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Self Separation Support for UAS

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Recent guidance from the U.S. Federal Aviation Administration suggests that self separation needs to be a component of an Unmanned Aircraft System Sense and Avoid solution. The greater time horizon associated with self separation allows for pilot-in-the-loop operation, and, in fact, the nature of self separation demands more pilot involvement. The ability to effectively conduct pilot-in-the-loop self separation will be critically dependent on decision aides and advanced displays that allow pilots to make accurate and timely maneuvering decisions. This paper starts with a presentation of eight criteria that should be considered when defining requirements for a future separation assurance and collision avoidance system. Using these criteria, it is illustrated how the concept of conflict probing and the associated scalability enables a range of possible implementations, specifically matched to the available data, interfaces and displays.

I. Introduction

RECENT guidance from the U.S. Federal Aviation Administration (FAA) [1] suggests that self separation needs to be a component of an Unmanned Aircraft System (UAS) Sense and Avoid (SAA) solution in order for UAS to behave similarly to manned aircraft. Conceptually, UAS self separation is the protective (or conflict avoidance) method that precludes a threat aircraft from ever triggering a time-critical collision avoidance maneuver. Under self separation, aircraft should remain "well clear" of other aircraft or airborne hazards by following the priority rules of 14 CFR 91.113 [2], which determine which aircraft that has 'right-of-way'.

Self separation is also a key component of future Air Traffic Management (ATM) systems envisioned for both North America and the European Union that shifts some separation responsibilities from ground-based air traffic controllers to pilots. While self separation for manned aviation is being driven primarily by the anticipated increase in traffic density, self separation is more of a critical enabling technology for UAS, given how they operate. That is, unlike most manned aircraft which conduct point-to-point flights, unmanned aircraft more often conduct aerial work (e.g., aerial mapping or surveillance missions) which may be ad hoc in nature. Without the ability to self separate from other aircraft, UAS will be challenged to effectively conduct such operations.

Due to communications latency and reliability concerns, the time-critical collision avoidance component of SAA may require a fully autonomous capability, at least to account for the possibility of lost link. However, the greater time horizon associated with self separation allows for pilot-in-the-loop (PITL) operation, and, in fact, the nature of self separation demands more pilot involvement. Furthermore, it is likely that ATM authorities will be more accepting of an initial PITL SAA system that can serve as a stepping stone to a fully autonomous capability.

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The ability to effectively conduct PITL self separation will be critically dependent on decision aides and advanced displays that allow pilots to make accurate and timely maneuvering decisions. This paper presents a concept for a UAS self separation system, including a traffic conflict probe and concepts for how the results of the conflict probe might be presented to the UAS pilot.

II. Requirements and Criteria

For navigation, Required Navigation Performance (RNP) has been introduced to allow airspace requirements (use of airspace) to be satisfied independent of a specific method [3]. Similar to RNP, rather than mandating a single conflict/collision avoidance maneuvering algorithm[4] that could serve all UAVs, a set of performance-based requirements could serve as the basis for future separation assurance and collision avoidance systems. Criteria that should be considered when defining such requirements comprise:

1. Method used for resolving conflicts (prescribed[5], optimized[6], or combination[7] thereof);
2. Ability to handle multiple intruders;
3. Ability to integrate constraints imposed by other hazards;
4. Allowable types of maneuvers (speed changes, lateral, and/or vertical maneuvers);
5. Degree of coordination among ownship and intruder(s), ranging from completely independent to coordinated and cooperative;
6. Level of autonomy (ranging from manual pilot-in-the-loop to fully autonomous);
7. Ability of the pilot to assess the situation;
8. Technology maturity level.

In previous work, the use of conflict probing has been proposed as a concept to support the pilot in maintaining separation with other traffic. A conflict probe display contains information that both informs the pilot about a predicted loss of separation and provides guidance on how to maintain or restore separation. The current paper uses these eight criteria to better identify the potential and limitations of conflict probing.

