Vehicle-to-Vehicle Datalink Communications: Enabling Highly Automated Aircraft and High-Density Operations in the National Airspace

GAMA EPIC Data Communications Ad-hoc Committee Concept Paper

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1.0 Executive Summary

This concept paper discusses development of a new Vehicle-to-Vehicle (V2V) datalink for aviation. The intention is to provide for scalable, cyber-secure, direct broadcast of aircraft position, intentions, and key safety messages to support long term growth of increasingly automated aircraft in a safe, efficient, and flexible manner. The key V2V datalink features and benefits discussed in this paper are meant as a starting point for further stakeholder discussion to help mature the concept.

Current aircraft-to-aircraft or "vehicle-to vehicle" communications in the form of VHF Voice and ADS-B broadcasts play an enabling role in a wide variety of aircraft operations. At most airports, pilots self-announce their position and intentions over the Common Traffic Advisory Frequency (CTAF). ADS-B provides direct digital broadcast of aircraft 3D position and velocity to nearby aircraft. The current V2V broadcasts greatly enhance a pilot's ability to avoid and coordinate with local traffic in a flexible manner. Aircraft automation could provide enhanced capabilities if limitations of current V2V communications are addressed. Voice communications are difficult to automate, easily misinterpreted, difficult to authenticate, and not readily scalable to high traffic densities. ADS-B does not broadcast vehicle intent, it is not scalable to high traffic densities, and it is unsecure. Understanding nearby vehicle intentions via authenticated V2V messages is critical to supporting increasingly automated vehicle interactions.

V2V datalink's primary mission is to enable real-time digital exchange of key information between nearby aircraft to support automated aircraft-to-aircraft level interactions such as tactical conflict management [1]. This real-time information exchange is ConOps agnostic, which can help a wider variety of vehicles to operate safely in shared airspace. V2V datalink is an airborne capability that is not reliant on ground infrastructure or air-to-ground communication links. The V2V datalink would provide an additional layer of capabilities to improve overall NAS safety and robustness.

Beyond the aircraft-to-aircraft context, V2V datalink could also augment ground-based capabilities. The intricacies of getting V2V data to the ground and the best ways to use it are beyond the scope of this initial paper. Therefore, this paper will focus only on V2V datalink's unique benefits to real-time aircraft-to-aircraft interactions.

GAMA and its member companies are interested in engaging with aviation stakeholders to get their perspectives and help mature a new V2V datalink concept.

[1] ICAO 9854 Global Air Traffic Management Operational Concept: *https://www.icao.int/Meetings/anconf12/Document%20Archive/9854_cons_en[1].pdf*

2.0 Introduction

A variety of highly automated aircraft are preparing for introduction into the National Airspace System (NAS). New technologies intended to supplement pilot functions have the potential to expand access to airborne transportation, provide operational safety improvements, and realize opportunities for scaling up traditional operational concepts. Companies are developing technologies to support two system changes:

1. higher levels of automation and autonomy; and
2. higher density operations while ensuring safe, efficient, and equitable long-term growth.

While no single technology alone can accomplish these goals, the proposed V2V datalink between aircraft is as a key enabler and provides complementary capabilities for airborne or ground communications, navigation, and surveillance (CNS).

This paper explores the V2V datalink benefits, proposes a framework of requirements, and discusses the importance of initiating development efforts to ensure the growth of increasingly automated aircraft operations are not constrained by existing Communication-Navigation-Surveillance (CNS) limitations. Because the implementation of the V2V datalink will take several years, this paper describes the importance of its future contributions and provides a roadmap for getting started.

3.0 Background

3.1 Automation is Changing Pilot Roles

Traditional pilot training is a lengthy rigorous process. Pilots must be proficient in both high-level aviation tasks and low-level monitoring and control of aircraft systems. Automation can remove the need to monitor and control low-level system tasks, so pilots can focus on higher-level flying tasks. For example, a full authority digital engine control (FADEC) automates low-level engine operations, so pilots can focus simply on setting the desired thrust level. As aircraft automation capabilities continue to increase, automation of sophisticated safety critical functions, such as landing, have become a reality.

A fundamental requirement for safety critical automation is reliable, accurate, and up-to-date information. In general, data for safe flight operations is generated from the following two sources:

1. On-aircraft data sources include the pilot, sensors and databases that provide real time local situational awareness which is critical for near term flight control tasks such as local navigation and collision avoidance.
2. Off-aircraft data sources sent to the aircraft via voice and data communications provide situational awareness for airspace beyond the reach of the pilot's and aircraft sensors. These transmitted data sources provide current and forecasted information about weather, air traffic, airspace conditions.

Off-aircraft data sources sent to the aircraft via voice and data communications provide awareness beyond the reach of the pilot's and aircraft sensors. These data sources provide situational and contextual knowledge regarding atmospherics, air traffic, and airspace conditions, current and forecast.

