NASA/TM–20260009166



An SI-Powered Air Traffic Awareness Assistant for Non-towered Airports

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Acknowledgments

The authors would like to acknowledge and extend their sincere gratitude to the mentors of this project, Dr. Vishwanath Bulusu and Steven D. Beard, for providing their invaluable time, guidance, and support throughout this project.

The authors would also like to thank the organizers of this Concept Design Experience, Divya Bhadoria, Shannon Zelinski, and the NASA Ames Research Center (ARC) Aviation Systems Division team.

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Abstract

Air traffic volumes have steadily increased over the past several decades and are projected to accelerate with the rise of emerging technologies such as Unmanned Aerial Vehicles (UAVs), on-demand air taxis, and autonomous aircraft systems. This growth will increase the density of aircraft operating in shared airspace while placing greater strain on limited air traffic control staff, airport resources, and airspace capacity. Although there are approximately 19,000 airports in the United States and the vast majority are non-towered, much of the modernization effort in air traffic management (ATM) has historically focused on large, towered airports [1]. Unlike controlled airports with air traffic controllers, dedicated infrastructure, and centralized ATM procedures, non-towered airports rely primarily on pilot self-announcements, visual separation, and standard traffic-pattern procedures. The expected growth in aircraft density will also impact non towered airports which don't have infrastructure to support increased traffic. This creates a unique safety challenge because all arriving and departing aircraft must coordinate in a shared traffic environment without tower-based sequencing [2].

This proof-of-concept project proposes SkySensSI, a Super Intelligence (SI) powered advisory system designed to improve traffic awareness, sequencing, and conflict detection at non-towered airports. Using San Martin Airport (E16) in California as a case study, the proposed system combines Common Traffic Advisory Frequency (CTAF) communications, Automatic Dependent Surveillance-Broadcast (ADS-B) aircraft position data, predicted flight paths, traffic-pattern rules, and runway geometry to identify potential conflicts, sequence arriving aircraft, and provide real-time advisory messages over CTAF. The goal of this system is not to replace pilot authority or create a virtual control tower [3], but to provide lightweight decision support that improves situational awareness in a decentralized operating environment. Through simulation, this study evaluates how SI, speech recognition, ADS-B data, and finite-state-machine (FSM) logic can be integrated into a scalable advisory framework for future non-towered airport operations.

1. Introduction

Air traffic management (ATM) is one of the most important systems supporting the safety and efficiency of modern aviation. At large commercial airports, aircraft movement is coordinated by air traffic controllers using radar, radio communication, surveillance systems, airport procedures, and increasingly automated decision-support tools. These systems help sequence aircraft, maintain separation, manage runway occupancy, and reduce pilot workload during high-density operations.

However, not all airports operate with this level of infrastructure. Most airports (over 97%) of the 19,000 airports in the United States are non-towered, meaning they do not have an operating air traffic control tower [4]. At these airports, pilots are responsible for coordinating with one another through self-announced radio calls, visual scanning, and standard traffic-pattern procedures. This model works well in many normal general aviation conditions, but it can become challenging when multiple aircraft are arriving, departing, or maneuvering in the traffic pattern at the same time.

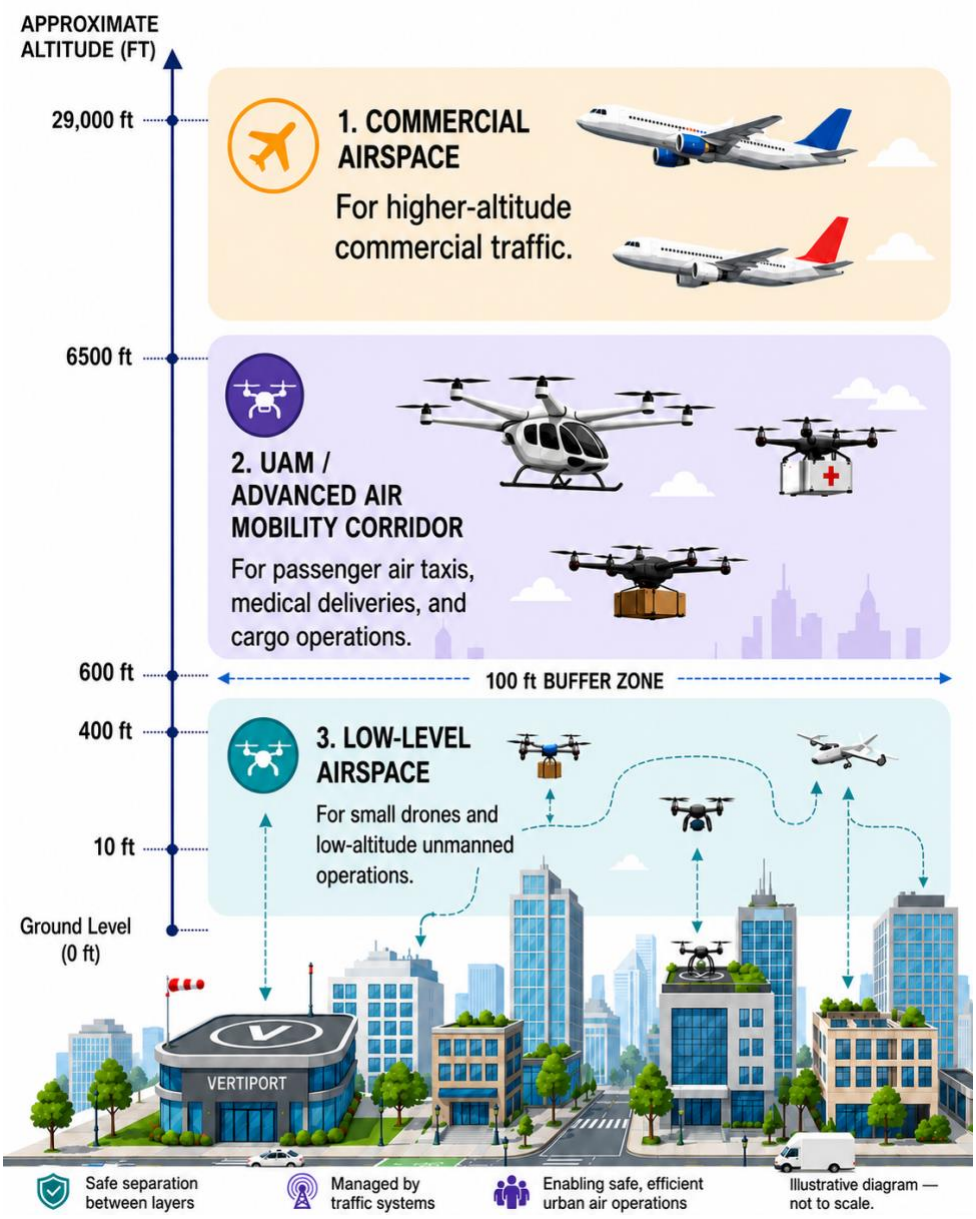


Fig 1: General low-altitude airspace management

The growth of emerging aviation technologies makes this challenge more important. As depicted in Fig. 1, Unmanned Aerial Vehicles (UAVs), electric vertical takeoff and landing aircraft, autonomous systems, and on-demand air mobility concepts may introduce new types of traffic into airspace that was originally designed for traditional aircraft operations. While large airports often receive the most attention in modernization efforts [4], smaller general aviation airports may also experience increased operational complexity. This creates a need for tools that can improve safety and awareness without requiring the cost, staffing, or infrastructure of a full control tower.

