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Vehicle to Vehicle Communications
White Paper

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FOREWORD

This document was prepared by Special Committee 228 (SC-228). It was approved by the RTCA Program Management Committee (PMC) on December 15, 2022.

RTCA, Incorporated is a not-for-profit corporation formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public. The organization functions as a Standards Development Organization and develops consensus-based recommendations on contemporary aviation issues. RTCA's objectives include but are not limited to:

- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;
- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;
- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

The organization's recommendations are often used as the basis for government and private sector decisions as well as the foundation for many Federal Aviation Administration Technical Standard Orders and advisory circulars.

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DISCLAIMER

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1 INTRODUCTION

1.1 Purpose

The purpose of this paper is to make recommendations on next steps for RTCA in addressing the needs of the operator community for vehicle-to-vehicle (V2V)[1] data exchange including surveillance information, trajectory intent, and other information beneficial for air traffic operations.

1.2 Background

Advances in technology are creating new aerial vehicles capable of new operational concepts that provide a wide range of benefits. These new operations are creating additional demand for airspace access. It is expected that existing air traffic control methods and airspace infrastructure will be insufficient to support significant growth in these new vehicles and operations.

One such concept, Advanced Air Mobility (AAM) envisions cost-effective air transport over and between nearby urban areas. Connecting people and/or cargo between points or to other modes of transportation, AAM is one part of a multi-modal regional transportation system.

One area that is lacking is an effective surveillance capability that scales to meet the conflict management needs for AAM. Real-time tactical coordination between nearby aircraft will be needed as operations increase.

Other emerging operations that may not fall within AAM definitions will also require similar information sharing so this document will consider a wide range of increasingly automated operations without regard to whether they are described as AAM operations or not. However, for simplicity, the term AAM will be used within this document.

To address the needs of the aviation community in this area, RTCA chartered a team to create a paper to determine how best to address the need for surveillance and coordination between collision avoidance systems for new airborne entrants and third-party service providers. This includes whether existing systems would be sufficient of if the community needs to define and standardize a new V2V system. This paper will make recommendations to RTCA on next steps (Section 6).

1.3 Intended Use

The envisioned use of a V2V link is to support air traffic operations while in flight operations and provide data necessary for traffic situation awareness, tactical collaboration, and collision avoidance. Flight operations may include operations on the aerodrome surface.

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[1] While the initial focus on this work was on vehicle-to-vehicle data exchange, there was discussion that there could be beneficial use cases for Vehicle-to-Infrastructure (V2X), although no specific applications have been proposed. We use V2V throughout this document but do not constrain future development from V2X if found to be sufficiently beneficial.

The V2V link should not be used for uses such as Command and Control or communications between a vehicle and the air traffic service provider, Air Traffic Controllers, Providers of Services for UAM, etc.

Additional information on the boundaries for the scope of the paper are contained in Section 2.

1.4 Environment Description

The V2V link described in this white paper will exist as part of a larger communications architecture consisting of a set of data services required for future operations and radio interfaces that support them. Understanding the entirety of the architecture provides additional context that may be useful in understanding the responsibilities and requirements of the V2V link.

AAM will require multiple data services to enable safe and efficient operations. Here is a list of potential data services that have been referenced in various AAM-related forums and documents in recent years:

- Vehicle Telemetry and Monitoring – periodic reporting of vehicle state, status, and diagnostics to the vehicle operator.
- Command – Flight plan adjustments, remote pilot interventions
- ATC Services – All required communications services to allow operation in controlled airspace.
- Contingency Communications – Enhanced communications between vehicle and fleet operator/remote pilot to safely and quickly mitigate off-nominal conditions of the vehicle or airspace
- Vehicle-Vertiport – Direct vehicle to vertiport communications to facilitate vehicle access to vertiport airspace and ground resources when terrestrial communications between fleet and vertiport operators are not available
- Surface Communications Services – All pre- and post-flight wireless communications to/from vehicle
- In-Cabin Monitoring – In-Flight monitoring of passenger health and conduct
- V2V Services: Described in more detail below

Data services are defined by data standards plus end-to-end requirements on how the data is to be moved to and from each element in a network. Radio interfaces are required to move data wirelessly to and from each AAM vehicle during flight. Ideally from a cost standpoint, all of the required AAM data services would be carried by a single radio interface, but this is atypical for aviation. The worst-case scenario from a cost perspective would be a dedicated radio for each data service. The optimum, and most likely, solution is a communications architecture that supports all required data services over a small number of radio interfaces.

Regarding V2V communications, a first step is to identify what the data service requirements are for any services that may require direct communications between AAM vehicles (and possibly other aircraft). This white paper describes cooperative separation assurance and collision avoidance services, which are the most widely discussed V2V data services for AAM. It is also important to consider any other potential V2V data services that might utilize V2V links, such as voice communications between pilots and relay transmission of command and/or telemetry data services when a primary air-to-ground link is down. A thorough understanding of these data service requirements and the larger AAM communications architecture may even support the possibility of routing some of these services through air-to-ground links instead of using direct V2V communications. Adding these additional services will require additional spectrum, and additional infrastructure, and additional cost. These considerations must be balanced against the benefit of those services.

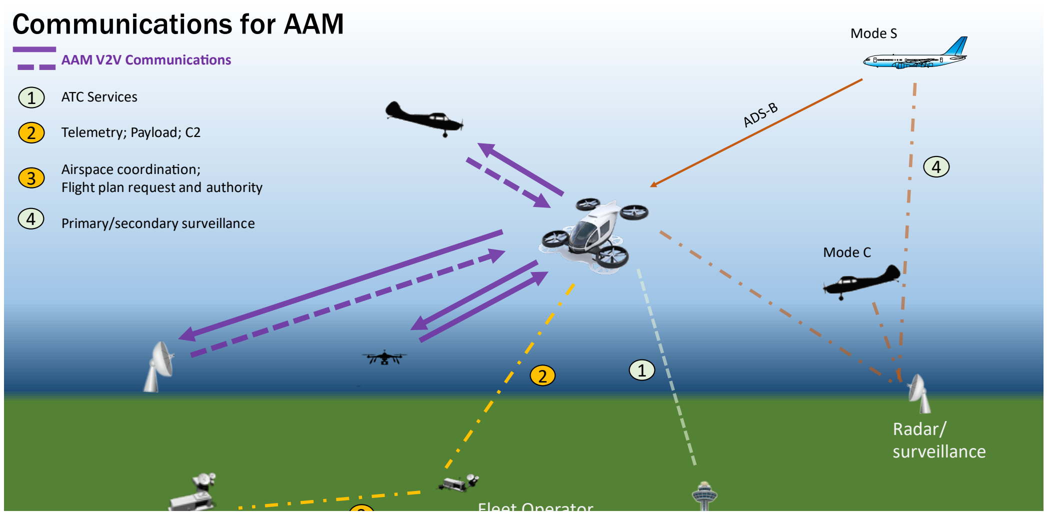

Figure 1-1: Notional Data Communication Architecture

Figure 1 shows a notional diagram of how the V2V link fits with other data communications links. The focus is on an AAM operation, but similar architectures would be expected for non-AAM operations that use this V2V link. The thick, purple lines represent broadcast over this V2V link. The thick, purple, dashed lines represent potential broadcasts from either infrastructure to the vehicle or from non-AAM vehicles. The orange dash-dot lines represent communications between the vehicle and their fleet operator (2) and the Provider of Services for UAM (PSU) (3). Depending on the operation and airspace, the AAM vehicle may need to be in contact with an air traffic controller [thin, white dashed line (1)]. There will be primary, and likely secondary, surveillance in the area (4) with data shared with ATC and other authorized entities. Finally, the AAM vehicle is expected to receive ADS-B information from those aircraft that are ADS-B out capable to ensure a complete traffic awareness.