Today, a pilot's interactions with data sources plays a critical role in flight safety. The pilot, as an onboard data source, has a sophisticated ability to sense the local environment through sight, sound, and feel. The pilot integrates both on-aircraft and off-aircraft data to improve overall situational awareness. During that effort, the pilot plays a critical role of monitoring data integrity to detect incorrect or misleading data, so that errant data does not put the vehicle at risk. The pilot's ability to perceive the situation, independent from information sent to the airplane, is vital to detecting incorrect or misleading data transmissions. For example, during the landing phase of flight, the pilot visually locates the runway and hand flies the final landing phase, which can nullify GPS data errors. Pilots also ensure data from voice communications are appropriate. If an air traffic control (ATC) request would put the aircraft at risk, the pilot will work with ATC to modify the request.

3.2 Automation's Desire for Cybersecure Communications

As pilot functions are delegated to increasingly automated systems that act without pilot intervention, these systems will need to ensure the integrity of the input data without depending on pilot oversight. While there are multiple methods to help verify data integrity, providing off-aircraft data over cybersecure datalinks becomes very important. Cybersecurity protects networks, devices, and data from unauthorized access, negligent, or criminal use and the practice of ensuring confidentiality, integrity, and availability of information.[2]

3.3 Drivers Motivating the Transition from Voice to Digital V2V Communications

Highly automated flight in the NAS faces many challenges, such as today's reliance on voice communications for tactical changes to flight operations, especially in dense terminal environments.

Voice communications are:

- *Not Scalable*: This may be a constraint when there are high numbers of aircraft per channel, and not scalable to larger numbers of aircraft.
- *Difficult to automate*: Voice data is difficult to convert into text for processing.
- *Easily misinterpreted*: Inconsistent pilot experience and training leads to wide variation in use of standard ATC language. Even standard language can be misinterpreted.
- *Easily jammed*: For example, a stuck microphone situation.

Even if automation could effectively use voice communications, the available VHF frequencies are already congested with limited bandwidth to handle additional traffic. The need to move towards digital communications is already reflected in the FAA Office of NextGen (ANG) Urban Air Mobility (UAM) ConOps 1.0 and NASA's Advanced Air Mobility (AAM) efforts.

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[2] U.S. Cybersecurity & Infrastructure Security Agency (CISA) *Publication ST04-001*, May 6, 2009. https://us-cert.cisa.gov/ncas/tips/ST04-001.

Controller Pilot Data Link Communications (CPDLC) provides some digital communication capability between the aircraft and ATC CPDLC enables certain digital communication capabilities between aircraft and ATC. CPDLC was developed to give air traffic controllers and air carrier pilots the ability to transmit clearances, instructions, advisories, flight crew requests, reports and other essential messages with the touch of a button. The current FAA CPDLC deployment is limited to just 62 towers for Predeparture Clearance Services (PDC) with additional deployment underway at Air Route Traffic Control Centers. CPDLC is mostly focused on operational benefits for air transport airplanes at large congested airports. The 62 towers are just a small fraction of the over 5000 public landing sites in the US. It is easy to understand that it would be too costly to equip the majority of landing sites with CPDLC. The proposed V2V datalink is not dependent on costly ground infrastructure; thus its capabilities are not limited to a small portion of the NAS.

Additionally, current CPDLC is not cybersecure and relies on the pilot to detect spoofed messages that would be inappropriate for the situation. The proposed V2V datalink by design would be cybersecure, so pilot data integrity monitoring is not required in most use cases.

3.4 The Need for Redundancy and Fault-Tolerance in Communications

System redundancy and fault tolerance is key to achieving aviation safety goals at both the aircraft level and the NAS level. These requirements also apply to communications as automated aircraft move towards greater reliance on digital datalinks. Safety-critical systems must consider the risk of datalink loss and "bad actor" intrusions. This fact is especially true for time-critical functions like aircraft detection and avoidance (DAA) which require action in a matter of seconds. Figure 1 illustrates the span of time-based actions across strategic and tactical frames.

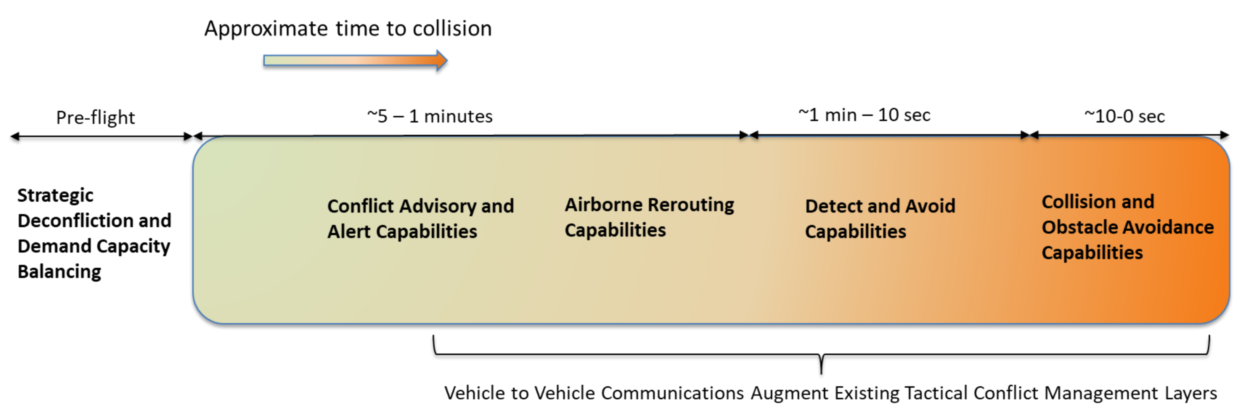

Figure 1. V2V Strategic and Tactical Conflict Avoidance Timescales

The proposed V2V datalink concept provides enhanced tactical deconfliction capability that is independent of air-to-ground communications and ground infrastructure. The V2V datalink is envisioned to augment the existing layered conflict management strategy (as depicted in Figure 1) in the NAS to enhance overall system robustness.