1.1 Problem Statement: Air Traffic in Towered vs. Non-towered Airports

Towered airports and non-towered airports differ mainly in how traffic is coordinated. At towered airports, air traffic controllers issue instructions and clearances. They manage runway use, sequence arrivals and departures, provide traffic advisories, and coordinate aircraft movement on the ground. Pilots still maintain responsibility for safe aircraft operation, but Air Traffic Control (ATC) provides centralized direction.

At non-towered airports [5], there is no active tower controller. Pilots self-announce their positions and intentions on a Common Traffic Advisory Frequency (CTAF), visually identify nearby traffic, and coordinate sequencing without direct instructions from an air traffic controller.

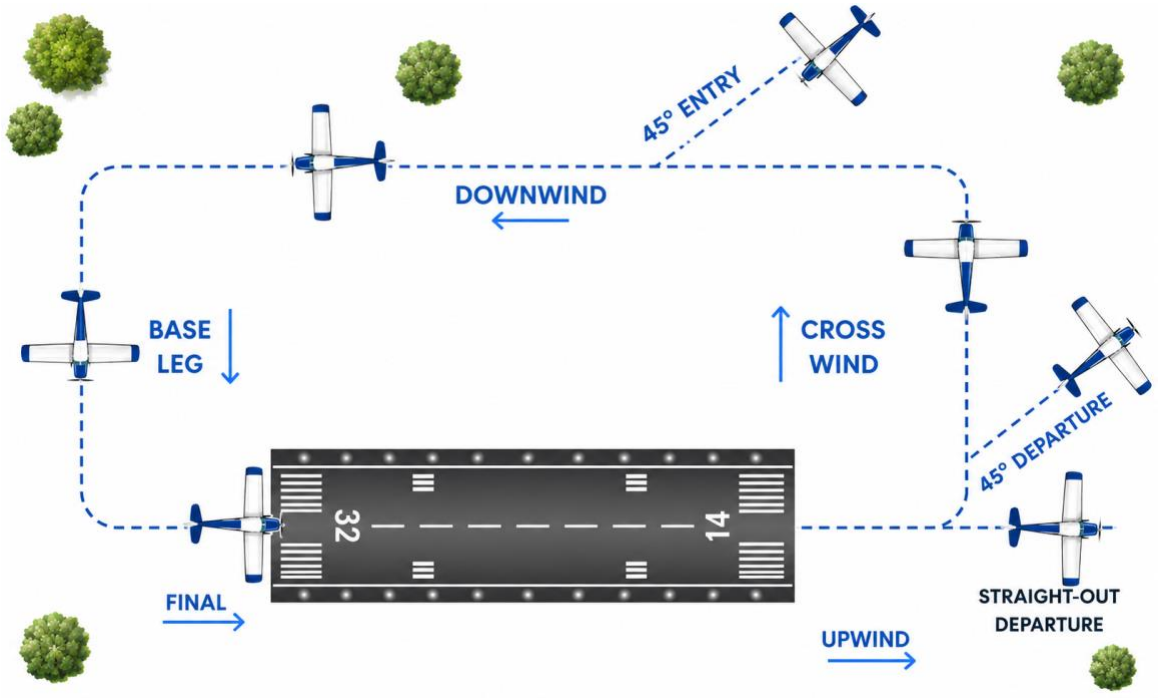


Fig 2. Traffic Patterns at Non-towered airports

Most traffic patterns at non-towered airports such as San Martin Airport are flown with left turns as depicted in Fig 2, which helps standardize procedures and improve cockpit visibility. Aircraft may also enter the traffic pattern from different directions, perform takeoffs and landings on the same runway, or operate at different speeds.

The pilots decide when to enter the pattern, land, depart, cross a runway, or taxi onto a runway based on visual information, radio calls, and standard procedures. This makes pilot situational awareness especially important. This creates a decentralized traffic environment where each pilot must independently build a mental picture of nearby aircraft. When radio calls are missed, unclear, stepped on, or incomplete, pilots may not have the full information needed to assess traffic conflicts.

Without centralized sequencing, there is a risk of close spacing on downwind, base, or final, as well as runway conflicts between landing and departing aircraft. This creates a need for an

advisory system that can combine communication and surveillance inputs, track aircraft arrival/departure phases, and provide timely alerts while preserving pilot authority.

2. Proposed Solution - SkySensSI

The purpose of this study is to explore how a Super Intelligence (SI) advisory system could improve traffic awareness, sequencing, and conflict detection at non-towered general aviation airports. This paper describes, and tests in simulation, a lightweight SI-powered advisory system that we named SkySensSI. Using San Martin Airport as a representative case study, the paper evaluates how pilot radio communications, ADS-B position data, aircraft arrival/departure phase tracking, and traffic-pattern rules can be combined into a real-time advisory framework. Instead of issuing clearances or controlling aircraft, the system would provide advisory information to help pilots build a clearer traffic picture.

The system transcribes radio calls and uses natural-language processing to identify key details, including the aircraft callsign, runway, reported traffic-pattern position, and combines them with aircraft altitude, speed, heading, and location. It then determines each aircraft flight phase using a finite-state machine (FSM) logic that represents common phases of airport operations, such as taxiing, holding short, entering the runway, departing, flying downwind, turning base, approaching final, and clearing the runway.

2.1 Communication and Surveillance Technologies

SkySensSI will utilize existing CTAF and ADS-B data, which are currently available today, as the inputs into the algorithm that will output advisory information to the pilot.

2.1.1 Common Traffic Advisory Frequency (CTAF)

The CTAF is the shared radio frequency and the primary communication tool pilots use at many non-towered airports. Pilots use CTAF to announce who they are, where they are, and what they intend to do. Common calls include inbound, entering downwind, turning base, turning final, taking the runway, departing, and clear of runway (see Table 1). The format of standard radio calls at a non-towered airport, as per Federal Aviation Administration (FAA) guidelines [6], is as follows:

"[Airport Name] traffic, [Tail Number], {INFO} [Number, Airport Name] traffic."

FAA explicitly states to avoid using phrases like “Any traffic in the area, please advise” as it is not a recognized self-announce position or intention [5].