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2 BOUNDARY CONDITIONS

The realm of Advanced Air Mobility is large, covering a wide range of new and emerging types of vehicles, missions, and operations not frequently seen in today's aviation environment. Even with a focus just on the needs of a vehicle-to-vehicle or vehicle-to-infrastructure data link, the scope is large and unmanageable. To stay within the purpose of this white paper and the allocated time, we have limited the scope, or boundary, of what we are considering when making our recommendations. This section describes what is within, and outside, our scope of consideration. Future work should reconsider if this boundary remains appropriate and adjust accordingly. Having a well-defined scope and staying within it is a key step to ensuring timely and appropriate initial standards and guidance.

For the purposes of this white paper, we will consider AAM to include a wide range of vehicles and missions that are new or are expected to have radical growth in the number of operations over current use. It is expected that AAM operations will require new technology, tools, and/or procedures to safely and efficiently integrate into the airspace beyond initial operations. This includes the increasing use of automation in operations up to autonomous operations (which remains undefined). Operations at high altitude introduce significantly different environmental conditions. It is recommended that high-altitude, operations above Class A airspace, not drive V2V performance requirements.

For these operations, we consider that the pilot of the vehicle may be on-board the vehicle or may be at a remote ground control station. It is proposed that the location of human decision makers will not have a direct impact on the requirements for the data link. It may however, influence performance for specific applications that use the data link.

The main identified use for this V2V link is to support applications for traffic management. Using the conflict management framework in the ICAO *Global ATM Operational Concept* (GATMOC) Conflict Management model [ICAO Doc 9854], the focus here is on uses for Collision Avoidance, some portions of Separation Provision (i.e., tactical deconfliction) and traffic synchronization in the context of self-deconfliction for AAM vehicles.

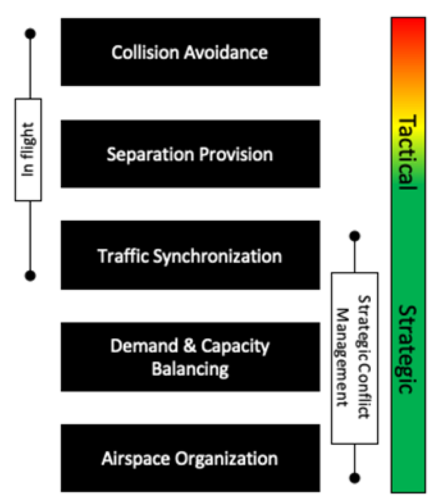

Figure 2-1: ICAO GATMOC Conflict Management Model

As described in Section 3.3.1, this work has considered both vehicle-to-vehicle direct exchange as well as potential vehicle-to-infrastructure operations. One-to-many (broadcast) exchanges of data are considered.

In order to define the performance requirements and message content for this link, it is necessary to fully understand the uses of the data that are transmitted. To this end, Section 3.1 describes several applications that are recommended for further consideration.

Equally important to what is considered within scope for consideration, are the things that are explicitly eliminated from consideration as being either outside the direct influence of RTCA standards, being addressed by other standards or regulatory development, or only being indirectly impacted by V2V data link development, and are out of scope for this paper:

1. Required regulatory changes necessary for V2V implementation and use
2. Navigation of AAM vehicles
3. Command and Control links for AAM vehicles
4. Air traffic management operations of flow management and noise abatement and user flight planning functions
5. Requirements for automation tools that will make use of the V2V link
6. Interoperability of different applications that use the V2V link
7. Any specific message elements or formats for information exchange

Additionally, this white paper documents discussions around spectrum but does not make specific choices or recommendations. Work is needed to understand the trade-offs between different solutions and a deeper understanding of the operational and performance requirements of the data link.

3 OPERATIONAL ENVIRONMENT

3.1 ATM Operations

The main goal of this V2V link is to support the allocation of certain air traffic management tasks to individual vehicles and their pilots to improve the overall safety and efficiency of operations. As traffic density and complexity increases due to new AAM operations and automation and digital data sharing become more prominent, the ability to allocate more tasks, such as separation provision and merging of traffic flows, to balance workload and enable vehicle operators greater influence to optimize their operations will increase. The information shared over this V2V link will be a necessary, but not complete, part of enabling that increased allocation of tasks. While there are other operational uses and benefits of sharing information for tasks or situation awareness outside of traffic management operations, this link is primarily focused on information needed to support the desired traffic management operations.

As the AAM market continues to grow and mature, there may be a need to make regulatory and policy changes regarding the allocation of tasks and responsibilities through modifying existing flight rules or introducing a new set of rules, such as Digital Flight [Wing, et al. 2021]. This white paper takes no position on those changes but does highly suggest that this link be designed in a way that will support that future operating environment.

The local ANSP may define certain airspace structures or constraints such as operating corridors and AAM navigation routes that will need to be incorporated into any automation and procedures. It is expected that such constructs will not directly impact the content of the V2V link but should be considered when defining performance requirements and assessing the safety of operations.

This V2V link will support operations on the aerodrome surface.

While there are many ways of thinking about the hierarchy or relationship between various ATM operations, we will use the ICAO GATMOC Conflict Management model [ICAO Doc 9854], Figure 2, as the reference point.

This model allows us to consider a range of proposed air traffic operations in an orderly manner based on their time-criticality to reduce the likelihood of a vehicle-to-vehicle collision.

Figure 3 shows a timeline of the emergence of a conflict using terms aligned with AAM vehicles. The conflict time horizon addressed by the V2V link is as indicated in Figure 3. It is important to note that the V2V link time horizon for supporting collision and obstacle avoidance is tactical in nature in that the V2V link provides surveillance information that supports conflict management close in time (i.e., within a few minutes) to the time where if unmitigated that a potential collision could occur. V2V communications is focused on a range and message length commensurate with short time horizon tactical communications.