4.0 Expected V2V Datalink Benefits

The proposed V2V datalink concept provides a common means for nearby aircraft to digitally exchange safety messages in a cybersecure and real-time fashion. The V2V direct broadcast of aircraft position, intentions, aircraft maneuvering limitations, and other key safety message content will help support integration of increasingly automated aircraft into the NAS in a safe, efficient, and flexible manner. While air-to-ground (A2G) links can provide a wealth of information, the beneficial aspects of a V2V airborne aircraft-to-aircraft broadcast are significant, as follows:

- **Availability throughout the NAS**: V2V datalink is not reliant on ground infrastructure for system wide coverage. Providing full NAS coverage for A2G links is a challenge. Differences between low and high-altitude flying make a seamless air-to-ground solution difficult. The V2V datalink's ability to provide system-wide coverage provides an additional layer of safety and robustness to the system-wide NAS communications.

- **Interoperability**: Any equipped vehicle can participate in V2V data exchange. V2V is independent of vehicle type or mission. Unmanned aircraft systems (UAS), advanced air mobility (AAM), general aviation visual flight rules (VFR) and instrument flight rules (IFR), and ATC may all have differing means to communicate within their systems, but all V2V equipped aircraft can locally interact/cooperate with one another regardless of mission type or equipage. Ability to exchange safety-related data between current and future mission objectives reduces the need to create special airspace to segregate differing missions. This interoperability mitigates many mixed-equipage challenges.

- **Redundancy**: The V2V datalink is not dependent on an A2G link, so its capabilities remain functional even with A2G link loss. Therefore, the criticality of a loss link is reduced, and the overall system robustness increases.

4.1 Cybersecurity

Cybersecurity must be designed into the V2V datalink from the beginning. As aircraft reliance on transmitted data increases, the need for better cybersecurity grows. A cybersecure V2V datalink providing "trusted" information can help compensate for corrupted information from non-cybersecure links. For example, ADS-B is not cybersecure and its data is used for Detect and Avoid (DAA) capabilities. ADS-B spoofing attacks can create nonexistent aircraft in an attempt to interfere with real aircraft by causing them to take avoidance actions. This is a challenging situation for automated avoidance systems that rely heavily on ADS-B data. The cybersecure V2V data will enhance automated systems to perform as intended.

The V2V direct broadcast of aircraft position, intentions, and other safety message content enable new capabilities for automated aircraft-to-aircraft interactions. One of such capabilities is cooperative tactical self-deconfliction and coordination.

4.2 Cooperative Tactical Self-Deconfliction and Coordination

The concept of "see and be seen" to enable vigilant pilots to "see and avoid" other aircraft has been a fundamental part of flight safety regulations since the introduction of the Air Commerce Act of 1926. The term "see and avoid" is pilot-vision centric. Thus, DAA, or the "capability to see, sense or detect conflicting traffic or other hazards and take the appropriate action[3]" is used. The V2V datalink enhances both the "be seen" and DAA capabilities even in reduced visibility conditions. The V2V system does so with size, weight, power and cost (SWaP-C) factors can be increasingly beneficial to smaller aircraft (GA, UAS, AAM) as technology advances.

The V2V broadcast of localized vehicle intentions significantly enhance the ability for aircraft to interact in a safe and efficient manner among each other. Accurately inferring another vehicle's intention is very difficult from current state data alone. With the V2V datalink, vehicles simply broadcast their intentions among each other. Aircraft intentions are primarily conveyed via shared localized 4D flight path that consist of the near-term 3D flight path, with time along the path as a fourth dimension. Knowledge of shared vehicle intentions enables the following outcomes:

- **Improved conflict detection**: Knowing real time intentions of nearby vehicles increases conflict trajectory detection accuracy while minimizing nuisance detections.

- **Improved conflict resolution**: Knowing vehicle intentions enables determination of deconfliction actions that may optimize flight path deviations and their effects on surrounding vehicles. This knowledge is increasingly important as traffic densities increase.

- **Improved verification of deconfliction actions**: Current "Rules of the Air" standardize deconfliction actions. Monitoring changes in the conflict vehicle's intentions enables quick verification that the vehicle is taking the expected deconfliction action. If their intentions indicate noncooperation, more evasive actions can be initiated. Standardized deconfliction can be enhanced by leveraging the V2V datalink and localized 4D flight-path information to provide efficient deconfliction actions even in challenging high-density traffic situations.

- **Cooperative Negotiation**: At times vehicles might not be able to perform the expected deconfliction response. The V2V datalink messaging can enable vehicles to negotiate alternative actions. Such capability could allow vehicles to cooperate in novel situations that emerge as the variety of flight operations increase.