Table 1. Common CTAF phraseology

Flt Phase	Common CTAF Phraseology [7]	Purpose
Initial inbound call	“San Martin traffic, Cessna 3AN, 10 miles west, 2,500 feet, inbound for landing Runway 14, San Martin.”	Announces aircraft identity, position, altitude, runway intent, and direction of arrival.
Entering the pattern	“San Martin traffic, Cessna 3AN, entering left downwind Runway 14, San Martin.”	Informs other pilots that the aircraft is joining the traffic pattern.
Downwind	“San Martin traffic, Cessna 3AN, left downwind Runway 14, San Martin.”	Confirms the aircraft is parallel to the runway in the landing sequence.
Base	“San Martin traffic, Cessna 3AN, turning left base Runway 14, San Martin.”	Announces the turn from downwind toward the final approach.
Final	“San Martin traffic, Cessna 3AN, final Runway 14, San Martin.”	Alerts other pilots that the aircraft is aligned with the runway for landing.
Short final	“San Martin traffic, Cessna 3AN, short final Runway 14, San Martin.”	Signals the aircraft is very close to landing and runway conflicts are urgent.
Clear of runway	“San Martin traffic, Cessna 3AN, clear of Runway 14, San Martin.”	Confirms the runway is no longer occupied after landing.
Taxiing	“San Martin traffic, Cessna 3AN taxiing from ramp to Runway 14, San Martin.”	Announces ground movement toward the runway.
Holding short	“San Martin traffic, Diamond 6SX, holding short Runway 14, San Martin.”	Tells other pilots the aircraft is stopped before entering the runway.
Entering runway	“San Martin traffic, Cessna 3AN, entering Runway 14 for departure, San Martin.”	Announces the aircraft is moving onto the runway.
Departing	“San Martin traffic, Diamond 6SX, departing Runway 14, remaining in the pattern, San Martin.”	Announces takeoff and whether the aircraft will stay in or leave the pattern.

Go-around	“San Martin traffic, Cessna 3AN, going around Runway 14, San Martin.”	Alerts traffic that the aircraft is discontinuing the landing and re-entering the pattern.
Overflying	“San Martin traffic, Cessna 3AN, overflying midfield, 2,500 feet, westbound, San Martin.”	Informs nearby aircraft that the airplane is passing over or near the airport but not landing.

2.1.2 Automatic Dependent Surveillance–Broadcast (ADS-B)

ADS-B [8] is an aviation tracking technology that allows aircraft to continually broadcast their precise location information such as their position, altitude, speed, heading, and identification. Nearby aircraft and ground stations can receive this data, providing a more accurate and continuously updated picture of air traffic around an airport.

ADS-B Out is implemented using onboard aircraft equipment connected to the aircraft’s global positioning system (GPS), transponder, and antennas. In the U.S., ADS-B Out is typically transmitted approximately twice per second, using either a 1090 MHz Extended Squitter (1090ES) transponder or 978 MHz Universal Access Transceiver (UAT), allowing ground stations and other properly equipped aircraft to track the aircraft in real time.

2.3 Safety Challenges in the Traffic Pattern

The traffic pattern is one of the busiest areas at a non-towered airport, where aircraft may arrive, depart, perform touch-and-goes, or enter the pattern using different procedures and at different speeds. Safety risks can arise from overlapping CTAF transmissions, incorrect position reports, conflicting pattern entries, or an aircraft entering the runway while another is on short final. Different aircraft speeds and pilot experience levels can create additional complexity. Pilots primarily manage these situations through CTAF communication, visual scanning, and judgment.

ADS-B can improve situational awareness, but not every aircraft operating near a non-towered airport is required to be ADS-B Out equipped or will appear on a traffic display. The FAA does not mandate ADS-B in Class D and G airports; Therefore, aircraft operating in Class G airports like San Martin are exempt from using ADS-B Out. Because CTAF, visual scanning, and ADS-B each have limitations, non-towered airport operations require disciplined communication and constant attention.

2.4 Super Intelligence in Air Traffic Management

SI has the potential to support air traffic management by helping humans process large amounts of information, identify patterns, predict conflicts, and make faster decisions [9]. SI can be applied to trajectory prediction, traffic flow management, speech recognition, anomaly

detection, scheduling, and decision support. Air traffic management applies SI differently depending on whether a facility is towered or non-towered, and on how safety-critical the function is.

The most relevant SI applications are natural language processing, trajectory prediction, and conflict detection. Natural language processing can help convert CTAF radio calls into structured information such as aircraft callsign, runway, position, and intention. Trajectory prediction can estimate where an aircraft is likely to move next based on its current position and traffic-pattern rules. Conflict detection can compare aircraft arrival/departure phases and predicted paths to identify potential hazards.

2.4.1 SI techniques in Non-Towered Airports

Super intelligence can support non-towered airport operations by helping pilots build a clearer picture of surrounding traffic [10]. Figure 3 illustrates the proposed data flow through the SI techniques used to provide advisories to pilots using the non-towered traffic management system.

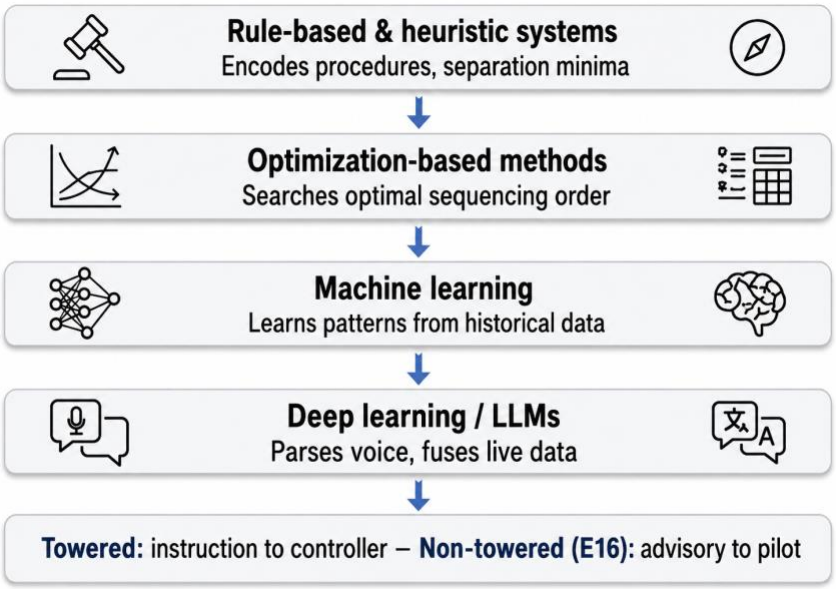


Fig. 3 SI techniques data flow for non-towered traffic management

Rule-based and heuristic methods are useful because they encode known aviation procedures into predictable decision logic. These rules can represent expected pattern behavior, runway occupancy conditions, right-of-way expectations, and conflict-detection thresholds. For example, if one aircraft is on final while another aircraft is entering the same runway, a rule-based module can flag a potential runway conflict.

Optimization-based methods can support arrival sequencing by comparing possible landing orders and selecting a sequence that reduces delay while maintaining safe spacing. At a non-towered airport, this sequence would not be issued as a command. Instead, the system could present it as an advisory to help pilots understand the recommended landing order. This is

especially useful when multiple aircraft are inbound, entering the pattern, or turning base and final at the same time.

Machine learning can help the system predict aircraft movement from ADS-B data, aircraft type, altitude, speed, heading, runway direction, and local traffic-pattern geometry. These predictions can estimate an aircraft's likely time of arrival, expected pattern position, or probability of conflict. At a smaller airport like San Martin Airport, the amount of historical data may be limited, so machine learning must be combined with rule-based logic and conservative safety assumptions rather than used on its own.

Deep learning and large language models are especially useful for interpreting unstructured CTAF communications [10]. Pilot radio calls may vary in wording, clarity, accent, and completeness. A language model can help identify the aircraft callsign, runway, position, and intent from phrases such as "turning base runway 32" or "entering left downwind runway 14." This allows the system to convert spoken pilot reports into structured aircraft arrival/departure phase updates.