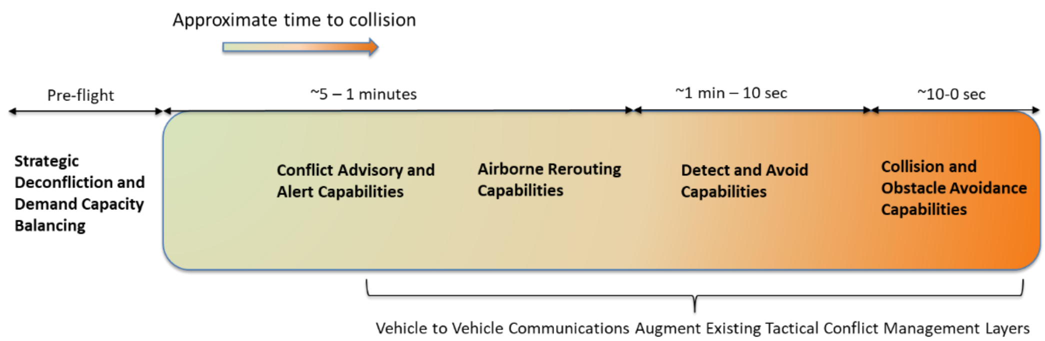

Figure 3-1: Notional timeline of application relative to conflict horizon

Over the years, there have been many proposals for different types of air traffic management operations that allocate new tasks to the flight crew and would leverage vehicle-to-vehicle data exchange such as the FAA and EUROCONTROL's *Principles of Operation for use of Airborne Separation Assurance Systems* [FAA, 2001] (PO-ASAS). This white paper will not propose or develop specific details on these potential operations that would leverage this V2V link. Instead, this paper focuses on a general discussion and identification of applications for greater consideration and development in future work. The selection of priority ATM applications built on the above past work as well as working group discussion.

3.1.1 Situation Awareness

A critical role the pilot and increasing vehicle automation have in ensuring safe and efficient operations in the airspace is to maintain situation awareness of their environment including nearby traffic. The existing methods on obtaining awareness can be augmented by data exchange from other vehicles that includes information such as their current position and velocity, near-term intent, other vehicle state and health information, and local atmospheric conditions. The PO-ASAS category of Airborne Traffic Situational Awareness describes several applications in this realm that should be considered for their relevance and potential modification to AAM operations.

3.1.2 Conflict Management:

Conflict management encompasses a set of tasks that limits the risk of collision between vehicles and hazards, including other vehicles, terrain, weather, etc., to an acceptable level. Within the GATMOC model, there are three layers encompassing strategic conflict management, separation provision (including self-separation), and collision avoidance. Applications that use data from this V2V link can play a role in each of those layers but may not completely address all of the needs of any of the layers.

The rest of this section will describe some of the ATM operations that could benefit from or be enabled by V2V data exchange. The specific scope, performance, design, and safety considerations of each of these ATM operations is left for future development. There is an expectation that future ATM operations will be proposed and developed. To the extent practical, the V2V link should support this future growth to enable continued maturation of AAM operations. It is undesirable for future operations to be constrained unduly by current design decisions.

3.1.2.1 Collision Avoidance

Collision Avoidance and DAA functions are the most timely and safety-critical of the discussed applications. These functions are necessary when the potential for a collision between vehicles is not averted through other means.

Airborne Collision Avoidance Systems (ACAS) systems are designed such that they may work cooperatively or independently to propose maneuvers that will avoid the pending collision. RTCA has developed a standard of ACAS which accommodates upon the exchange of vehicle data. The V2V link should be designed to satisfy these needs as a critical design consideration.

3.1.2.2 Separation Provision and Self-Separation

Separation provision includes a set of applications, that taken together, aim to keep aircraft away from hazards by at least the appropriate separation minima. As the GATMOC model notes, separation provision is only used when strategic conflict management tools can't be used efficiently to ensure at least minimum separation. This timeline can be further broken down into near-term conflicts and longer-term conflicts. For the former, the potential loss of separation will generally occur within a few minutes and therefore, time is of the essence when executing maneuvers. Maintaining separation will generally take precedence over operational efficiency when determining appropriate maneuvers.

Longer-term conflicts cover those with high enough likelihood of occurring that action is warranted but far enough into the future that efficiency and other considerations are considered alongside safety to construct an "optimal," multi-constraint solution. The transition from longer-term conflict to near-tern conflict is generally a smooth transition although different tool and procedures may be used based on the available time. Longer-term conflicts may allow for coordination with other traffic and Air Traffic Management (ATM) systems such as an Air Traffic Controller (ATC) or Provider of Services for UAM (PSU) as appropriate for the given airspace and AAM operation.

The PO-ASAS categories of Airborne Separation and Airborne Self-separation cover a number of potential applications that have been considered in the past. This is an area with rapid research and development and recent advances and concepts should be researched to help define productive and acceptable applications for standardization.

This V2V link design should prioritize support for near-term conflict management as a key enabling concept for AAM operations. As practical, support for longer-term conflict management should be supported, but not at the expense of collision avoidance and near-term conflict management. An important consideration is that the longer-term nature allows for less frequent exchange of information but also would require the greatest communication range and potentially more data elements in the exchange. A trade study between potential operational efficiency and safety gains against broadcast range and period should be conducted to support the determination of acceptable solutions.

3.1.2.3 Traffic Synchronization and Spacing

Traffic synchronization refers to the tactical establishment and maintenance of a safe, orderly and efficient flow of air traffic. While traffic synchronization encompasses both ground and airborne parts, only the airborne parts are of direct relevance to this white paper. These types of operations have gone by multiple names including Time, Speed, and Spacing; Interval Management; and the PO-ASAS category of Airborne Spacing. Some spacing operations may be very tactical in nature but maintain the vehicles involved well beyond the separation minimum which separates these operations from separation provision. The common thread relevant for this work is of allocating the task of actively managing the relative spacing between two or more aircraft to a vehicle. These operations can include not only the merging of flows and in-trail spacing allow flows, but also coordinated arrival or departure operations where there are dependent operations between multiple runways or vertipads.

That relative spacing is dependent on knowing specific data about the other involved vehicles. The V2V link should support airborne traffic synchronization operations as practical with priority toward those spacing operations that provide the biggest capacity or throughput benefits.

3.1.2.4 Non-traffic ATM Applications

There are many situations where the sharing of local knowledge between vehicles could benefit the overall traffic management system. These include sharing information on items such as:

- Vehicle health and emergency status that could be used in support of other operations (limited maneuverability or declared emergency giving priority in separation provision operations)
- Agreed-upon operational priority for a flight such as emergency services
- Local weather and atmospheric conditions including winds, temperature aloft, precipitation, and icing
- Known rogue or non-conforming vehicles operating in the airspace
- Ground events causing airborne hazards such as fires (wild or man-made structures)

This list of uses should be maintained and expanded upon including identifying information needs. Where practical, these ATM applications should be supported; however, unique requirements or information needs should not be prioritized over the traffic operations described previously.

3.2 Vehicle Characteristics

The V2V system enables collaborative traffic management, providing an additional layer of collision avoidance through communication and collaboration. Vehicle operating characteristics, including the relevant rules the vehicle follows while operating and its concept of operations, are important parameters that will impact or determine the technical requirements of the V2V system. With that noted, there are a few vehicle and airspace characteristics that are especially important in developing the V2V standard:

- Aircraft cruise speed affects both broadcast range and spectrum requirements
- Aircraft maneuverability information to support deconfliction calculation.
- Low altitude operations that can be affected by multipath transmission issues.