III. Conflict Probe and Pilot Displays

Earlier research has addressed the potential of conflict probing to support UAV pilots with the Detect, Sense and Avoid task [4] and the integration of vehicle maneuvering constraints [5,6]. PITL simulations, in which the potential of conflict probing to support level 3 traffic awareness was evaluated, have demonstrated advantages in terms of safer and more efficient maneuvering decisions [7].

A. Method for resolving conflicts

Conflict probing consists of predicting the future separation between ownship and hazards for a set of ownship velocity vectors -representing possible combinations of Track, Flight Path Angle (FPA) and Speed- up to a predefined prediction horizon or look-ahead time. Separation requirements result in a cylindrical volume. Using predefined separation criteria, e.g., thresholds used to define a loss of separation or a collision hazard, the probing data indicates which ownship velocity vectors will lead to a future conflict and what the corresponding time to loss of separation is.

[4] Like what was done for the Traffic Alert and Collision Avoidance System (TCAS)
[5] Prescribed maneuvers are determined a priori based on a set of procedures (e.g., “right of way rules”).
[6] Optimized maneuvers involve a rule-based decision among several avoidance options that minimizes a given cost function.
[7] Combined approaches determine optimal maneuvers that follow prescribed rules, if possible.

To illustrate the concept of probing, Fig. 1 shows a top view of an example conflict geometry resulting from the presence of converging traffic. Vehicle A (center) represents ownship, vehicle B is the intruder aircraft; the dashed lines represent the current Tracks. Initial Bearing of the intruder is 290, initial Range is 5 NM; the intruder's Track is 050, flying level at a Speed of 250 kts. Both airplanes are at the same Flight Level. The depicted conflict Track band and conflict probe result from probing for a range of variations of the ownship Track angle (Ψ_A), for the current FPA and Speed. The separation criteria (yellow) used in this example are 1 NM lateral and 1kft vertical. The collision hazard criteria (red) used in this example are 0.25 NM lateral and 500 ft vertical.

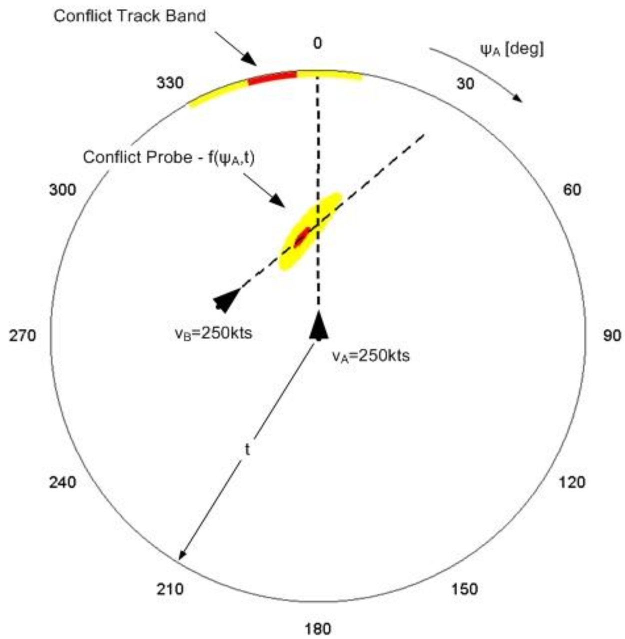

Figure 1. Top view of an example conflict geometry and Conflict Probing in the Track (Ψ_A) domain. The conflict probe indicates the ownship tracks that will result in a violation of the separation (yellow) or collision hazard criteria (red).

Note that although the separation requirements result in a cylindrical volume around the intruder, and the top view would yield a circle, the probing area shown in Fig. 1 does not represent this circle. The contours of the yellow area indicate the instants at which the separation circle will be penetrated, and the red area at which the collision hazard circle is penetrated, in case ownship changes its track in that particular direction.