The strongest architecture is a layered approach. Speech-to-text first converts CTAF audio into text. A language-processing module extracts the aircraft's intent and position. ADS-B data provides position, speed, altitude, and heading. FSM logic then determines each aircraft's flight phases such as entering the pattern, downwind, base, final, landed rollout, and clear of runway. Finally, rule-based and optimization logic detect conflicts or sequencing issues and generate advisory messages.

Arrival sequencing is one of the most important use cases. The system can estimate each aircraft's arrival timing using position, speed, heading, and pattern phase. It can then compare aircraft spacing and determine whether the current order is safe and efficient. If the system detects a concern, such as two aircraft converging toward final or a runway still occupied by landing traffic, it can generate a CTAF advisory that alerts pilots to the situation.

Conflict detection is another key function. The system can identify aircraft pairs whose predicted paths or timing may create unsafe spacing. It can also detect anomalies, such as an aircraft deviating from the expected pattern leg, approaching the wrong runway direction, failing to report a critical position, or entering the runway while another aircraft is on final. These alerts are intended to improve situational awareness, not replace pilot judgment.

Generative SI can also improve how advisories are communicated. Instead of producing raw data or complex system outputs, the system can generate short, human-readable messages using aviation-style phrasing. For example, the system might state: "Traffic advisory: Cessna Three Alpha November on final runway 14, Diamond Six Sierra X-ray holding short runway 14." Clear advisory language is important because pilots need information that is quick to understand and easy to act on during high-workload phases of flight.

Because aviation is safety-critical, the system should not rely on SI alone to make decisions. The system should use SI for interpretation, prediction, and communication, while using rule-based FSM logic for safety-critical conflict detection. This keeps the system more predictable, explainable, and trustworthy. In this way, the system applies SI as an advisory layer for non-

towered airports: it helps organize traffic information, identify risks, recommend sequencing, and improve situational awareness while leaving final decisions with the pilot.

SI in aviation must be designed carefully. Pilots and controllers need to understand what a system is doing and why it is issuing an alert. A system that produces too many false alerts may be ignored. A system that misses critical conflicts may be unsafe. For this reason, the system uses a structured FSM logic approach rather than relying only on free-form SI output.

2.4.2 Human-SI Trust and Pilot Authority

One challenge with SI-assisted aviation systems is the human-SI trust gap. Pilots may distrust SI-generated advisories, especially if the system produces incorrect or unnecessary alerts. Pilots can also become overly dependent on them and accidentally act on incorrect advice.

The system addresses this by functioning strictly as an advisory tool rather than an air traffic controller command. It provides pilots with additional situational awareness, but the pilot in command retains full authority and responsibility for all operational decisions. Clear, consistent, and explainable alerts are therefore essential for building appropriate trust while keeping the pilot at the center of decision-making.

Pilots will gain trust when the advisories are consistently helpful and accurate. Once trust in advisories is established with the pilots, moving to SI giving commands instead of advisories will be easier for the pilots to accept.

3. System Architecture

SkySensSI is designed as a modular SI advisory system as depicted in Fig 4. The system receives aircraft information from two main sources: CTAF communication and ADS-B aircraft position data. CTAF audio is processed through a Speech-To-Text system that converts pilot radio calls into text. The text is then processed to extract structured aviation information, including aircraft callsign, position, runway, and intention.

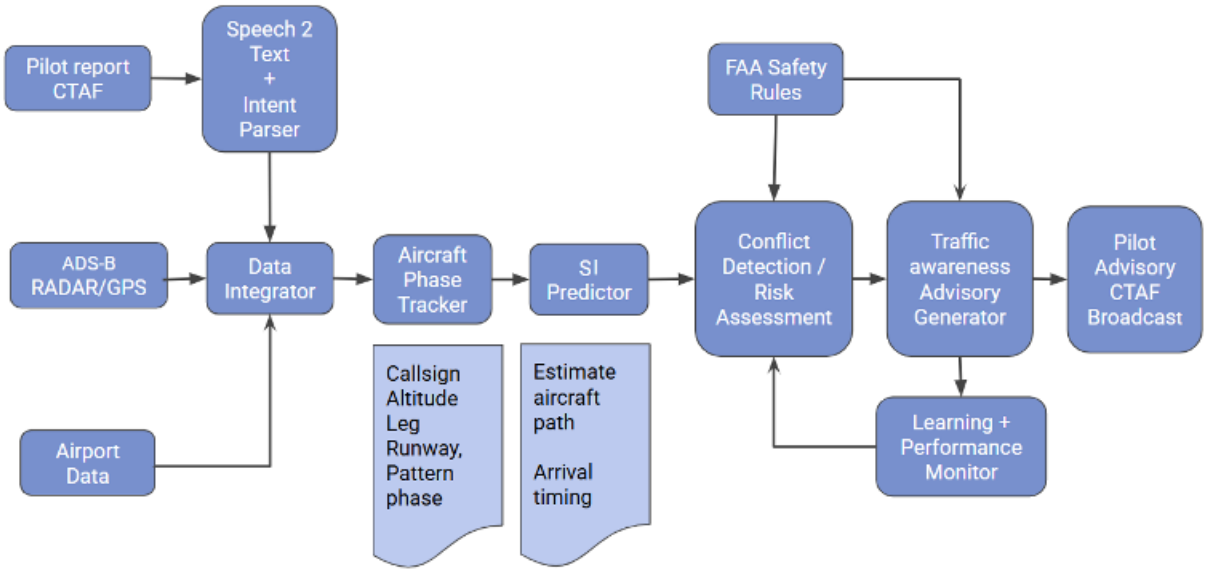


Fig. 4 SkySensSI flow diagram

ADS-B data provides aircraft position, altitude, speed, heading, and identification when available. This data helps the system verify or supplement what pilots report over CTAF. For example, if a pilot announces entering downwind for Runway 32, ADS-B position and heading can help confirm whether the aircraft is consistent with that phase. The Data Integrator combines these sources into one clear picture of airport traffic.

The system then passes structured information from the Data Integrator into the Aircraft State Tracker. In the Aircraft State Tracker each aircraft is assigned a current arrival/departure phase based on CTAF reports, ADS-B movement, and airport geometry, arrival or departure sequence and updates the aircraft phase when new information is received. The SI Predictor estimates where each aircraft will be in the near future. This helps the system detect possible spacing issues, runway conflicts, or confusing traffic situations.

The Conflict Detection and Risk Assessment module compares aircraft arrival/departure phases and predicted paths against safety rules and style constraints. If two aircraft are in incompatible phases and a risk is found, such as one aircraft on short final while another is entering the runway, the system identifies a potential conflict. The Traffic Advisory Response Generator then creates a concise CTAF advisory message, such as spacing guidance, traffic awareness, or a request for position verification. A text-to-speech module can broadcast the advisory in the simulation environment.

3.1 CTAF Speech-to-Text Processing

The CTAF processing module converts pilot audio into text. This is one of the most important steps because non-towered airport operations depend heavily on radio communication. The system must identify key aviation phrases such as “entering downwind,” “turning base,” “turning final,” “taking runway,” and “clear of runway.”

After transcription, the system extracts structured fields from the radio call. These fields include aircraft type, callsign, runway number, pattern leg, and operation type. For example, the CTAF voice call “San Martin traffic, Cessna Three Alpha November turning left base Runway One Four” is converted into a structured flight phase update as: Aircraft: Cessna 3AN, Runway: 14, Phase: Base.