3.2.1 Operating Density, Separation, and Low Altitude

Radio signals on different frequencies travel shorter or longer distances, so the distance needed to effectively warn air vehicles of other vehicles' approach needs to be known in order to specify a suitable spectrum. For example, if the required separation distance is three miles, then the spectrum and its transmit power need to be specified to exceed three miles, plus a suitable distance margin to allow for vehicle travel during the time that the pilot and vehicle observe the conflict, evaluate the alternatives, select the best alternative, and act to avoid conflict.

Greater operating density will increase the opportunities for separation warnings, as aircraft and pilots are alerted to aircraft approaching the warning distance. To avoid signal congestion and signal interference, it is desired that aircraft V2V signals fade out after the desired transmission distance and do not create interference for vehicles further away.

The extent to which the surrounding environment can block signals should be characterized. Low altitude operations will be subject to higher incidence of signal blockage and multipath from structures like buildings and bridges. Generally, areas of high multipath should be served by lower strength signals. Multipath can be used in an additive fashion if the signal coding is constructed to recognize the time difference of bounced signals.

3.2.2 Aircraft Speed

To minimize bandwidth congestion, V2V transmission range should be limited to the shortest distance required by V2V supported functions. On-aircraft V2V based deconfliction likely has the highest transmission range requirement as this function requires a minimum deconfliction time for it to operate effectively. A head on approach of two high speed aircraft provides a worst-case scenario for determining the V2V range requirements. GAMA's V2V whitepaper suggests setting 300 kts as a practical upper limit for high-speed GA aircraft and a 60 seconds deconfliction time requirement which results in a 10 nautical mile (NM) V2V range requirement. Operationally this has precedence in AC No: 90-66B which suggests a 10-mile range for announcing an aircraft's intentions when approaching an uncontrolled airport to support traffic deconfliction.

As aircraft speed increases, the imprecision in its reported position also increases due to system latency in communicating position information. This affects the required separation distance by increasing the amount of uncertainty.

Doppler shifting will lengthen or shorten the wavelength of the signal, so that a receiver tuned precisely to the desired frequency will no longer receive the strongest point of that transmission. Doppler shifting is worse the higher the frequency, as the amount of the shift is higher in proportion to the carrier wavelength. Doppler shifting leads to incorrect symbol translation for phase modulated symbols, errors in frequency modulated encoding, and amplitude misreading, so it affects virtually all methods of encoding. Vehicles traveling faster than approximately 600 miles per hour (mph), or relatively at 600 mph – such as two vehicles traveling at 300 mph towards each other or away from each other – will induce doppler shifting in their received signals. Below 600 mph for these spectra, the doppler shift is fairly easily compensated for by using framing and coding.

There are no negatives associated with slow speed aircraft.

3.2.3 Aircraft Maneuverability

Like Code of Flight Rules, CFR 91.113 "Right-of-way" rules, Tactical deconfliction logic may rely on an understanding of an aircraft's maneuverability. Detailed discussion about broadcasting information about the vehicle's maneuverability is covered in the Information Elements section of this paper.

3.2.4 Intent Information Accuracy

Many traffic applications will use the 4D flight path information from other aircraftincluding how accurately the path will be flown. Detailed discussion about the 4D flight paths informational elements is covered in the Information Elements section of this paper.

3.3 Information Environment

Each aircraft has data that is useful to other aircraft. The state and the intent of the aircraft are the primary pieces of data provided by the V2V link, but not necessarily the only pieces of information that are relayed.

3.3.1 Information Flows

The V2V link is a "one way data flow"; it is a broadcast. Any V2V receivers in the area receive and process any data it is able to decode.

The primary destination for this broadcast data is another equipped aircraft – who is also transmitting. This link is not an "interrogation / response" type of communication. Each aircraft broadcasts its data independent of any other aircraft's transmissions.

Consideration for specific data elements of a V2V broadcast addressed to a specific user should be given. There are use cases where "point to point" messaging may be necessary.

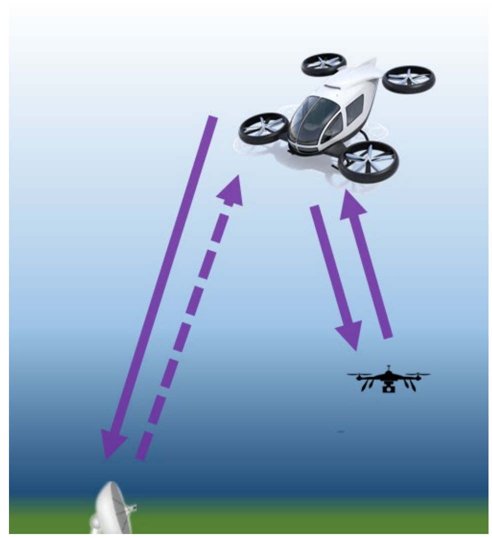

Figure 3-2: Typical Data Flows

Another destination of an AAM V2V broadcast is a ground station. A ground station is not necessary for proper operation of the system, but receipt and storage / usage of transmissions is thought to be beneficial for many purposes (e.g., law enforcement, accident investigations, etc.).

Another possible transmitter of data is a ground station. A ground station may have information that aids in the safety of the operation. Research into what may be sent by a ground station is just beginning, but thoughts of what might be included are traffic information (such as Traffic information service – broadcast) and/or wind alerts. As with an aircraft, the data transmitted by the ground is a broadcast intended to be received and processed by any receiver in the area.

3.3.1.1 Information Elements

This section discusses key informational elements for transmission over the V2V link. Details on how to encode this information is left for follow on V2V development activities. This document assumes spectrum limitations will significantly limit the amount of data that can be transmitted in high traffic density scenarios, so informational elements are prioritized into two categories:

1. **Required data elements**: Critical data elements needed to support the core V2V tactical deconfliction functions.
2. **Discretionary data elements**: Additional data elements to support enhanced capabilities as available V2V bandwidth allows. In situations of high traffic densities where V2V spectrum can become saturated, discretionary messages are automatically suppressed to leave room for required message transmission. When the V2V link has extra capacity, discretionary messages can be sent based on priority. A method to assign such a prioritization level should be defined.

The V2V ecosystem must be designed so that the V2V message set can evolve as needs and missions evolve. As the wide variety of AAM missions gain operational experience, it is expected that modification to the message set will be needed. This is a key reason why it is critical that the V2V ecosystem has built in upgradability. For example, the V2V system could be planned with yearly software updates that would enable modifications to the message set.

3.3.1.1.1 Required Data Elements

These data elements are expected to be required by all of the priority applications that the V2V link supports. Future development should validate the need for these elements as well as precisely define how they are encoded.

Vehicle Identification (ID)

A unique vehicle digital ID as needed to support communications. To improve privacy, this does not have to be the plane's registration. It could be a unique ID assigned just for the flight.

Vehicle State

Several aspects of vehicle state can be communicated. First among them is the vehicle's **geometric state** that situates the vehicle in the airspace. Both position and velocity data are required to fully support the operations outlined in Section 3; in particular, collision avoidance can be best optimized for safety and operational suitability when both position and velocity are known. Position and velocity data are to be separated into horizontal and vertical components.

Horizontal position and velocity can be provided by the vehicle's navigation system (e.g., GNSS) in the World Geodetic System (WGS84) reference system. Horizontal velocity may be represented either as vector components or as a magnitude and direction.