In [8] an analytical approach is presented to determine six solution vectors (two track changes, two FPA changes and two speed changes) that prevent an intersection with the cylindrical volume. To illustrate the similarity between the probing approach and the approach discussed in [8], consider the situation depicted in Fig. 2. In this example, the required separation distance, represented by the circles, is 2 NM. The conflict space, with a separation below 2 NM, is visualized by mapping the conflict probes to a spatial reference frame, using the grey scale on the right.

In Fig. 2, the intruder comes from the right and will reach its Closest Point of Approach (CPA) exactly on the current track. If both aircraft continue with the current track and speed, actual loss of separation will take place at t_{LOS} with ownship in location 1 and the intruder in location 3 (ownship location on circle around intruder). If both vehicles maintain track, speed and FPA (and would not collide), the loss of separation will continue until the

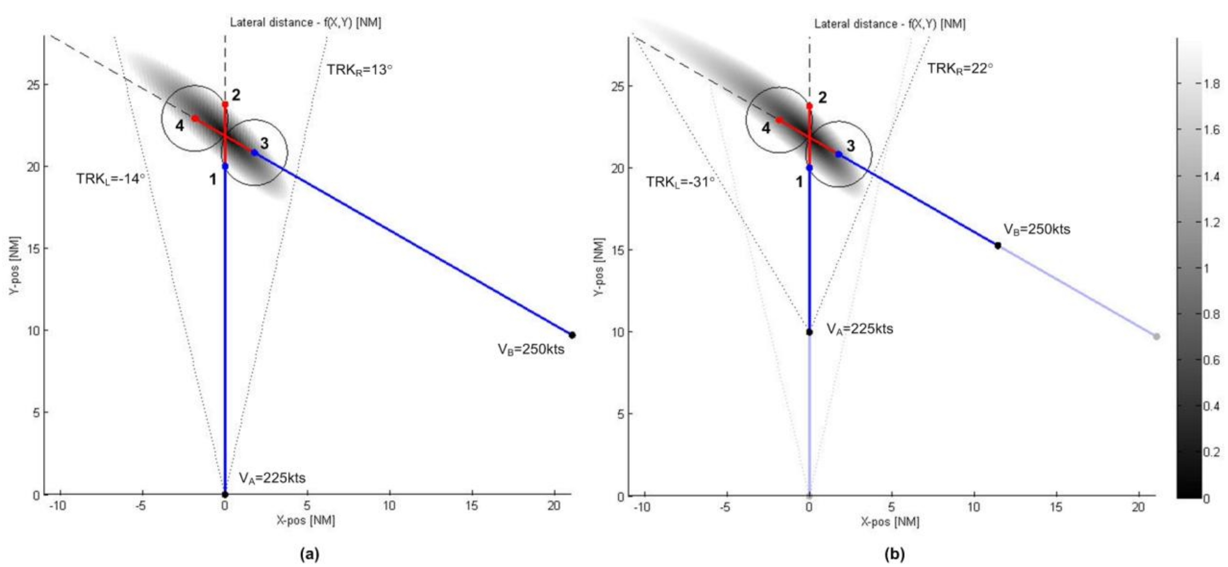

Figure 2. Probe-based visualization of an encounter and the resulting lateral options.

intruder reaches the location identified by point 4. Ownship will again be on the circle, this time at point 2. To prevent a loss of separation, ownship needs to maneuver in such a way that it stays outside of this (moving) circle. Assuming speed remains constant, ownship can avoid the circle by changing its track to the left or the right before t_{LOS}. The minimum change in track that is needed to avoid a loss of separation increases with a reduction in distance towards the location where the loss of separation is predicted. In Fig. 2b, ownship has travelled 10 more miles compared to the situation depicted in Fig. 2a. Since the probing area visualizes the locations where a loss of separation is predicted to occur for each particular track, it follows that the minimum required track change to avoid a loss of separation yields a track that just misses the area. In Fig. 2 these options are visualized as TRK_L and TRK_R. In [8] it is stated that the '*NextCAS II technique provides a novel approach to solving the collision detection and resolution problem. It differs from other methods we have examined in that it does not require a fixed look-ahead time (i.e., RA alert threshold) to declare a conflict situation*'. Analysis of the proposed algorithm reveals that this is achieved by computing the time t at which the aircraft has to maneuver from a pre-defined upper limit on vehicle maneuvering constraints which in turn yields maximum values for $TRK_L(t)$ and $TRK_R(t)$. In Fig. 2 this is the time at which ownship reaches the location on the current path where the track line that represents the avoidance maneuver has an angle with the current track that is equal to the computed threshold.