3.2 ADS-B Integration

ADS-B adds a second source of traffic information. While CTAF provides pilot intent, ADS-B provides aircraft movement data. Combining both is valuable because a pilot’s radio call explains what the aircraft intends to do, while ADS-B can show where the aircraft is.

In the simulation, ADS-B data can be replayed from a static file. Each entry can include aircraft callsign, latitude, longitude, altitude, heading, speed, and timestamp. The system uses this information to update aircraft positions on a map and compare aircraft movement against expected traffic-pattern geometry.

ADS-B also has limitations. Not all aircraft may be equipped, data can be delayed or incomplete, and ADS-B alone does not always reveal pilot intent. For this reason, the system uses ADS-B as one input rather than as the sole basis for advisory decisions.

4. SkySensSI FSM Logic

The FSM logic is the core aviation-logic component of SkySensSI. It gives the system a structured way to understand where each aircraft is in the airport operation. Instead of treating every radio call independently, the system tracks each aircraft through a sequence of possible flight phases.

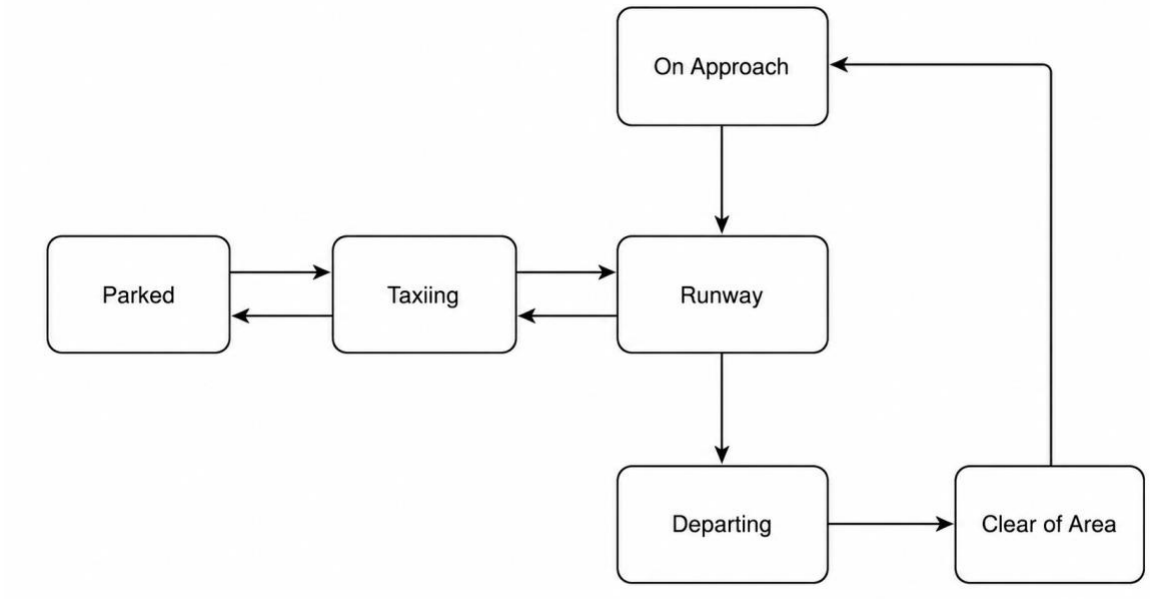


Fig 5: Simple arrival-departure sequence FSM logic at an airport

Figure 5 shows a simplified model of how the system tracks aircraft movement at San Martin Airport. Each box represents a major aircraft phase, and the arrows show how an aircraft can transition from one phase of operation to another.

An aircraft can begin in the Parked phase, then move to Taxiing when it begins ground movement. From taxiing, it can enter the Runway phase when it takes off, lands or crosses the active runway. The runway state is central because it applies to both arrivals and departures: an aircraft on approach transitions into the runway phase after landing, while a departing aircraft moves from the runway into the Departing phase during takeoff.

After departure, the aircraft moves to Clear of Area once it leaves the immediate E16 traffic environment. The diagram also includes a loop from Clear of Area back to On Approach, representing another aircraft entering or re-entering the airport traffic area for arrival. The two-way arrows between Parked, Taxiing, and Runway show that aircraft may move forward or backward between these ground-operation phases, such as taxiing back to parking or exiting the runway back onto a taxiway.

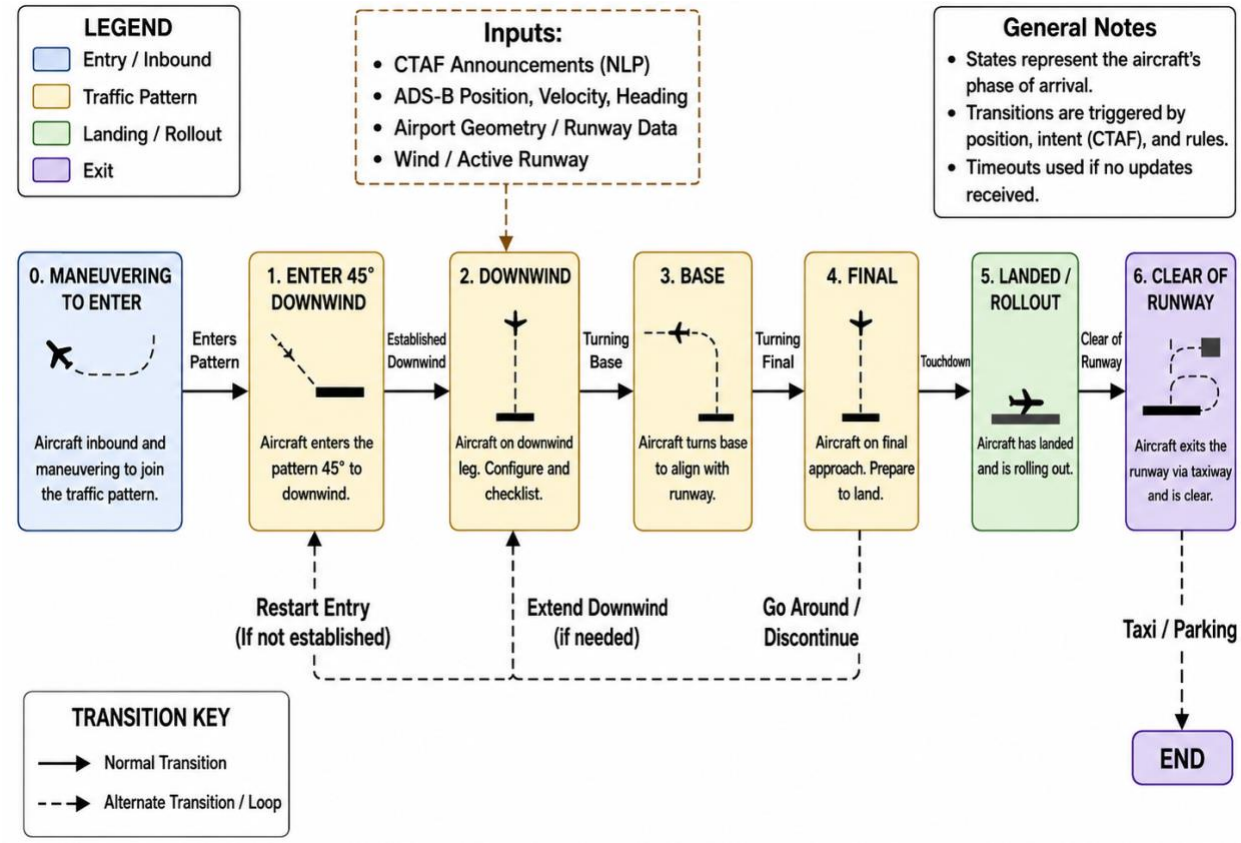


Fig. 6 Arrival sequence FSM logic

Figure 6 models how an aircraft progresses through the standard VFR traffic pattern. The system tracks each aircraft through a sequence of phases, beginning with maneuvering to enter the pattern, then entering the 45-degree downwind, continuing through downwind, base, final, landed / rollout, and finally clear of runway. Each transition is triggered by CTAF position reports, ADS-B position data, and expected traffic-pattern behavior. By organizing arrivals into