4.3 Non-Cooperative Self Deconfliction

Cooperative Self Deconfliction presumes a level of equipage that will not initially exist on legacy aircraft. The V2V datalink can be helpful for deconfliction with unequipped vehicles through the following factors:

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[3] CFR14 Part 91.3

- **Most new highly automated vehicles will be V2V capable**: It is expected that the new highly automated vehicles will drive the future increase in traffic densities. Equipping these vehicles with V2V datalink reduces the noncooperative traffic problem over time.

- **V2V datalink upgrades to legacy aircraft:** The benefits of V2V may entice some legacy aircraft to voluntarily upgrade, where operational benefits dictate. For example, for legacy aircraft that are in common contact with evolving high-density and highly automated traffic.

- **V2V-Listen only upgrades:** Many legacy aircraft are not capable of providing localized 4D flight path intention data on a regular basis so fully participating in V2V communications is not possible. These aircraft could passively listen to V2V broadcasts for improved conflict detection and deconfliction responses. Such voluntary equipage has happened before as in the case of ADS-B In Only. ADS-B-In Only was a relatively low-cost upgrade, so many aircraft voluntarily upgraded to get improved situational awareness.

- **Non-cooperative aircraft alerts:** When V2V datalink equipped vehicles encounter non equipped vehicles, they could broadcast acquired data about those vehicles to surrounding V2V datalink participants.

4.4 Cooperative Spacing[4]

As the distances between aircraft decrease, the need for real-time exchange of accurate flight path data increases. Real-time V2V data sharing of localized 4D flight path and navigational performance between aircraft increases the ability for vehicles to safely self-separate in all weather conditions and in areas where other separation services are unavailable. This aircraft-to-aircraft separation capability is not affected by A2G link loss and would provide an additional layer of safety even in areas where ground-based separation services are in use. The same V2V data could also enhance ground-based separation capabilities, especially near landing sites, but the details of getting V2V data to the ground and the best ways to use it are beyond the scope of this initial paper. Note that the V2V datalink only provides the foundation for sharing of key information and the ultimate ability to reduce spacing depends on how aircraft and ground systems utilize this information.

[4] "Spacing" is intended to generically include both VFR or IFR operations.

4.5 System-Wide Tactical Traffic Coordination

Traffic coordination and spacing is a function distinct from spacing deconfliction or DAA, which is concerned primarily with ensuring adequate separation between aircraft. Traffic coordination requires maneuvering in an efficient manner relative to other aircraft. Ground based control centers have greater visibility to system wide data and are more effective at strategic coordination. On-aircraft data sources provide real-time local situational awareness, enabling tactical coordination. Adding V2V could enable nearby vehicles to conduct real-time-tactical-level traffic coordination more rapidly than ground coordination can today, thereby enabling smaller buffers in strategic coordination which may reduce required vehicle separation and enable higher-traffic densities.

Research and technology demonstration of traffic coordination in non-towered, non-radar-surveilled airspace was conducted under the NASA-FAA-Industry Small Aircraft Transportation System (SATS) Project from 2000 to 2005. The SATS project culminated with a flight demonstration of four operating capabilities intended for use in on-demand, point-to-point air transportation in Technologically Advanced Aircraft (TAA)[5]. TAA aircraft employ glass cockpits and related integrated CNS systems, including data communications. The four SATS operating capabilities enabled aircraft to perform sequencing, merging, and spacing, based on aircraft communications with a ground-based unit at an airport that would have no air traffic services. Some of the lessons learned by the NASA and FAA research teams provide insight into the ways in V2V may support similar operating capabilities at landing facilities which may serve Advanced Air Mobility operations.

4.6 Local Hazard Warning

When an aircraft encounters an unexpected hazard, such as icing, or turbulence, V2V can provide real-time notification to nearby aircraft, which improves overall airspace safety.

4.7 Safety Message Relay

When an aircraft experiences A2G link loss, the ability to relay safety-related messages is very beneficial. A nearby aircraft with a working A2G link could relay messages for an aircraft experiencing an A2G link loss. Providing communication redundancy for safety-related messages enhances overall system safety and robustness. This is intended for safety-of-flight related messages only.

4.8 System-Wide Uses of V2V Datalink Broadcasts

Beyond the local aircraft-to-aircraft context, real-time V2V datalink information is useful for ground-based capabilities. To minimize bandwidth congestion, V2V datalink broadcasts are limited in range. The intricacies of getting V2V data to the ground and the best ways to use it are beyond the scope of this initial proposal, which focuses on its unique benefits to real-time aircraft-to-aircraft interactions.

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[5] AIAA: *Overview of the Small Aircraft Transportation System Project Four Enabling Operating Capabilities* https://ntrs.nasa.gov/api/citations/20080015452/downloads/20080015452.pdf

That being said, a landing site could readily receive local V2V data and use the information to provide enhanced capabilities while also making that data available for system-wide use. For example, the SATS project incorporated an A2G capability in non-towered, non-surveilled airspace. The function was supported by a ground "Airport Management Module," a computer with a A2G radio to communicate sequencing and spacing between participating aircraft[6]. For AAM, this functionality may support high density vertiport and general aviation airport operations lacking air traffic services.

