grew alongside the manned aviation community, most commonly for hobby, education, and research applications
• Commercial Transport Flight Management Systems offer aviators and passengers a wealth of displays to augment autopilot and triply-redundant hardware.
• The modern UAS (Unmanned Aircraft System) has capitalized on Aerospace, power systems, sensing, and computing advances
• Regulators struggle to keep pace
Who Flies in the 21st Century?

• Passengers on “Tin Cans with Wings”
• Cargo on similar planes (FedEx, etc.)
• Manned Military Aircraft
  – Modern fighters have more autonomy than commercial transport and most UAS...
• General and Business Aviation
  – Equipage ranges from no radios and VFR only to full IFR-certified glass cockpits
  – Velcro’ed tablets are increasingly popular
• Unmanned Military UAS (small to large)
• Civil UAS (mostly small)
  – ALREADY THE DOMINANT 21st CENTURY CATEGORY BY NUMBER OF PLATFORMS
Autonomy + Flight: Part I

- Passenger Transport
  - FMS were designed to assist pilots
  - Passengers trust pilots more than autonomy
  - Economic, psychology concerns are dominant

- Cargo Transport
  - Economics: Use passenger transport designs
  - Integration: Must share airspace and airports with passenger transport

- Military Manned Aircraft
  - Unclear “next-generation” fighter will be manned
  - Legacy platform upgrades may involve “robot pilots” (DARPA ALIAS)

- Military Unmanned Aircraft
  - Air Force: RPAS (remotely piloted aircraft system)
  - Others: RPAS plus Autonomous (small) UAS
Autonomy + Flight: Part II

- **General Aviation**
  - Flight for fun and training: Pilots want to retain the ability to manually fly
  - Personal Air Vehicles (PAV): Non-pilots fly point-to-point -- pilotless planes would be welcome
  - Pilots can’t afford certified avionics but are increasingly “velcroing” tablets to their controls

- **Civil UAS**
  - High-altitude persistent flight: Autonomy is essential
  - Low-altitude delivery / surveillance:
    - Low-integrity UAS OK for LOS (line of sight) flight over unpopulated areas
    - High-integrity UAS (link + onboard intelligence) essential for urban applications and flight in mixed-use airspace
Autonomous Flight Research (Atkins)

• Emergency (Adaptive) Flight Planning
  - Automation to select a reachable nearby landing site and build a landing flight plan
  - Nominal, loss-of-thrust, control surface jam, structural damage cases studied

• Envelope-Aware Flight Management
  - Automatically override crew/automation when LOC (loss of control) is imminent

• Small UAS Risk Analysis → High-integrity Geofencing for Small UAS
  - Trigger, Guidance, Navigation, Control
  - Options: Integrated in autopilot, add-on
  - Focus: Resilience to tampering
    - GPS denial, data entry error, failures/faults
Autonomous Flight: Technology / Community Needs

• **Certification and Licensing:**
  – The FARs (Federal Aviation Regulations) are out of date and hard to change.
  – Modern systems engineering and certification (V&V) need to be linked to actual safety and risk not legacy regulations \( \rightarrow \) Formal methods to specify/update regs?
  – Complex, adaptive autonomy can be “licensed” like human pilots to end the stalemate \( \rightarrow \) Build/test sequences to license UAS autonomy?

• **Metrics:**
  – Safety: How do we assess & assure safety given UAS flying over populated areas and in shared airspace?
  – Economics: How do we trade access to airspace for UAS v. manned operations, and how do UAS negotiate low-altitude airspace access?

• **Complex, Adaptive Systems:**
  – We can deploy automation that knows the rules and how to fly.
  – How do we assure the system-of-systems is correct and complete even to expected situations?
  – We cannot guarantee the autonomous aircraft will be safe – we also cannot guarantee this for a piloted aircraft – collaborative assessment of “which solution will work best” is essential.
“Autonomy” in Aviation

AMY PRITCHETT
GEORGIA TECH
FEBRUARY 16, 2016
Moving from Capability to Safety

Machine capabilities have improved marvelously! Can operate:

- In predictable conditions
- With a codified definition of task
- Acting alone

The challenge is in moving to safety…

- The ability to respond to the unpredicted
- The ability to ignore procedures or adapt the task
- The ability to interact with the other agents in the system in flexible ways, redefining communication and negotiation protocols as necessary

When Tesla owners activate their car's new autopilot feature, a warning appears in a small box at the bottom of the dashboard:

Always keep your hands on the wheel. Be prepared to take over at any time.

The biggest challenge driving the Tesla was remembering what Autopilot can and cannot do.

Yes, it can follow traffic and handle almost any situation—except for Washington's many traffic circles, which consistently threw it for a loop... But Autopilot doesn't obey stop signs or traffic lights... several times I had to stop the car blowing through a red light.

Autopilot also highlighted just how stubbornly rules-based driverless cars will be... They follow the rules. They are not like human drivers at all.
Aviation Can’t Allow for Single-Point Failures

Fumbling for his recline button, Ted unwittingly instigates a disaster.
Humans Capture More Failures Than They Cause

Accidents Tend to Involve Breakdowns in Communication and Coordination

The Turing Test for Aviation

What would one aviation agent expect from another?