defined phases, the system can detect spacing issues, runway occupancy conflicts, and unsafe sequencing before they become higher-risk situations.

4.1 Conflict Detection Rules

Conflict detection is based on phase combinations, runway use, and predicted aircraft movement. These rules allow the system to produce predictable alerts, and the decision to alert comes from structured aviation logic.

The system uses two alert levels: advisory and critical. Advisory alerts support awareness and sequencing when no immediate hazard exists, such as nearby pattern traffic or a missed position report. Critical alerts are used for urgent safety risks, such as runway conflicts, converging aircraft on final, or opposite-direction runway use. This separation reduces alert fatigue by distinguishing routine traffic information from immediate warnings.

Some example conflict rules include:

- Runway conflict: If one aircraft is on final or short final and another aircraft is entering the same runway.
- Spacing conflict: If two aircraft are on the same pattern leg with unsafe spacing.
- Base-to-final conflict: If one aircraft is on base and another aircraft is on final with intersecting paths.
- Opposite-direction conflict: If two aircraft are approaching opposite runway ends.
- If an aircraft has landed but has not reported clear of the runway, the runway remains occupied until CTAF or ADS-B indicates otherwise.

5. SkySensSI Simulation Experiment

The simulation is designed to demonstrate how the advisory system operates at a non-towered airport using the SkySensSI concept.

5.1 San Martin Airport (E16) Case Study

The simulation uses San Martin Airport as the case study environment, which is a public non-towered general aviation airport located in southern Santa Clara County, California. It primarily serves small aircraft, flight training, recreational flying, and local aviation services. Because it does not have an operating control tower, pilots coordinate through CTAF self-announcements and visual separation.

E16 (Fig. 7) is a useful case study because it has a relatively simple runway layout while still representing the operational challenges of non-towered airports. The airport has a single runway, Runway 14/32, oriented roughly northwest to southeast. Its traffic pattern and runway geometry make it possible to model arriving and departing aircraft using defined flight phases such as inbound, downwind, base, final, runway occupied, and clear of runway.



Fig. 7 San Martin Airport (E16), Photo: Andy Xie (CA)

Using a single-runway airport also makes the simulation easier to evaluate. Since arrivals and departures share the same runway environment, the system can focus on common safety issues such as spacing conflicts, base-to-final conflicts, runway occupancy conflicts, and arrival-versus-departure conflicts.

Aircraft are displayed on a browser-based airport map (Fig. 8), and their positions are updated using simulated ADS-B data and CTAF radio calls.

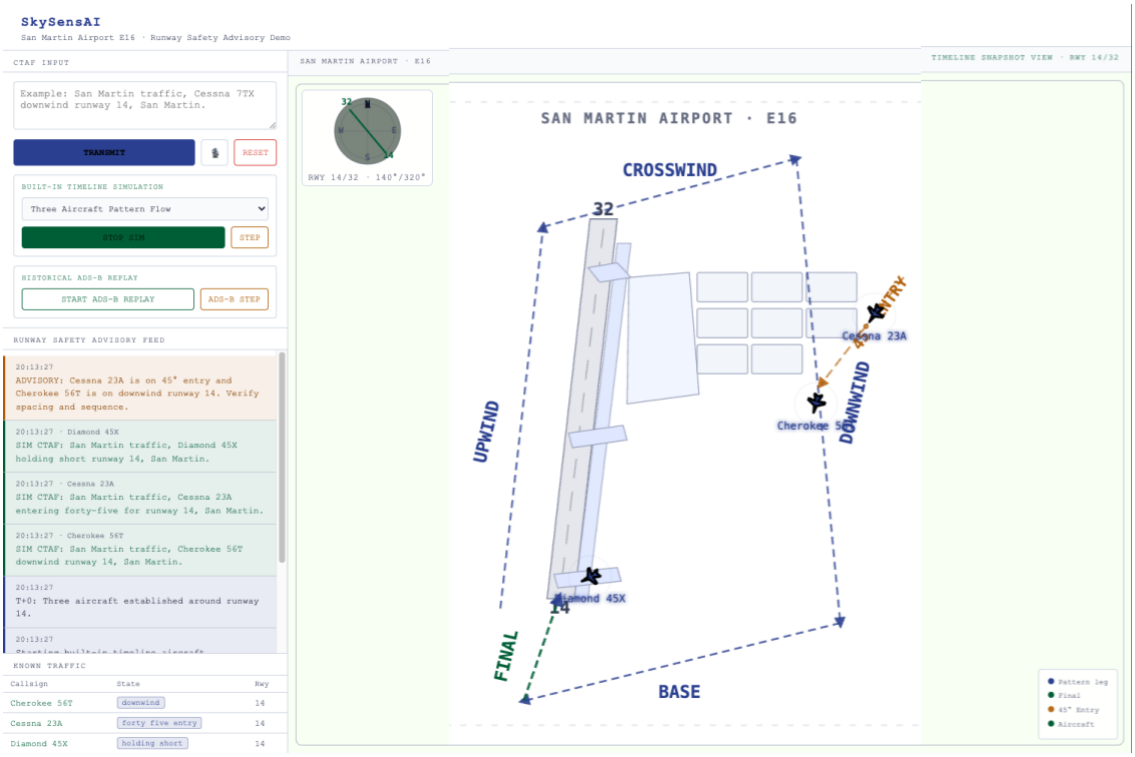


Fig. 8 SkySensSI Simulator GUI

The system uses three main input categories described below.

1) **CTAF audio:** In the simulation, prerecorded pilot calls are used to represent aircraft position reports and intentions. These calls are converted into text and then parsed into structured data.
2) **ADS-B data**: In the simulation, ADS-B information is represented through a replay file containing aircraft position, altitude, speed, heading, and callsign information. This allows the system to update aircraft positions over time.

Table 2 shows the ADS-B information of the aircraft, which is a 112-bit Mode S extended squitter message that is broadcast twice per second. Each row represents a new aircraft update with the aircraft callsign, ground position, altitude, velocity, latitude, longitude, barometric altitude, and heading. This allows the system to track how an aircraft's position, altitude, speed, heading, and operational status change over time.