1. Limitations and solutions

The result of a state-based prediction is only valid for the time that the state of the involved aircraft does not change. This limits the useful look-ahead time. However, if intent information is available, it can be used to filter out false positives (predicted loss of separation that will not occur because the state of the intruder will have changed before the point is reached where a loss is predicted to occur). Furthermore, intent information can be used to identify those locations where a loss of separation will occur once the intruder has maneuvered. An example implementation of an Airborne Separation Assurance System (ASAS) Cockpit Display of Traffic Information (CDTI) that uses such a hybrid concept to control a conflict heading band was developed by NASA Langley and is discussed in [9].

To eliminate false positives when intent information is available, the time at which the intruder vector is specified to change (at the transition point) is used as the look-ahead limit for the state-based prediction that uses the current state. To prevent false negatives, the state from the transition point is used by the probing function beyond this time, and up to the total look-ahead time.

B. Ability to handle multiple intruders

When there is more than one intruder, the probing algorithm will generate additional areas where a loss of separation is predicted. The amount of the areas that will be displayed are a function of the look-ahead time (i.e., the prediction horizon); the size of the areas is a function of the separation criteria and data uncertainty. *For the same traffic density*, the amount of areas will increase with an increasing number of aircraft, but the location of these areas will also be further away from ownship. Because the effect of uncertainty in track and speed increases with an increase in look-ahead time, also the size of the area will increase. Figure 3 shows an example of a plan-view conflict probe display in the situation where a loss of separation is predicted on the current path and four other aircraft are in the vicinity.

Probe-area A indicates where a loss of separation with aircraft 1 (TRF3-1), flying in from behind, is predicted to occur. The conflict resolution system has computed that a change in track to the left is a feasible solution (indicated by the dashed magenta line, S). Figure 4 shows the same situation, depicted on a HUD with integrated Track-FPA probe. Subsection F, addressing the ability of the pilot to assess the situation, discusses the depicted elements in both displays in more detail.

Figure 3. Plan-view conflict probe display, depicting an example scenario with four other aircraft and an impending Loss of Separation.