To best accommodate interoperability with other aircraft, vertical position (i.e., altitude) must be provided relative to mean sea level (MSL) assuming the standard atmosphere (i.e., barometric altitude) and relative to the WGS84 ellipsoid (i.e., geodetic altitude). Representation of one altitude type as an modelled offset from the other may be suitable.

Besides the position and velocity data themselves, additional data elements to indicate the accuracy and integrity of the position and velocity data are also required. Understanding data accuracy allows decision systems to make optimal decisions in the presence of uncertainty. For example, lower accuracy data may necessitate earlier alerting.

Integrity is used to determine whether a source's data should be used at all. Integrity indications for horizontal data and for vertical data should be provided.

The link design must enable receivers to determine the time of applicability of received data items, including uncertainty associated with the time value. A technical solution to this may be explicit timestamp and accuracy fields transmitted alongside corresponding data items, or a link protocol design which supports extracting time values and accuracies from the process of message exchange (such as time of message receipt).

Vehicle Intent

Incorporating the intended flight path of nearby aircraft greatly enhances the ability to interact in a safe and efficient manner and is required by some, but not all, traffic applications. Accurately inferring another vehicle's intentions is very difficult from vehicle state data alone. An aircraft's intent could be conveyed by broadcasting its local 4D flight path. Since V2V is limited in range, only a local flight path extending a limited time into the future is required.

Having aircraft broadcast local intent greatly reduces future state uncertainty which enables:

- Improved conflict detection: Real-time understanding of nearby vehicle intentions increases conflict detection accuracy and minimizes nuisance detections.
- Improved conflict resolution: Knowing nearby vehicle intentions enables determination of deconfliction actions that minimize deviations for all affected aircraft. This becomes increasingly important as traffic densities increase.
- Ad hoc tactical coordination: With a common set of rules for deconfliction, a vehicle can monitor changes in a conflict vehicle's intentions to verify that the vehicle is taking the expected deconfliction action. If their intentions indicate noncooperation, more evasive actions can be initiated.

3.3.1.1.2 Discretionary Data Elements

Environment State

This message enables vehicles to share transient safety related data about the local environment. This message could include data on hazards such as icing, windshear, non-cooperative traffic, unmarked obstacles, landing area obstructions, large flock of birds, etc.

Critical Message Relay

This message enables nearby aircraft to relay safety related data to a vehicle experiencing an air-to-ground connection loss. For example, this could include landing requests and clearances. Providing communication redundancy for safety-related messages enhances overall system safety and robustness.

3.3.1.2 Collision Avoidance Coordination

One of the key characteristics of a collision avoidance system is its capability to coordinate its maneuver choice with the collision avoidance systems of other aircraft in the encounter, if they are so equipped. Though originally defined for two-way communications via 1030 MHz interrogations and 1090 MHz replies, the Minimum Aviation System Performance Standards for the Interoperability of Airborne Collision Avoidance Systems (DO-382) also defines coordination schemes for broadcast communications: passive coordination between peer aircraft and responsive coordination between non-peer aircraft. V2V can enable coordinated avoidance and the attendant safety benefits for additional airspace users if it includes coordination information exchange consistent with the protocols defined in DO-382. The message would include information about the broadcasting aircraft's identity and coordination capability along with maneuver information to guide the receiving aircraft's maneuver choice. V2V coordination messaging could be modeled on the ADS-B Operational Coordination Message (OCM).

3.3.2 Security

Existing cooperative surveillance mechanisms, including Air Traffic Control Radar Beacon System (ATCRBS), Mode S, and ADS-B, do not implement specific technical solutions to ensure the security of exchanged information. With the development of a novel V2V link comes an opportunity to more closely examine information security topics and explore how they may be approached in the V2V context. In the following sections specific security concepts of interest are defined and explained in the V2V context.

3.3.2.1 Information Exfiltration

Information exfiltration is the extraction of information from a system (i.e., V2V link) in ways unintended by the link participants or design. Privacy to protect business-sensitive information was identified as an important industry need. Specifically, the concern is associated with information exfiltration in the V2V context and will have to be balanced with the needs for safety.

3.3.2.1.1 Media Access

Provisions for limiting information exfiltration begin with authorized media access. The assumption of a connectionless, radio frequency (RF) broadcast is a hurdle for ensuring any sort of limitation on media access. Consumer grade SDRs can easily access and decode digitally modulated transmissions across nearly the entire RF spectrum. While transmission power limits may cap maximum practical reception range and limit the effective eavesdropping capability of any one station, eavesdropping on the link by a network of geographically distributed receivers remains possible. Many examples exist targeted towards ADS-B. Widespread media eavesdropping by disinterested parties must be an assumed and accepted reality of any RF based V2V solution.

3.3.2.1.2 Anonymity

Given that eavesdropping is assumed, the next approach to ensuring user privacy on the link is to assure anonymity. V2V functional requirements introduced earlier dictate that each broadcast participant on the link identify themselves with a unique address from a link-global address space. This identifier supports message-message association, and therefore must remain link-unique and static for any duration that a broadcaster is under surveillance by any given peer. In the connectionless model of broadcast surveillance, senders are not aware of the specific surveillance sessions associated with their broadcasts, and thus must maintain a static and unique address over the maximum possible duration of any surveillance session. In the expected context of this link, we can define the maximum surveillance session as the duration of single aircraft operation, from departure to arrival parking (note we specifically include ground operations, such as taxiing, in the operation definition). While link addresses can remain static beyond the duration of a single operation, this is not a requirement. As a result, there is no requirement which associates link addresses with an identifying vehicle or operator registration.

The lack of a hard requirement associating link addresses with identifying information permits a degree of anonymity within the link. While anonymity is beneficial, it is not sufficient to ensure a complete privacy solution. Due to the open nature of the link medium, a receiver could leverage aggregate observations to extract identifying information from operational patterns (e.g., operations associated with a specific departure terminal and temporal pattern may strongly correlate with a known operator). As link addresses must remain static over the course of an operation, once an identity is associated with an address, that identity could conceivably be tracked over the duration of the operation. Furthermore, data elements included in the broadcast messages may contain additional identifying characteristics, such as an ICAO address for transponder-equipped aircraft.

Despite these weaknesses, a link-global unique address assigned per-operation provides a level of anonymity to support a reasonable expectation of privacy. The technical competence and infrastructure required to uniquely identify the operator of a vehicle utilizing the link is a barrier to all but an extremely concerted and well-funded attacker. Notably, the use of per-operation addresses provides increased privacy compared to visual identifiers such as registration numbers or license plates. Given the per-operation static address requirement, the common UTM/AAM concept of a "Globally Unique Flight ID" (GUFI) is an example of an appropriate value to use for the link address.

3.3.2.1.3 Encryption

Encryption ensures that only those actors with access to the necessary decryption keys can access the plaintext of a message. These intended recipients must either be provided with the decryption key *a priori*, or else a mechanism must exist for the sender to identify authenticated and authorized recipients and securely transmit the decryption key in real time.