5.0 Recommended V2V Requirements

Industry and government will benefit from developing a standard for an aviation V2V datalink to enable high-density and increasingly automated operations. A V2V datalink standard can be built by leveraging avionics' standards that already exist or are in development by Standards Development Organizations (SDOs).

RTCA (in the U.S.) and EUROCAE (in the EU) are recognized leaders in the development of standards to support communication, navigation, and surveillance technology, as well as airborne safety equipment such as ACAS and DAA. These SDOs should be tasked with developing aviation V2V datalink standards. Top-level requirements of V2V datalink operational capabilities include the following:

- Vehicle to vehicle messaging of aircraft intentions via localized 4D flight path data in a manner that supports tactical conflict management capabilities.
- Broadcast aircraft intention via a localized 4D flight path.[7]
- High reliability with low error rates.
- Independence from a ground infrastructure component but operating with the needed capability as an airborne-only function.
- A defined cybersecurity level to support the operation.
- Interoperates with DAA systems.
- Collaborative relationship with existing sensor equipment, such as ADS-B, GNSS.
- A defined target level of safety for higher traffic density, including challenging urban environments while operating independently of other aircrafts' equipage.
- Uses a common frequency in appropriate spectrum.

5.1 Message Set and Protocols

A digital message set and messaging protocols can be designed to suit the needs of cooperative surveillance between two aircraft, including not only current state (e.g., today's ADS-B standard), but also aircraft trajectory intent and additional information about vehicle capability and maneuvering limitations (see 5.2.1).

[6] AIAA: *Overview of the Small Aircraft Transportation System Project Four Enabling Operating Capabilities* https://ntrs.nasa.gov/api/citations/20080015452/downloads/20080015452.pdf
[7] V2V datalink should include multicast, small group broadcast, and vehicle to vehicle messaging

To realize security objectives, the vision for a V2V datalink system relies on various components of a cybersecure environment (e.g., the use of cryptographic keys for authentication and confidentiality). While signal transmission challenges may make airborne transmission of an encryption key impractical or unreliable, a key could be uploaded digitally to the vehicle before each flight and remain valid for the period of the flight, providing both message security and privacy.

5.2 Message Types

The primary message is the localized 4D trajectory broadcast to support enhanced DAA functions, including additional message types are also envisioned. The message set should be expandable to add future capability as it becomes warranted.

5.2.1 Broadcast Messages

5.2.1.1 **Localized 4D Flight Path:** An aircraft's 4D trajectory consists of the 3D intended flight path with time along the path as a fourth dimension. Current navigational accuracy and 4D navigation performance is also provided. This message broadcasts an aircraft's intentions to nearby vehicles which enables enhanced DAA algorithms and efficient traffic flow coordination. To provide additional vehicle intent information, the current phase of flight is provided. Phase of flight can indicate such conditions as "holding for takeoff area X", "transition to horizontal flight", "on final" or even "emergency landing." A continuously updated localized 4D flight path should be broadcasted at a rate defined by a Standards Developing Organization [SDO].[8] An example is provided in Figure 2 below.

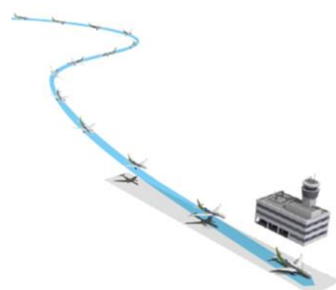

Figure 2 Example of Localized 4D Flight Path

5.2.1.2 **Unique Vehicle ID**: A unique vehicle digital ID is needed to support communications. For privacy this does not have to be the plane's registration. It could be a unique ID assigned just for the flight.[9]

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[8] For reference, ADS-B airborne position is broadcast between 1-2 HZ transmission rate.

[9] To address privacy concerns, the FAA has initiated the Privacy ICAO Address (PIA) program to improve the privacy of the following eligible aircraft:

- U.S registered
- 1090 MHz ADS-B equipped
- Using a third-party call sign (continued on following page)

5.2.1.3 **Intended Destination**: Providing Intended Destination information helps DAA when the localized 4D flight path broadcast is a short-term trajectory that does not extend to the intended destination.

5.2.1.4 **Aircraft Capability**: Broadcasting current vehicle performance limits such as minimum and maximum airspeed, max rates of climb and descent, and range can improve deconfliction algorithms.

5.2.1.5 **Aircraft Health Status**: This message indicates a vehicle's health status to modify deconfliction results. In essence it can give a troubled vehicle additional space or higher priority to help maintain NAS level safety. This message can give the following status indications: nominal, limited maneuverability, sensor failure, communication failure, energy state, emergency, etc.

5.2.1.6 **Hazard / Warning Message**: This message can share warnings to surrounding vehicles of sensed hazards such as non-cooperative traffic, unmarked obstacles, wind shear, landing area obstruction, flock of birds, etc.

5.2.2 Direct Digital Messages

This section presents types of direct digital messages that V2V datalink should communicate. While the content is similar to TCAS / ACAS messages, this paper is not intended to prescribe the specific source or required equipage for aircraft. Those details are left to a standards organization to determine. No inference should be made regarding procedural air traffic implications of alerting messages based on the similarity of their descriptive names and ACAS messages.

5.2.2.1 **Conflict Alert Message:** Notify an affected aircraft of detected flight path conflict.