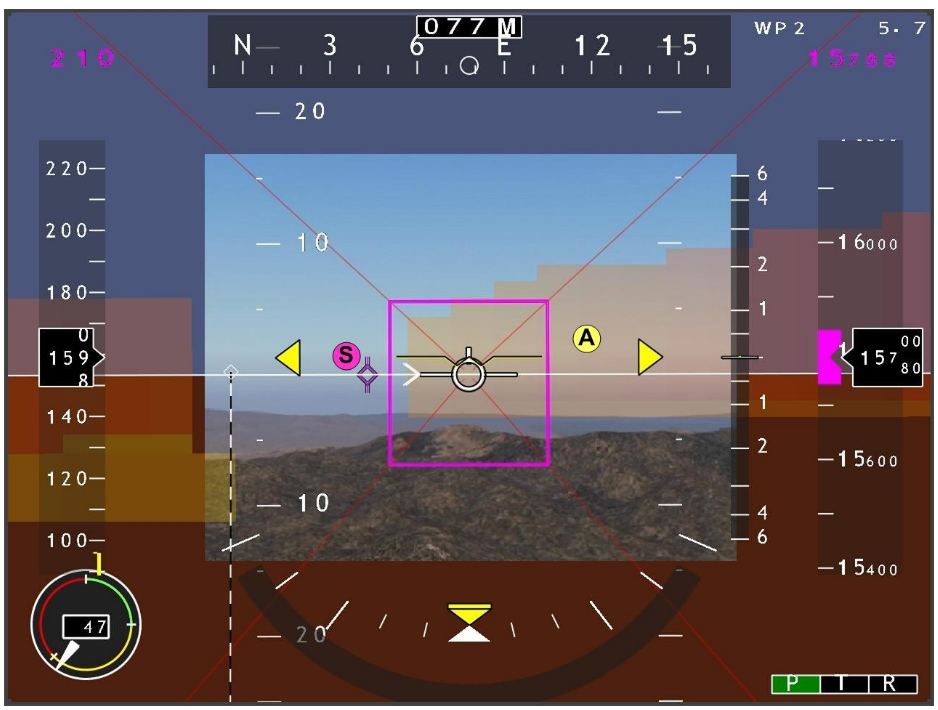

Figure 4. HUD with integrated Track-FPA probe, depicting the situation as displayed in Fig. 3, from an egocentric perspective viewpoint.

When computing a maneuver to prevent a loss of separation that is predicted to occur at a time T_{AL} ahead, it is important that the solution will not yield a new conflict within a pre-determined time. The approach discussed in [8] does not include a requirement that prevents the situation where a computed resolution almost immediately yields a conflict with another aircraft. It is indicated that in future work the '*resolution will be expanded from pair-wise to multi-aircraft situations*'. In [10] it is illustrated how by using an alert limit of T_{AL} seconds, and a search algorithm in the probing matrix that looks for vectors that are conflict free for at least T_{LA} seconds, a solution is generated that is conflict free for at least T_{LA}-T_{AL} seconds [add disclaimer regarding change in traffic speed or direction].

C. Integration of constraints and other hazards

In [11] the design and evaluation of an integrated avionics alerting system is described. Regarding the lack of integration, it is pointed out that *current alerting systems lack a common framework to share intent and integrate and prioritize information*. Furthermore, the lack of integrated strategic information for predictive SA and planning ahead is identified. In [12] it is discussed how conflict probing can provide a common framework for the computation of coordinated conflict avoidance maneuvers that include integration of multiple types of hazards and constraints such as vehicle performance and right-of-way rules. To illustrate this, Fig. 5 depicts the elements and information flow of a conflict avoidance concept that uses conflict probing as a framework for integrating data.