The concept of a generalized broadcast surveillance link is incompatible with *a priori* knowledge of specific message recipients, complicating the potential for pre-shared decryption keys. The assumption of a connectionless protocol further eliminates any hand-shake process by which peers can establish shared keys for secure sessions. In the most general case, a shared secret key could be made available to all link participants. This approach would limit public access to data broadcast on the link but would still allow any link participant with the shared key to access any data broadcast on the link, regardless of whether the data was relevant for the receiver. This approach carries the obvious risk that a single breach of secrecy by any link participant leads to a total collapse of the encryption scheme. Such a naïve approach is obviously unsuitable.

3.3.2.2 Information Injection

The injection of inaccurate information onto V2V link, either unintentionally or maliciously, is of paramount concern. DAA/CA systems may use information received via V2V to produce guidance, which either directly or indirectly affect the trajectory of the vehicle. Any ability for an external actor to affect the vehicle's trajectory may present a safety-of-life risk.

3.3.2.2.1 Authentication

In the V2V context authentication is the mechanism which establishes trust in the claimed authorship of each message. Message senders identify themselves by including an identity or address with each broadcast message (see previous section for a deeper treatment of link addresses – this discussion assumes each **valid** address is unique and static for the duration of a surveillance session). A strong authentication mechanism ensures that any possible recipient can determine whether the author of a broadcast message has a valid claim to the address provided in the message.

Absent strong authentication, any broadcaster can indicate any address in their messages and recipients cannot trust the claimed address of each received message. Without strong authentication a data entry error or malicious action could result in an address collision among broadcasters, leaving message recipients (i.e., ACAS Xr) to deal with the resulting message-message association challenges. ADS-B and Mode S both allow for this duplicate address possibility. Users must account for it either by leveraging encoded or derived location data to attempt to correctly associate messages to unique senders, or else by rejecting all messages with the duplicate addresses in order to avoid track divergence. Messages with addresses that are invalid for other reasons are typically discarded. These approaches are necessary in the absence of strong authentication, but result in either rejected valid data, or else are vulnerable to tracking errors introduced by the invalid data.

Furthermore, the lack of established authentication mechanism opens the door to spoofing attacks, where a malicious attacker can choose any address for their broadcasts. While an effective authentication mechanism does not entirely preclude spoofing attacks, it acts as an important layer in a defense-in-depth strategy, presenting a substantial hurdle that must be overcome by any attacker.

3.3.2.1.4 Authorization

Authorization is a process that limits the transmission of data to only specifically allowed participants. Where authorization is enabled, no user can introduce data onto the link without have obtained the necessary authentication from a controlling agent. In the context of an RF broadcast link utilizing licensed RF spectrum, there is a legal form of authorization in play in order to broadcast in the protected spectrum. The likelihood of enforcement of that legal authorization requirement may be remote, and a nefarious user could broadcast messages containing decodable content with few technical hurdles. Therefore, any form of authorization must be achieved by the message recipients themselves in determining whether received message bear specific hallmarks (which may indicate authorization limitations, such as geo-temporal authorization limits) of having been transmitted by an authorized user. In so doing, authorization as a provision of the V2V security model prevents applications from utilizing any data contained in broadcasts from unauthorized peers.

3.3.2.1.5 Non-Repudiation

In a link security model supporting non-repudiation, the existence of a valid message is sufficient itself to assure all recipients that it was produced by the indicated sender. In other words, the sender cannot retroactively deny having sent the message. Non-repudiation implies a form of authentication (the message was produced by the claimed sender) along with a form of message integrity validation (the received message is a faithful copy of the intended message to be sent).

The value of non-repudiation in a V2V link is a stand in for stronger forms of validation. While a non-repudiable message may contain invalid data, the existence of the message serves as an indisputable record of it having been sent. If the address of the sender can be traced to an individual (a process that may be limited to law enforcement or other authorities), then there exists public information which can be leveraged during post incident investigations. The risk to the spoofer of being identified and punished are significant, and with that the motivation for spoofing is decreased.

3.3.2.1.6 Validation

Validation is the gold standard of data assurance in the V2V context. Validation leverages independent, physics-based observations of the intruder or some characteristic of the received signal which cannot be forged. In the presence of validation, the utility of non-repudiation is moot. However, validation typically carries burdens of increased cost along with burdensome size, weight and power implications. Avoiding the need for independent validation of V2V messages would serve to simplify the adoption of a V2V solution throughout the small UAS (sUAS) and AAM fleet.

4 ASSUMPTIONS / CONSTRAINTS

There are many views as to what the formation of an AAM V2V communications link might entail. This section identifies the assumed constraints that were used in developing this paper.

4.1 Considerations for Link Use

The design of the link should not be limited by the terms “AAM” or “V2V”.

The V2V link will be used by any type of aircraft that operates in an airspace where the use of this link is expected. This includes small uncrewed vehicles, package delivery drones, urban air taxis, regional cargo aircraft, and standard helicopters.

Advance Air Mobility / Urban Air Mobility operations are considered drivers towards needing this link to be defined. However, confining this link to “AAM” operations is limiting. This link needs to support “Increasingly Automated Operations.” The design of the link must provide a framework on which aircraft are allowed to automate their operations safely using the information from the aircraft around them. Initially it is envisioned that this link will be used primarily for AAM or UAM operations, but its use is expected to be expanded later to include other non-AAM/UAM aircraft.

The name “V2V” is called out in the ACAS sXu MOPS as a foundational piece of how that system is envisioned to work. However, “V2V” has also been used to describe the link between ground vehicles. The other issue with “V2V” is that it seems to indicate it is a link from one vehicle to one other; it does not lend itself to a “broadcast” message that may be processed by many other vehicles or by a ground station; it does not lend itself to a message that may be sent by a ground station (which is proposed in some of the potential V2V link use cases). It is recommended that a clear distinction, including possibly a different term, be made to separate aviation V2V from ground transportation V2V.

4.2 AAM V2V’s Primary Purpose: Traffic

The primary use of the V2V link is to support collision avoidance and other traffic applications for non-transponder-based operations.

Other uses of the data transmitted on the link may be found; other uses of the radio used for V2V communications may be found; but these uses are subservient to the needs of traffic surveillance in the definition of the V2V link. Other uses of the radio, including command and control, payload data exchange, and direct vehicle to controller messages, are considered to be outside the scope of the V2V link definition.

V2V is independent of the existing ADS-B functionality. Some aircraft, for example small UAVs, will likely only have a V2V transmitter from which it is able to participate in airspace traffic surveillance. Other aircraft will likely transition from transmitting on the V2V link to using a transponder and back based upon the phase of the operation being performed. It is possible that during a transition between operations using a transponder/ADS-B and operations using V2V that an aircraft may transmit on multiple links, but this is not considered to be a primary use case for V2V. This does not mean that an aircraft transmitting on one link may not “listen” on the other. Small UAS transmitting on the V2V link and equipped with ACAS sXu will have an ADS-B In receiver to remain well clear from ADS-B Out aircraft. Some GA operators transmitting ADS-B will want the additional situational awareness of where aircraft on the V2V link are located.