5.2.2.2 **Conflict Negotiation Message:** V2V datalink broadcasts should provide the information needed to enable vehicles to independently calculate the appropriate flight path modification based on standard "Rules of the Air" for traffic deconfliction. Verification that vehicles are taking appropriate actions is accomplished by monitoring the localized 4D flight path broadcasts. The vast majority of deconflictions can occur without direct messaging (i.e., alert messages) between vehicles. For situations where the standard deconfliction is not sufficient, the Conflict Negotiation Message is used to negotiate an alternative solution.

5.2.2.3 **Ground Message Relay**: highly automated vehicles must have fail-safes to handle loss of safety-critical air-to-ground communications. If that loss is localized to a particular vehicle, a V2V Message Relay capability could enable transmission of safety critical messages, such as requests and clearances to ground control, via network communications with nearby aircraft.

- Flying in domestic U.S. airspace

The PIA program enables interested aircraft owners to request an alternate, temporary ICAO Address, which will not be assigned to the owner in the Civil Aviation Registry (CAR).

5.3 V2V Datalink Requirements

5.3.1 **Altitude**: surface to at least 18,000 ft.

5.3.2 **Air to Air Range = ~10 NM**: To minimize bandwidth congestion, the V2V datalink broadcast should be limited to the range required to support V2V datalink functions. Table 1 below shows why a 10 nm range may be sufficient to support V2V datalink functions. The conflict avoidance V2V datalink range requirement is dependent upon the relative speed between vehicles. For example, if a minimum 60 second conflict avoidance time requirement is selected, then the required range would be as follows:

Table 1. V2V Signal Range Requirements

Airspace	Max Speed for altitude (kts)	Required Range at Max Speed (nm)	Required Range at Hover (nm)
Below Class B	200	**7**	**4**
Below 10,000ft	250	**8**	**4**
10,00ft to 18,000ft	300	**10**	**6**

The speed limits below Class B and 10,000 ft are set by the FAA. The 300 kt speed limit for between 10,000 ft. and 18,000 ft. is a suggested practical speed limit as planes flying faster than that are likely under ATC control. The V2V datalink range near a landing facility should enable two vehicles approaching from opposite directions to coordinate arrivals. For guidance one can look at the 5nm Class C inner ring where aircraft are required to make radio contact. This suggests a 10nm broadcast range is sufficient to communicate with a vehicle entering from the opposite side of the 5nm ring. AC No: 90-66B also suggests a 10-mile range for announcing one's intentions when approaching an uncontrolled airport.

5.3.3 **Availability and Integrity to Support Real-Time Safety Messaging**

5.3.4 **Common Frequency and Message Set:** See section 6.2 Spectrum Considerations**.**

5.3.5 **Coverage Area:** North America *(Worldwide desired)*

5.3.6 **Cybersecurity**: Encryption, Authentication, Validation *(Internet connection will likely be required prior to take off to validate credentials).*

5.3.7 **Futureproofing**: V2V protocol must accommodate contemplated future requirements so adaptability must be designed in from the beginning. For example, the system could plan for updates to add new functions or improve cybersecurity, as telecom protocols advance from 5G to 6G and radio/antenna technologies advance to software-defined systems.

5.3.8 **Interoperability**: Any aircraft should be able to participate in V2V communications regardless of vehicle type, equipage, or entity providing flight services.

5.3.9 **Relative Vehicle Speed**: ~600 kts *(The spectrum and waveform management must have the ability to handle the Doppler shift)*

5.3.10 **Resiliency**: Need dynamic creation of ad hoc mobile and mesh networks that are not dependent on active air-to-ground connection. Datalink must work with loss of GPS timing.

5.3.11 **Scalable for Aircraft Density of ~300 aircraft in 10 nm radius: This is an initial** estimate and should be refined during the development of the standard.

6.0 Acting Today to Make Aviation V2V a Reality

Highly automated and higher density operations in the NAS could greatly benefit from V2V datalink. At the same time, advanced technology deployment in aviation typically takes decades from concept to introduction into operation to wide adoption. V2V is envisioned as an enabler of long-term growth in capacity, especially in urban environments and high-density situations. The outcome expected is maintenance of safety and airspace efficiency. To achieve these outcomes, the development of the V2V standard should start now.

6.1 Roadmap

A voluntary equipage plan, supported by manufacturers of highly automated aircraft and operators pursuing high-density utilization of the NAS, would provide a cost-friendly roadmap for implementation of V2V datalink. Over time, our experience suggests that operators will see voluntary implementation evolve into a need for V2V datalink avionics equipage. In the future, some shared airspaces' increased density may be coupled with a requirement for V2V datalink equipment for normal operations.

It is challenging today to establish specific dates or conditions which must exist to drive a mandate for V2V equipage. However, we recognize that a future need will evolve, and that work must start now to develop solutions to address those future needs. Technology advancements and related safety case analyses may ultimately lead to equipage requirements for some airspace users. The proposed notional roadmap described in Table 2 should be updated with consultation from a broad set of stakeholders.