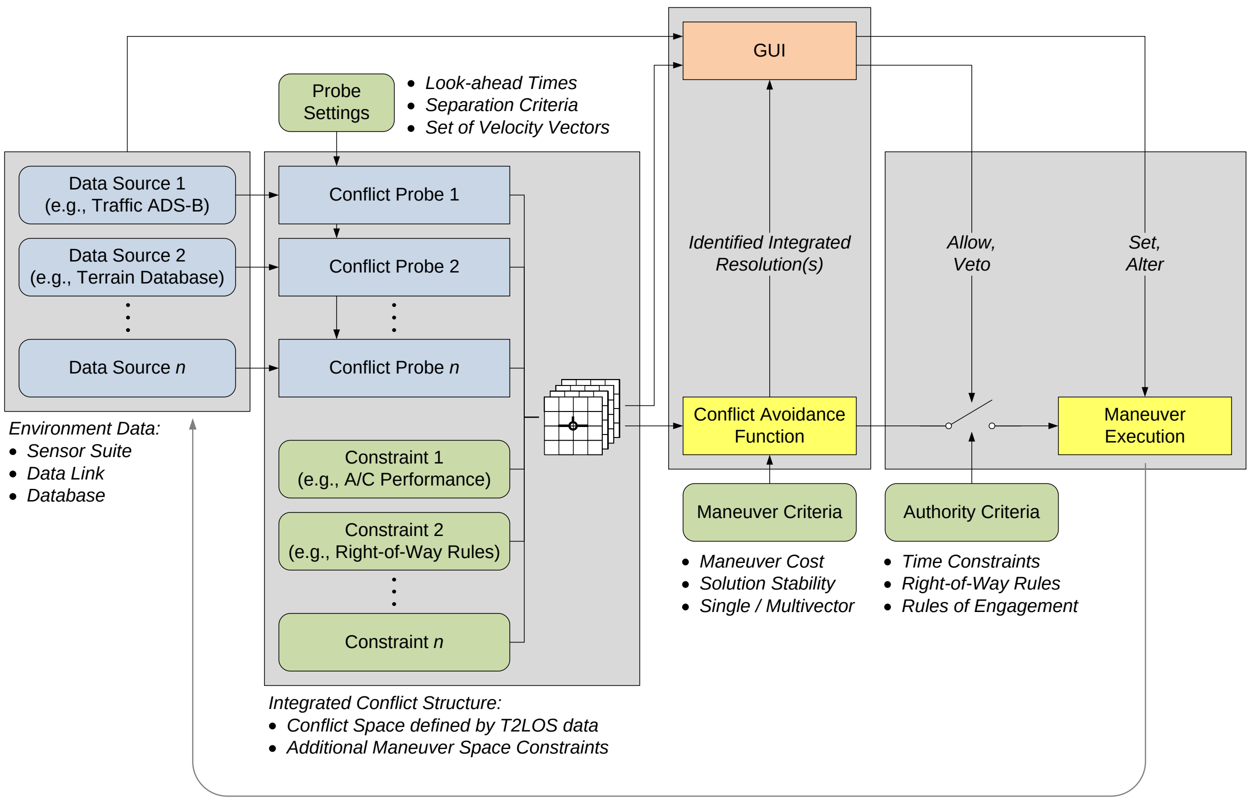

Figure 5. Elements and information flow of an integrated conflict avoidance concept based on probing.

The *integrated conflict structure* contains the conflict space, defined by the output of the conflict probes, and additional constraints to the maneuver space. Each cell in the structure represents a specific combination of Track, Flight Path Angle (FPA) and Speed; the value of the cell indicates whether that velocity vector leads to a conflict or whether it has to be excluded for any other reason. E.g., aircraft performance characteristics pose a fundamental constraint on the solution space. Procedural constraints such as the right-of-way rules [2] can be regarded as a set of situation dependent 'no-go' directions, and can be implemented as such, as one of the structure's layers.

In the approach presented in [8], performance limitations are specified as constraints for each of the six vectors that are computed. To maximize the available time until a loss of separation can no longer be prevented, conflict resolution should be able to use the full performance capabilities of the UAV, rather than command standard resolution maneuvers designed to accommodate the worst performing class of UAVs. The available 3D space for conflict resolution can be maximized by combining vertical and lateral maneuvers, and utilize the ability to convert the available speed margin relative to V_{min} or V_{max} (excess kinetic energy) into altitude (potential energy). For humans it is almost impossible to maximize the maneuvering performance in this way without violating one or more maneuvering constraints such as angle of attack, stall speed, load factor and bank angle. In [6] it is illustrated how information about the maximum safe maneuvering authority is integrated into the conflict prevention/resolution function of a probe using integrated control authority allocation and envelope protection functionality.

D. Allowable types of maneuvers

In Fig 1, an example conflict geometry was used to illustrate the concept of conflict probing from a single dimensional (Track) perspective. For that conflict geometry and separation criteria, the corresponding time to loss of separation (T2LOS) for a range of variations of all three velocity vector dimensions is depicted as a color coded object in Fig. 6a. This 3D data structure is one of the layers of the integrated conflict structure discussed in the previous subsection. The depicted 'volume' represents the conflict space in the velocity vector domain, providing a 'translation' of the relative motion problem, to a set of velocity vectors that should be avoided. All combinations of ownship Track (Ψ_A), FPA (γ_A) and Speed (v_A) that lie outside of this volume represent possible conflict prevention/resolution maneuvers. Hence, information about the trade-offs and *interdependencies of changes of the velocity vector components* can be readily obtained form the structure, supporting multi-dimensional conflict resolution. Figs. 6b-d show 'slices' of the 3D data structure for the original speed (v_0), FPA (γ_0) and Track (Ψ_0). E.g., Fig. 6b represents the conflict space in the Track-FPA domain. This data can be conformally integrated in a HUD or SV PFD (as was illustrated in Fig.4), providing a readily actionable representation of the maneuver space that is available with respect to traffic.