4.3 No Assumed Infrastructure

The V2V structure is assumed to be ad hoc. The envisioned applications are enabled by systems solely contained within the interacting vehicles. Any two proximate vehicles must be able to interact over the link with no pre-existing knowledge of one another. Existing ADS-B functionality is the model that is used for this constraint upon the system; an ADS-B transmitter will work without input from any "off aircraft" source.

This means that the use of the V2V link does not require the existence of a ground-based system. The collision avoidance capability enabled through the use of the V2V link must be independent of any ground-based system.

Interactions with ground-based infrastructure prior to flight are allowed. For example, information security requirements may require that a key update is performed. If it is available, the ground infrastructure may be used during a flight to provide additional information for safety of operations.

Of all the constraints introduced in this white paper, this one that had some dissent. There are proponents for requiring an external, real-time input – specifically for time. Uses for an absolute time stamp (from something like a GPS system) have been noted. Other proponents noted the expected high-levels of infrastructure in urban environments that could enhance the data and range of this link. While recognized, there was a strong desire to have a fully functioning link outside dense urban environments, including during early adoption, and to limit external dependencies and failure modes.

4.4 Cybersecurity

Any system proposed includes a basis for security and validation of the data provided.

The following are included in this assumption.

- Authorization: before broadcasting data, authorization is provided to a sender
- Authentication: a receiver is able to validate the sender is authorized
- Non-repudiation: the origin of a message can be determined (probably through post processing); a sender cannot repudiate the transmission of a message it sends
- Privacy: the system should allow for anonymous operations with respect to other users of the system
    - Law enforcement and ANSPs must have access to the operator's identity

This paper does not preclude the encryption of messages from being implemented as part of the V2V link.. Global operation may preclude encryption due to security and technology export concerns.

In order to support information security requirements, some sort of preflight authorization may be required.

In the end, the system needs to be developed to address many of the security questions that have not been fully addressed by ADS-B / Mode S transponders systems (see section 3.3.2 Security).

4.5 Scalable, Lasting, and Economically Extensible

The assumption is that the technology, both the hardware and the software, is scalable, lasting, and economically extensible.

The V2V link will need to be adapted for the operations and the challenges presented to the industry during the lifetime of the link. This includes the need to consider reserving a portion of the bandwidth for growth.

This assumption means that care must be taken to ensure that the system can grow and adapt as the needs of the system change. It is not feasible to expect that every system is updated for new operations, so backward compatibility must be maintained over an appropriately long period of time. The hardware relied upon to make this system must be something that is going to remain available for the foreseeable future.

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5 KEY TECHNOLOGY ASPECTS

5.1 Spectrum Utilization

A regulator has more options to protect systems using safety spectrum than systems in other frequency bands. For example, interference can be acted on proactively and with greater urgency than what might otherwise be possible. A function using safety spectrum, or a system designated as a safety system should be a goal.

Each frequency band has unique characteristics. Range, channel capacity, signal blocking and multipath are some of the characteristics that will be considered as part of the overall system design. For example, some frequencies will be more susceptible to blocking and multipath than others in an urban environment. As the performance requirements of the V2V link become clearer, these characteristics will inform spectrum needs.

Consideration should also be given to using underutilized aviation spectrum (e.g., 15 GHz) and what the implications to operations would be. If operational requirements can be defined within the performance available in such a band, there would be fewer barriers to bringing a system on-line.

This system concept targets both lightweight and larger vehicles. The ability of vehicles across this range to carry the necessary equipment will vary. Additionally, the required range will likely vary as well given the speeds flown by the various vehicle types. Since there is typically a correlation between range/power and radio weight, variable power could be a tool use to maximize participation across these vehicle types.

A review of potential RF interference sources needs to be made, including non-aviation interference sources as well as potential RF interference sources onboard the vehicle.

Regardless of the spectrum chosen, modern approaches to spectrum utilization should be undertaken to ensure spectrum is used efficiently and provides the maximum utility to the airspace users.

Considering the heavy usage of existing safety spectrum, a general review of how the current safety spectrum is used should be conducted and a set of options should be identified.

5.2 ADS-B as a Potential Solution for V2V

ADS-B contains many of the data elements that are necessary for the defined V2V link. This brings forward the inevitable questions, “Can an existing ADS-B link be used for V2V?” and “Why is V2V not just another version of ADS-B?”

5.2.1 Current ADS-B Link Limitations

The density of traffic envisioned to use this link is far greater than the density of traffic that use the current transponder / ADS-B links. It is well known that certain metropolitan areas are already experiencing significant frequency congestion on 1090 MHz. Use of the existing 1090 MHz link for this purpose would be problematic.

Additionally, current airspace rules do not allow an uncrewed aircraft to use a transponder / ADS-B transmitters (either 1090 MHz or UAT) unless certain rules are followed (e.g., in direct contact with ATC and on a flight plan; Ref.: 14 CFR 91.225(i)(2)).

5.2.2 Current ADS-B Functional Limitations

Although some of the elements of V2V mirror those of ADS-B, V2V goes beyond the capabilities that ADS-B has currently defined. There are two major categories where ADS-B is lacking in what is desired.

The first major category is for elements that can come from cybersecurity. A key limitation of ADS-B is the need for validation. A current assumption for V2V is the ability for it to operate without ground infrastructure while in flight.

ADS-B was developed primarily for situational awareness. As such the current design does not have the capability to validate the data that is contained within the link. For example, some ADS-B In applications require TCAS validation of the position at close ranges. Within the United States, the airspace where a Mode C transponder is required mirrors the airspace where ADS-B Out is required, so one is assured of having the required equipment on-board. ADS-B currently also lacks the ability to address other cybersecurity threats.

The other main category where the current ADS-B definition is lacking is in the broadcast of intent information. The intent information for emerging airspace operations varies widely. In order to perform the intended functions, a more extensive information exchange is required to describe intent than is supported in ADS-B.

5.2.3 V2V Over 1090 MHz ADS-B

Current operations that include transponders are causing spectrum issues in certain metropolitan areas – areas where V2V would be used. Due to spectrum issues, the use of 1090 MHz ADS-B is not believed to be a good solution, even if it would be allowed in the future.

5.2.4 V2V Over 978 MHz ADS-B

The spectrum overload issues on 1090 MHz are not as evident over the existing Universal Access Terminal (UAT) data link of 978 MHz. However, UAT does not currently have any provision for cybersecurity or for intent information. Therefore, it also is not considered a viable approach.

Adding the additional provisions for intent, cybersecurity, and anything else that is specified for V2V may be possible. Doing this would most likely include some fundamental changes to the UAT definition (e.g., introduction of variable / low power; the introduction of methods to increase the bandwidth of the link; etc.).

6 CONCLUSIONS

Over 100 people, representing a range of industry, government, and academia participated during the development of this white paper. The goal was to identify where development of standards by RTCA would help advance the community towards an operational Vehicle-to-Vehicle (V2V) data link. The working group participants identified such a need and the recommendations to RTCA for next steps are captured below. In addition, several detailed considerations and studies were identified during development. These are captured to provide a starting point for future work.