It is important to recognize that at this time there is no desire to mandate V2V datalink equipage for legacy users of the NAS. As new users adopt V2V datalink technologies, systems are likely to be developed to update legacy ADS-B equipment to receive and interpret V2V datalink messages. These systems may offer traditional users of the airspace benefits without full equipage requirements. Implementation strategies for equipage, training, and operations need to consider both forward-fit and retro-fit solutions. About half of the General and Business Aviation fleet in service today (2021) can be expected to be in service in another 30-40 years or more while air carrier aircraft typically remain in operation for 20-25 years. All users of the NAS may eventually benefit from the investments by early adopters.

Table 2: Notional Equipage Roadmap

Evolution	Compliance Considerations
Legacy Aircraft	– Voluntary equipage for legacy aircraft in areas with legacy airspace requirements.
New Highly Automated Aircraft	– 0-X Years: Voluntary equipage for the first X years after aviation V2V standard created, effectiveness is proven, and COTS hardware exists. – X+ Years: Required equipage on new highly automated aircraft.
Reduced Separation Airspace	– Following the completion of research to assess the safety value of V2V equipment in highly utilized airspace. – As needed, require V2V equipment to support normal operations in designated airspace, unless granted clearance by a controlling authority.

6.2 Spectrum Considerations

Obtaining the appropriate spectrum for V2V datalink is critical to timely enablement. The V2V datalink requires a common frequency to form the ad hoc communication network. Spectrum is very valuable and setting aside a band of spectrum for a particular purpose is very difficult. Aviation has its own protected spectrum for safety of flight and for operational capabilities. There is spectrum that could be repurposed for V2V as described below.

For example, 1104 MHz, is a frequency reserved for aviation that the FAA expected would be needed as a secondary Universal Access Transceiver (UAT) frequency for GA aircraft. To date, it has not been incorporated into avionics equipment because the uptake of UAT1 has been slower than expected, and a second frequency has not yet been needed. Representatives from the FAA have indicated that 1104

MHz, also called UAT2, could make a suitable candidate for the V2V datalink.[10] Use of the 1104 MHz frequency would allow ATC to receive targets, or to hide them, using a combination of geography and frequency. Thus, an air traffic controller could potentially mask all the 1104-transmitting aircraft above an urban center but have them revealed when they approach within a specified distance of a controlled airport.

The FAA requires a designation of flight-criticality for allocation of a spectrum bands. Flight critical means “necessary to continue safe flight.” Given the signal propagation challenges of the urban and suburban environments, vehicle-to-vehicle cooperative surveillance on a reserved frequency is necessary for see-and-avoid, as well as efficient flight planning. Achieving safe, scaled AAM operations will require a level of dynamic operational density that cannot be supported due to limitations of human ATC voice commands for separation. There are numerous proposals for the separation function to be carried by individual vehicles. Latency and delay in A2G communications dictate greater separation in ground-based separation schemes than for on-aircraft methods. Safety of flight is usually designated at the point of vehicle certification; however, increasingly automated aircraft self-separation requires an operational definition as well.

6.3 Combined Industry/Government Effort

The aviation community and agencies responsible for the NAS must create a foundational V2V industry consensus in order to achieve future goals of highly automated flight. This is a primal purpose of the present document. Test cases should be designed to explore system robustness which consider peak operational throughput, minimum acceptable meteorological conditions, as well as cybersecurity constraints. Here are specific recommendations to help make V2V datalink a reality:

- **Federal Aviation Administration (FAA)**
  - Conduct R&D on V2V by the FAA RE&D lines of business.
  - Implement coordination and collaboration between the FAA and NASA on the V2V datalink technologies, systems standards development, and regulatory considerations.

- **Federal Communications Commission (FCC) / FAA Spectrum Office**
  - Concur and designate flight critical spectrum for V2V use.

- **National Aeronautics and Space Administration (NASA)**
  - Coordinate R&D on V2V with FAA.
  - Incorporate V2V testing in the AAM National Campaign or similar activities.
  - Develop and validate enhanced DAA methods that explicitly use intent from broadcast of V2V 4D flight path.

- **Trade Associations**
  - Build industry consensus on top level V2V requirements.
  - Advocate V2V among the aviation community and agencies responsible for NAS.

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[10] See “Reliable, Secure, and Scalable Communications, Navigation, and Surveillance Options for Urban Air Mobility,” NASA Contractor Report 20205006661, August 2020.

- Secure commitments from vehicle manufacturers to implement proposed V2V service on highly automated aircraft.
- Obtain commitments from operators who are pursuing high-density utilization of the NAS.
- Negotiate commitments from avionics manufacturers to develop necessary equipment.

- **Standards Development Organizations (SDOs)**
  - RTCA/EUROCAE: Develop a ConOps and MASPS for capabilities that will incorporate V2V.
  - ASTM International: Develop a ConOps and standards for DAA capabilities that will incorporate V2V.
  - IEEE: Identify and develop security and networking protocols for V2V.

7.0 Summary

The time for strategic thinking about V2V solutions to support long term growth of increasingly automated aircraft in a safe, efficient, and flexible manner is now. We propose the following three recommendations:

1. V2V use the 1104 MHz frequency band allocated for GA ADS-B, with redesign to support expanded uses.
2. R&D by the FAA to accelerate the pace of development of solutions and implementation pathways for the V2V datalink; and
3. RTCA commitment to writing standards for V2V. V2V standards need to be flexible to meet future needs, scalable, and provide cyber-security while interoperating with legacy airspace users.