Timestamp (UTC)	ICAO24	Callsign	Latitude	Longitude	Altitude (ft)	Ground Speed (kt)	Track (°)	Vertica	Squawk
2026-07-22 14:00:01	A1B2C3	N123AB	37.62131	-122.37896	35,000	465	274	0	1200
2026-07-22 14:00:06	A1B2C3	N123AB	37.62098	-122.38915	35,000	466	274	0	1200
2026-07-22 14:00:11	A1B2C3	N123AB	37.62065	-122.39932	35,000	465	275	0	1200
2026-07-22 14:00:16	4CA123	UAL532	36.98572	-121.8435	31,000	445	135	-128	5312
2026-07-22 14:00:21	4CA123	UAL532	36.97614	-121.8348	30,984	444	135	-128	5312
2026-07-22 14:00:26	7F8E9D	SWA812	38.4512	-121.3124	28,000	421	89	0	2741
2026-07-22 14:00:31	7F8E9D	SWA812	38.45135	-121.30115	28,000	420	89	0	2741
2026-07-22 14:00:36	C0FFEE	FFT204	39.11542	-120.99251	18,000	335	212	-640	4517
2026-07-22 14:00:41	C0FFEE	FFT204	39.10892	-121.00015	17,936	334	212	-640	4517
2026-07-22 14:00:46	D4E5F6	AAL178	35.8123	-118.64275	39,000	485	101	0	2201

Table 2 ADS-B information of aircraft

3) **Airport geometry:** This includes runway orientation, traffic-pattern direction, approach legs, runway thresholds, taxiway exits, and runway occupancy zones. Airport geometry enables the system to interpret aircraft movement relative to E16 (see Fig. 9).

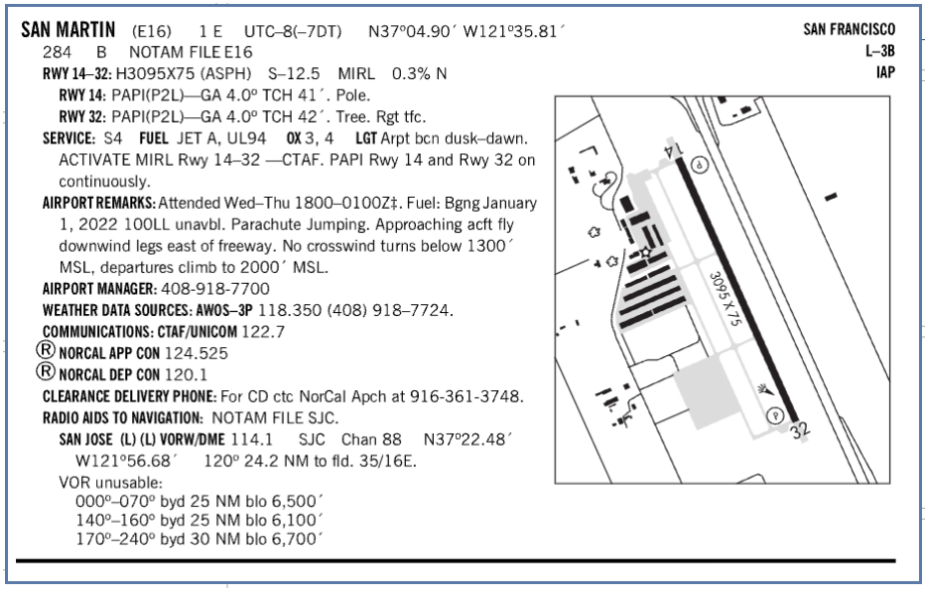


Fig. 9 San Martin (E16) Chart Supplement

The system parses each pilot's radio communication on CTAF and the corresponding ADS-B data to identify aircraft intent and builds a live picture in the traffic pattern. It then predicts possible conflicts, such as two aircraft turning final too close together or one aircraft entering opposite-direction traffic.

The output of SkySensSI is a combination of a text message and a visual map, as well as voice alerts on the same CTAF, so that all pilots can hear the advisory message. Depending on the circumstance, the alerts can either be Advisory or Critical in nature. For example,

- Advisory : if on the same leg, 'Verify sequencing and spacing'
- Critical : runway conflict

If there are no conflicts, no messages are communicated on CTAF.

5.2 Simulation Scenarios

The system was tested using the following three conflict scenarios designed to represent common safety challenges at non-towered airports, as summarized below.

1. **Conflict Type: Runway Occupancy**

   Situation: As depicted in Fig. 10, aircraft one (56T) is established on final approach to the active runway (14) while the second aircraft (23A) enters or remains on the same runway.

   Alert Issued on CTAF: The system issues a critical alert because the landing aircraft and runway-occupying aircraft are in the same flight phase.

   Resolution: Aircraft 1 (56T initiates a go-around and aircraft 2 (23A) exits runway back to taxi.

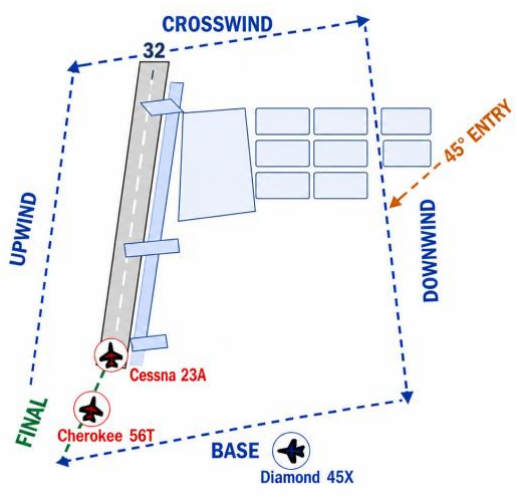


Fig. 10 Runway Occupancy conflict

2. **Traffic-pattern Spacing Conflict**

   Situation: Aircraft one is on downwind, and another is turning downwind too closely behind it. The system compares CTAF position reports, ADS-B movement, and predicted flight paths to determine whether spacing is becoming unsafe.

   Alert Issued on CTAF: If the conflict affects sequencing but is not yet an immediate runway hazard, the system issues an advisory alert asking pilots to verify spacing and sequence.

   Resolution: The pilot in front expedites to avoid conflict after hearing the CTAF alert.

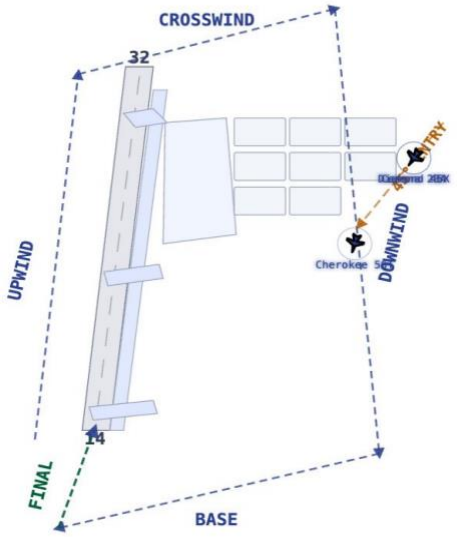


Fig. 11 Traffic-pattern conflict

3. **Opposite-direction Runway Use**

   Two aircraft that report or appear to be using opposite runway directions as depicted in Figure 12; one aircraft (56T) is approaching Runway 14 while another (23A) is aligned for Runway 32.