6.1 Summary

There is strong interest in an Advanced Air Mobility (AAM) V2V link to support a range of traffic applications. Use of such a link is expected to improve the safety and efficiency of operations. It was recognized that a wide range of proposed and future operations would benefit from this link. AAM should be interpreted as broadly as possible with a specific focus on increasingly automated operations. It was also recognized that the ground transportation community also uses V2V to describe their data link capabilities. It is recommended that a clear distinction, including possibly a different term, be made to separate aviation V2V from ground transportation V2V.

Section 2 of this white paper describes the scope considered in this activity. In future work, this scope should be validated or updated. We considered the V2V link to exclusively focus on data shared between multiple aircraft or to and from ground systems. Other uses such as Command and Control, payload delivery to flight operator, and navigation are explicitly excluded from this development.

Section 3 describes the expected operating environment with a focus on applications that would use data provided by the V2V link (section 3.1), considerations from air vehicle performance (section 3.2) and initial thoughts on the information environment (section 3.3) including high-level descriptions of potential data classes and information security considerations. There were discussions around the desire for some level of privacy and anonymity by some users and the potential impacts on message content and bandwidth. These competing interests need to continue to be explored to ensure acceptable compromises are found.

The applications captured in section 3.1 describe a range of traffic applications that would likely benefit from the V2V link. Work is needed to prioritize these applications along with understanding the data and performance needs.

Section 4 captures some self-imposed constraints or assumed conditions that drove the recommendations captured in this white paper. Future work should review and validate these.

Section 5 captured discussions and thoughts on potential spectrum allocation and spectrum usage including a discussion on why the current recommendation is to develop a new system instead of modification of existing ADS-B standards. Future work should validate this. It is noted that there are many lessons learned and knowledge captured in the ADS-B work that should be used in development of the V2V link.

6.2 Recommendations

There is a need to develop standards for both the V2V link, including message sets and performance requirements, as well as the applications that will make use of the data elements delivered via V2V.

This working group therefore recommends RTCA determine the appropriate Special Committee (SC) to lead and organize the development of said standards. Expertise will be needed from multiple committees and no one SC stood out as the best place to continue this work. While SC-186 has the experts and experience with ATM applications and ADS-B, a good template for AAM V2V, the key users and operators have not generally participated in their work. SC-228 has many of the AAM users and operators participating but lacks the expertise for ATM application and message content development. SC-228 also has several other new activities that have recently started. While SC-147 has identified some needs for AAM V2V they lack the participation by the AAM users and operators and the ATM application experience. Given the broad interest in the ad hoc working group that drafted this white paper, creating a new SC might attract the expertise needed for this work.

The selected Special Committee should be charged with the following tasks including developing a schedule that will meet stakeholder, including industry and the FAA, needs and timelines:

- Create a report on potential spectrum options and identify key characteristics. There will need to be trade-offs made between the availability of spectrum and the bandwidth and performance needs of the V2V link. This report should capture the key spectrum options and considerations to support such trades and enable responsible parties to take action to ensure the desired spectrum will be available.
- Develop a MASPS, OSED and any other documents necessary for a MOPS that capture the currently identified applications that would use the V2V link, prioritize for both message content need and time until operational need, and extract key data needs to support spectrum allocation decisions. These documents should also capture:
    - the airspace environment
    - a candidate architecture
    - actors, roles and responsibilities: information producers and consumers, regulator, etc.
    - equipment requirements
    - additional standards development needs

6.3 Suggestions for follow-on work

In addition to the above recommendations, during deliberations, several suggestions were captured to assist the work of the follow-on group (6.2 Recommendations). These are captured throughout sections 3, 4, and 5 and are summarized here.

This white paper had three core (or guiding) principles. These should be considered and validated as work proceeds.

1. The primary purpose of the V2V link is to support traffic applications by exchanging vehicle data with other participants.
2. The V2V link is an independent link. It should not depend on other data links including ADS-B. The V2V link should inter-operate with other links but does not depend on another link working for it to work.
3. The V2V link operates without requiring ground infrastructure. This eliminates the need to install ground infrastructure or depend on systems outside the vehicle operators control to perform as designed. This does not preclude gaining additional benefits by using ground infrastructure, but it is not a minimum requirement.

Several trade studies were identified that will help guide future decision making. These include:

- Trade-off of cybersecurity and message size and bandwidth. Increased information protection likely requires additional message overhead. This white paper made assumptions on the level of protection needed and these assumptions should be validated during requirements development.
- Trade-off between available spectrum and benefit of available applications and time-to-market. Different spectrum options may require significant lead time before they are available for use. The impact of that time on industry to realize initial benefits of V2V applications should be considered.
- Several aspects of aircraft performance and expected operational use may impact the V2V link performance. Future work should consider effects of max cruise speed and multipath transmission issues on broadcast range and spectrum requirements.

While this white paper considers vehicle-to-vehicle, vehicle-to-infrastructure (V2I), and infrastructure-to-vehicle (I2V), only applications that make use of V2V were identified. Further consideration of V2I and I2V uses is warranted; if no priority applications are identified, the link scope should be appropriated adjusted. Additionally, consideration should be given to the impact that the V2V link definition has on the tools and systems that use this link.

Privacy concerns have been raised within this paper and in many other forums. Work needs to be done regarding the issue of privacy, including defining what privacy means, how it is achieved, and expected limitations.

Finally, it is recognized that as the types of vehicles and operations considered within the broad AAM umbrella matures, future applications will be identified and matured. To the extent practical, the V2V design should allow for future growth that will enable operations not yet fully envisioned that will benefit the operators, aviation users, and other stakeholders.

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APPENDIX A ACRONYMS AND ABBREVIATIONS

A.1 ACRONYMS AND ABBREVIATIONS

AAM	Advanced Air Mobility
AC	Advisory Circular
ACAS	Airborne Collision Avoidance System
ACAS sXu	Airborne Collision Avoidance System X for Small Unmanned Aircraft
ACAS Xr	Airborne Collision Avoidance System X for Rotorcraft
ADS-B	Automatic Dependent Surveillance Broadcast
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATM	Air Traffic Management
CA	Collision Avoidance
CFR	Code of Flight Regulations
ConOps	Concept of Operations
DAA	Detect and Avoid
FAA	Federal Aviation Administration
GA	General Aviation
GAMA	General Aviation Manufacturers Association
GATMOC	Global Air Traffic Management Operational Concept
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GUFI	Global Unique Flight Identifier

I2V	Infrastructure-to-Vehicle
ICAO	International Civil Aviation Organization
ID	Identification
MASPS	Minimum Aviation System Performance Standards
MOPS	Minimum Operational Performance Standards
MPH	Miles per Hour
MSL	Mean Sea Level
NM	Nautical Mile
OCM	Operational Coordination Message
OSED	Operational Services and Environmental Definition
PO-ASAS	Principles of Operation for use of Airborne Separation Assurance Systems
PSU	Provider of Services for UAM
RF	Radio Frequency
SC	Special Committee
UAM	Urban Air Mobility
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
sUAS	Small UAS
TCAS	Traffic Collision Avoidance System
V2I	Vehicle-to-Infrastructure
UAT	Universal Access Terminal
UTM	Unmanned Traffic Management
V2V	Vehicle-to-Vehicle
WGS-84	World Geodetic System reference system

APPENDIX B REFERENCES

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