Investment in proactive research, testing, standards, and protocols development will enable long term success and increase NAS safety, especially in highly automated and scaled UTM/AAM operations.

A.1 Glossary

i. **Automatic Dependent Surveillance** [11]: Broadcast: ADS-B is a Surveillance technique that relies on aircraft or airport vehicles broadcasting their identity, position and other information derived from on board systems (GNSS etc.). This signal (ADS-B Out) can be captured for surveillance purposes on the ground or on-board other aircraft in order to facilitate airborne traffic situational awareness, spacing, separation and self-separation (ADS-B In). The FAA's Remote ID rule prohibits use of ADS-B Out and transponders in UAS operations under 14 CFR Part 107 unless otherwise authorized by the FAA and it defines when ADS-B Out is appropriate for UAS operating under Part 91.

ii. **Air-to-Ground Datalink**[12]: A general term encompassing a means of digitally communicating between ground operators or systems and airborne systems, to include the networks, equipment, and radio frequency use intrinsic to that link. CPDLC and ARINC VHF data comm are examples of air-to-ground datalink. ADS-B is not considered an air-ground data link.

iii. **Controller-Pilot Data Link Communications (CPDLC)[13]:** CPDLC is a means of communication between controller and pilot, using data link for ATC communications. Messages from an aircraft to the Air Traffic Service Unit (ATSU) may follow a standard format or may be free text. Messages from a controller normally follow a standard format and usually require a response from the pilot. There is no requirement in CFR for an operator to use CPDLC. An operator must obtain FAA design approval and a revision to their 14 CFR Part 121, 125, 125M, or 135 operation specifications (OpSpecs), or Part 91 Specs or LOA to use CPDLC.

iv. **Detect and Avoid (DAA):**[14] The capability to see, sense or detect conflicting traffic or other hazards and take the appropriate action.
Discussion: For the purposes of this paper, DAA is not limited to remotely piloted vehicles.

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[11] *Source: Remote Identification of Unmanned Aircraft, FAA, Federal Register, March 16, 2021 and skybrary.aero*
[12] *Source: FAA, Data Link Communications, AC-90-117, October 3, 2017.*
[13] *Source: FAA, Data Link Communications, AC-90-117, October 3, 2017.*
[14] *Source:* International Civil Aviation Organization (ICAO) Annex 2 Rules of the Air July 2005.

A.2 GAMA Supporting Committee and Contributing Members

The Electric Propulsion & Innovation Committee (EPIC) of the GAMA Board of Directors enables hybrid & electric propulsion, increased automation and other key innovations into general aviation design, production, maintenance among the global aviation regulators in key states of design. The EPIC also supports concepts and changes to operational and licensing obstacles which may exist in key markets.

EPIC considers likely developments and technologically mature innovations which can support the growing safety and utility of general aviation over the near (1-4 years) and medium term (5-10 years). The committee focuses efforts to create an environment conducive to efficient design and production certification in the nations of key aerospace design. Further the committee will assure proper operational, maintenance and training infrastructure is on a successful course and is being addressed.

Key technological considerations will evolve over time, and they currently include:

- **Data Communications Ad-hoc committee (DATA):** *The DATA ad-hoc committee supports data communications needs and potential opportunities for eAircraft. The Ad-Hoc will consider current and future needs and opportunities with consideration to both public, private and agnostic link solutions with specific focus on emerging links such as 5G.*

- **Hybrid & Electric Propulsion Subcommittee (ELC)**: *The ELC Subcommittee works with global regulators, research groups and the aviation community implement electric aircraft utility systems and propulsion.*

- **Infrastructure Subcommittee (INF):** *The INF Subcommittee works to understand and address the off-aircraft support needs of eAircraft.*

- **eVTOL Subcommittee (eVTOL):** *The eVTOL subcommittee includes representatives from eVTOL manufacturers and operators who wish to coordinate on issues of common interest and standardization.*

- **Simplified Vehicle Operations Subcommittee (SVO):** *The SVO subcommittee supports the evolution of design and operational requirements that will enable simplified operations and the increased automation of GA aircraft systems and manned flight without traditional pilot skills. SVO is responsible for the review existing pilot licensing rules and commercial/private operating standards to determine their applicability to eVTOL pilot/operator qualification and identify any need for policy changes in the European and U.S. FAA regulatory systems.*

The following Data Communications ad-hoc committee members and supporting experts in industry have contributed the development and review of this GAMA Concept Paper.

NAME	ORGANIZATION
Al Capps	NASA
Brad Snelling	NASA
Bruce Holmes	Holmes Consulting, LLC.
Francis Govers	Bell
Greg Belaus	Joby Aviation
Kamesh Namuduri	University of North Texas
Milan Beslac	Lilium
Paul Johnston	Cirrus Aircraft
Ryan Naru	Joby Aviation
Tamara Casey	Aura Network Systems
Tom Gunnarson	Wisk
Virginia Stouffer	Aura Network Systems

GAMA CONTACTS:

- Christine DeJong Bernat, Director, Global Innovation and Policy, cdejong@gama.aero
- Jens Hennig, Vice President, Operations, jhennig@gama.aero