As probing is performed in real-time, the conflict space (i.e., its 'position', shape and T2LOS content) is continuously updated while the situation develops. Should intruder aircraft maneuver, this will be reflected by a corresponding change of the conflict space. By storing the probing data as presented here, as T2LOS records for the variations of the ownship velocity vector, the temporal characteristics of potential conflicts are retained, allowing prioritization and timing of avoidance maneuvers.

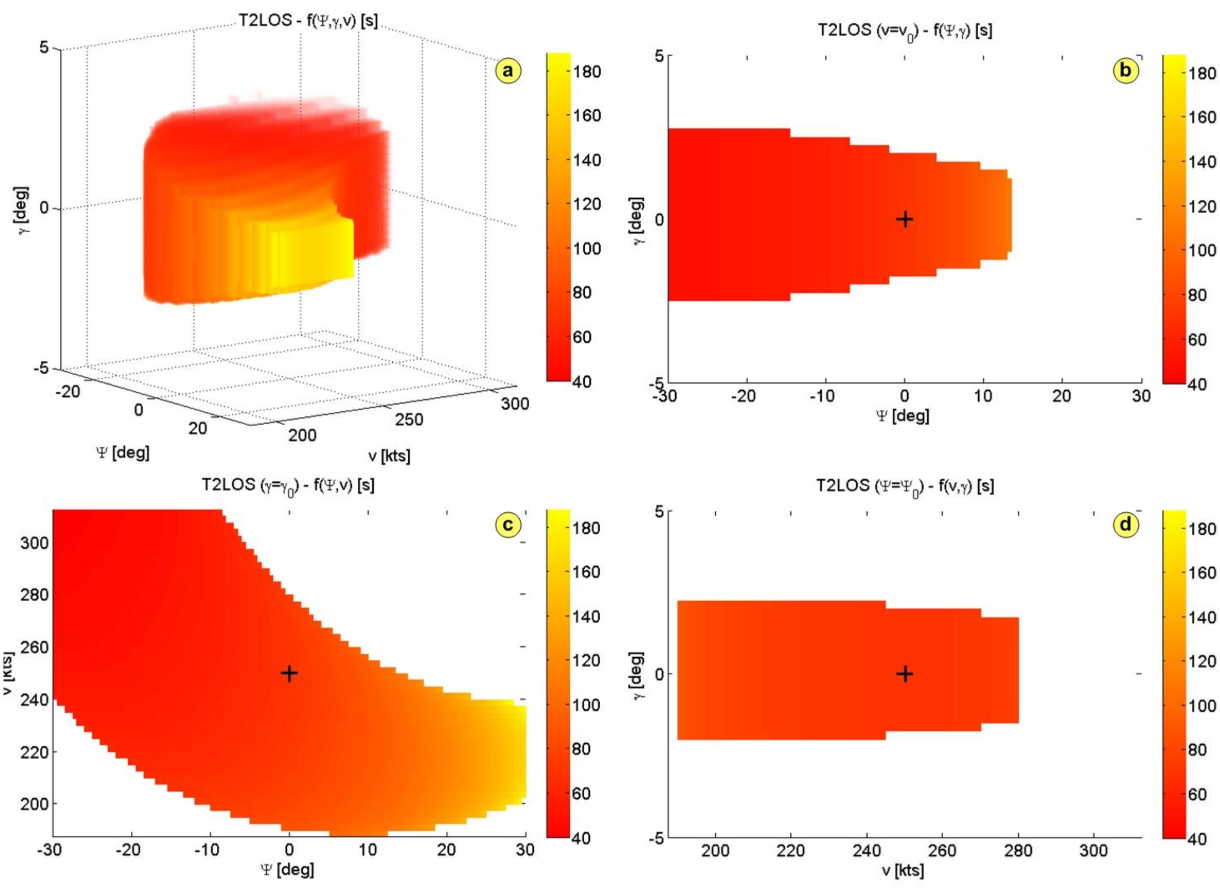

Figure 6. Example conflict space presented in the three domains constituting the flight path vector.