- Ability to do a task
- Ability to report when it can’t do a task
- Ability to flex the task structure to achieve desired ends
- Ability to adapt its goals to the situation
- Ability to communicate and coordinate in manner that makes sense to other agent
- Ability to ignore other agent when necessary
- Ability to recognize and use interdependencies in inter-agent activities
- Ability to operate at many levels of abstraction simultaneously
Autonomy in UAS Traffic Management

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February 16 2016
Air traffic in Oakland Center

- Safety critical: 1000 ft, 5 nmi separation
- Standard corridors of well-travelled routes

[NASA ETMS, FACET]
Controller must keep aircraft separated

- Small set of control actions
- Infrequent deviations from nominal
- Grouping by potential conflict
Growing numbers of UAV applications

1. Safety
2. Simplicity
3. Ability to adapt to new information

[NASA]
- Collision avoidance system
- Forced landing system
Example: Platooning UAVs
Example: Platooning UAVs

Free:
- Vehicle not in a platoon or on a highway

Leader
- Leader of platoon

Merge onto highway

Follow highway

Create new platoon

Merge with platoon in front

Join platoon

Leave highway

Follower
- Member of platoon

Follow platoon

Faulty
- Descends after a duration of $t_{\text{internal}}$
Merging onto highway and joining platoon

Red vehicle merges onto highway

Blue vehicle joins red vehicle’s platoon
Merging onto highway and joining platoon

4 vehicles join platoon following red vehicle
Platoon responding to intruder (red vehicle)

Reachable sets for blue vehicle are shown

Blue vehicle must stay outside of all dotted boundaries
Mykel J. Kochenderfer
Stanford
TCAS
TCAS

COUNTERDOWN TO NEAREST APPROACH 46 SECONDS

Traffic... Traffic
TCAS

COUNTERDOWN TO NEAREST APPROACH 33 SECONDS

Climb... Climb
PROCESS Reversal modeling:

- Default modeled separation for current RA is 0 if current RA is negative;
- Set own altitude and own rate to own tracked altitude and own tracked rate.

IF (own does not follow his RA):

THEN Model separation achieved assuming RA not followed;
- IF (current RA is a climb RA)
  THEN CLEAR flag indicating the sense of the RA after a reversal;
- ELSE SET flag indicating the sense of the RA after a reversal;
- IF (modeled separation achieved by continuing current RA greater than 1.2 * P.CROSSTHR)
  THEN CLEAR reversal flag in ITF;
ELSE
- Begin own is assumed to follow its RA:
  IF (current RA is positive)
    THEN model response to current RA;
    - model maximum displayable rate for climb if current rate exceeds
      maximum displayable rate or minimum displayable rate for descent if
      current rate is less than minimum displayable rate;
    IF (tracked response lags modeled response in RA direction AND
      own's rate has not changed by more than P.MODEL.ZD since the
      RA was first issued)
      THEN set own altitude and own rate to modeled altitude and rate
      for use in reversal modeling;
- Model separation achieved by continuing current RA:
  Set delay time to greater of pilot delay time remaining for last advisory against a
  new threat, and the pilot quick reaction time;

IF (considering a reversal from a descend RA to a climb RA):

THEN set own goal rate to greater of own tracked rate (or maximum
  displayable rate, whichever is less) and nominal climb rate;
ELSE IF (own too close to ground to descend)
  THEN set own goal rate to zero;
ELSE set own goal rate to lesser of own tracked rate (or minimum
  displayable rate, whichever is greater) and nominal descent rate;

IF (vertical chase, low VMD geometry was not the reason for considering
  reversal)

THEN IF (inbound causing crossing OR (inbound level AND own crossing
  from above) OR inbound rate and own modeled rate are opposite in sign)
  THEN use outer rate bound to model inbound;
ELSE use inner rate bound to model inbound;
ELSE use inbound is tracked vertical rate to model inbound;
\[ \text{CALL MODEL SEP} \]
IN (delay, goal rate, own altitude, own rate, acceleration response, sense after
  reversal, inbound altitude, modeled inbound rate, ITF entry)
OUT (predicted separation for sense reversal);

IF (Predicted separation for sense reversal is not positive OR
  modeled separation achieved by continuing current RA GE G.ALM)

THEN CLEAR (reversal flag in ITF);

END own is assumed to follow its RA:

END Reversal modeling;

RESOLUTION HIGH-LEVEL LOGIC

6-P22

RTCA DO-185B Volume 1 (1799 pages)
# Building Trust in AI for Aviation

## Airspace Encounter Models
- Generate many encounters representative of airspace

## Recorded Radar Tracks
- Recorded radar tracks with known TCAS intervention

## Formal Methods
- Apply hybrid system theorem provers to approximate models

## Stress Testing

## Scenario Specific Mini-Models
- Exhaustive variations of certain classes of encounters
- Focused models constructed from expert knowledge and data

## Most Likely Failure Condition
- Use black box sampling to find most likely failure
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Unmanned Aircraft System Traffic Management (UTM)