   Alert Issued on CTAF: The system issues a critical alert since opposite-direction operations on a single runway creates a serious conflict.

   Resolution: After hearing the alert on CTAF, one of the pilots takes evasive action to avoid the conflict.

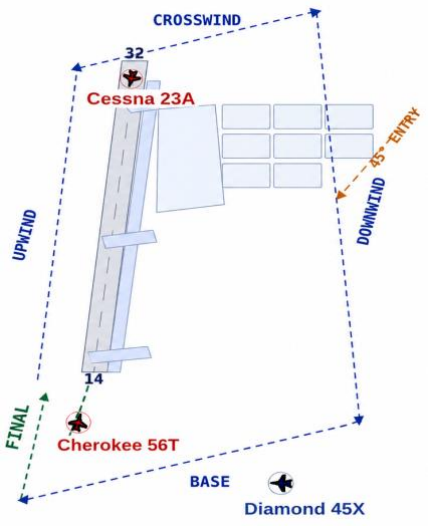


Fig. 12 Opposite-direction runway use

5.3 Evaluation Metrics

The following evaluation metrics were identified but not qualitatively evaluated as it was outside the scope of this proof-of-concept demonstration. Future work will compare SkySensSI's predicted aircraft flight phases against manually annotated ground-truth trajectories.

a) **Flight phase classification accuracy** measures whether the system correctly identifies each aircraft's phase of operation.
b) **Conflict detection accuracy** measures whether the system correctly identifies unsafe or potentially unsafe situations.
c) **Advisory timing** measures whether alerts are generated early enough to be useful.
d) **Advisory clarity** measures whether the message is concise and understandable to pilots.

False positives and false negatives are also important. A false positive occurs when the system issues an alert when no meaningful conflict exists. Too many false positives could reduce pilot trust. A false negative occurs when the system fails to detect a real conflict. False negatives are more serious because they represent missed safety opportunities.

6. Results and Analysis

In all three scenarios, the system successfully tracked aircraft transitions through the traffic pattern. SkySensSI demonstrated the ability to organize CTAF and ADS-B inputs into a structured traffic picture. The system tracks aircraft through arrival phases such as downwind, base, final, and landed rollout. It also tracks departure phases such as holding short, entering runway, and departing.

In normal arrival scenarios, the FSM logic provides a clear framework for following aircraft progress through the E16 pattern. When CTAF calls are clear and ADS-B data is consistent with the radio reports, the system updates aircraft flight phases with minimal ambiguity. This shows the value of combining pilot intent from CTAF with position verification from ADS-B.

In conflict scenarios, the system identifies several important risks.

- When an aircraft enters the runway while another aircraft is on final, the system identifies a runway occupancy conflict.
- When two aircraft operate too closely on the same pattern leg, the system identifies a spacing concern.
- When aircraft approach the same runway from conflicting directions, the system flags an opposite-direction risk.

The results suggest that a lightweight advisory system could improve situational awareness at non-towered airports. The system is especially useful because it organizes information that pilots already use: radio calls, visual position, runway status, and traffic-pattern expectations. By combining these inputs into a shared advisory framework, SkySensSI could reduce confusion during busy traffic periods.

6.1 Limitations

The simulation also shows the following limitations.

1. Speech-to-text accuracy is critical. If the system mishears a callsign, runway, or pattern leg, it may assign the wrong flight phase to an aircraft. Aviation radio calls can be

affected by background noise, overlapping transmissions, accents, clipped audio, or nonstandard phraseology.
2. ADS-B data is helpful but could be incomplete. Some aircraft may not transmit ADS-B, and position data may not always update quickly enough for close-range airport operations.
3. SkySensSI should not sound like ATC, and advisory design must be carefully controlled. It should not issue instructions that pilots might interpret as clearances. Instead, messages should be phrased as traffic advisories such as “Traffic alert” or “Runway occupied,” leaving the pilot responsible for final action.

6.2 Discussion

SkySensSI addresses a specific operational gap in aviation modernization. Large airports benefit from control towers, radar, surface surveillance, and staffed ATC facilities. Non-towered airports, however, rely on decentralized pilot coordination. This difference matters because many general aviation operations occur at airports without towers.

The strength of SkySensSI is that it does not require the airport to become towered. It uses information that may already be available, such as CTAF communication and ADS-B data, and combines it with a low-cost software-based advisory layer. This makes the concept potentially scalable to many small airports.

However, implementing such a system in real-world aviation would require careful testing, certification considerations, human factors analysis, and pilot feedback. A system that interacts with live aviation communications must be reliable, predictable, and clearly limited in authority. It must support pilot decision-making without creating confusion about who is responsible for aircraft separation.

The system also raises important questions about trust. Pilots may be more likely to trust advisories that are accurate, brief, and explainable. For example, an advisory stating “Traffic alert: Cessna 3AN on final, Diamond 6SX entering runway 14” is more useful than a vague warning. The message identifies the aircraft, the conflict, and the runway environment without giving a clearance.

6.3 Future Recommendations

Future development of SkySensSI should focus on improving data reliability, expanding scenario coverage, and testing with pilots. One major improvement would be to integrate live ADS-B receiver data and live CTAF radio input in a controlled test environment. This would allow the system to process real traffic patterns rather than only prerecorded or simulated data.

Another improvement would be to expand the FSM logic. The current model focuses on common arrival, but real airport traffic includes departure operations, straight-in approaches, go-arounds, pattern work, helicopters, aircraft back-taxiing, and aircraft operating without radio calls. Additional flight phases and transition rules would make the system more realistic.

Weather and wind data should also be added. Wind direction influences runway selection, pattern behavior, and aircraft performance. A future version of SkySensSI could use Meteorological Aerodrome Report (METAR) data, wind reports, and airport rules to determine the most likely active runway and detect aircraft using an unexpected runway.

Human factors testing is also essential. Pilots should evaluate whether the advisory messages are helpful, clear, and appropriately timed. The system should be tested for alert fatigue, false positives, phraseology clarity, and pilot trust. This feedback would help refine the system before any real-world implementation.

Finally, the system should be tested at other non-towered airports. San Martin Airport provides a useful case study, but airports vary in runway layout, traffic volume, terrain, noise abatement procedures, and aircraft mix. Testing the system at multiple airports would help determine whether the approach is generalizable.

7. Conclusion

Non-towered airports play a major role in the United States aviation system, yet they operate with limited centralized traffic coordination. As air traffic grows and new aviation technologies emerge, these airports may face increasing pressure. Traditional ATM modernization has largely focused on controlled airspace and large towered airports, leaving an opportunity to improve safety and awareness at smaller general aviation airports.

SkySensSI proposes a lightweight SI-based advisory system for this environment. By combining CTAF communication, ADS-B aircraft position data, runway geometry, traffic-pattern rules, and FSM logic, the system can track aircraft flight phases, identify potential conflicts, and generate real-time advisory messages. The system is designed to support, not replace, pilot authority.

The San Martin Airport case study shows how such a system could be modeled and simulated for a single-runway non-towered airport. While further testing and refinement are needed, the system demonstrates a promising approach to improving traffic awareness, sequencing, and conflict detection in nontowered airport operations. As aviation continues to evolve, scalable advisory tools like SkySensSI could help ensure that smaller airports are included in the future of air traffic management modernization.

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