E. Degree of coordination

Current collision avoidance systems use the TCAS transponder to coordinate the resolution advisories that are provided. At present, no guidance exists for the coordination of maneuvers between two separation assurance systems. One possibility to enable cooperation between two systems is to provide the intended maneuver as intent information to the other system.

F. Assumed level of autonomy

In earlier work it has been argued that, although collision avoidance systems for UAS need to have sufficient authority to autonomously execute maneuvers in loss-of-link and/or time-critical situations, all other situations provide for the possibility of pilot involvement in the maneuver selection and execution. This enables a more evolutionary approach to UAS integration, allowing a gradual increase in separation system authority[8] as these systems mature and the complexities associated with automatic maneuver selection and execution are better understood.

With the probing concept and an appropriate Graphical User Interface (GUI), at the lowest level of system autonomy the pilot can derive the maneuvering decision from the location of the conflict areas and other constraints. At a higher system autonomy level, the identified avoidance maneuvers can either be used as suggestions, serving to support the pilot's decisions, or they can be executed automatically based on predefined authority criteria (triggered by e.g., time-critical or lost link conditions). In [4], the different options for the Level of Autonomy (LOA) are discussed.

G. Ability of the pilot to assess the situation

For all levels of autonomy where pilot involvement is required, pilots need to be provided with information that allows them to determine or assess a maneuver. In earlier research it has been demonstrated that a visualization of the probing data using a conformal integration in the Navigation Display (ND) and Head-Up Display (HUD) provides an intuitive understanding of the situation. Because this enables pilots to *anticipate* the results of changes to the current velocity vector, such a presentation contributes to obtaining level 3 Situation Awareness (SA). Additionally, in case the current velocity vector leads to a future conflict, and an automatic conflict avoidance function identifies one or more suitable avoidance maneuvers, the pilot can assess the proposed maneuver relative to all depicted constraints.

Whereas a conventional CDTI only supports level 2 traffic awareness, a particular benefit of a probing display is that it continuously supports level 3 traffic awareness. The following example illustrates this. The CDTI in Fig. 7 shows a plan view of the traffic situation, and Fig. 8 shows the corresponding HUD format.

The probing data shows that for the current path, no loss of separation is predicted with the other traffic. The proximity of probe area C to the current path provides the pilot with awareness that in case he has to depart from the current path, maneuvering to the left can quickly lead to a loss of separation. On the CDTI, probing area D represents the location where a loss of separation with aircraft 4 will occur if the track were changed in that direction. Area C indicates this for aircraft 3. For the current flight path angle, no loss of separation is predicted with aircraft 1 and 2.

The HUD view in Fig. 8 shows three probing areas. Area C corresponds to area C in Fig. 7, but now presented in the Track-FPA domain. Area D from Fig. 7 lies outside the field-of-view of the HUD (represented by the dashed white lines in Fig.7). The CDTI did not show areas A and B because these areas lie respectively above and below the current FPA. Area A represents the directions in which a loss of separation with aircraft 1 from Fig. 7 will occur and area B provides this information for aircraft 2.

From the HUD view, the pilot can see that climbing to the right will lead to a loss of separation with the overtaking traffic 1. This cannot be derived from the CDTI, since the altitude where the loss of separation is predicted is more than 1000 ft above the current flight path. This emphasizes the point that the depiction of the location where a loss of separation is expected to occur (level 3 awareness) is more relevant than the depiction of the current location of traffic itself (level 2 awareness).

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[8] Autonomy indicates what the system can do without pilot involvement, authority indicates what the system is allowed to do without pilot consent.

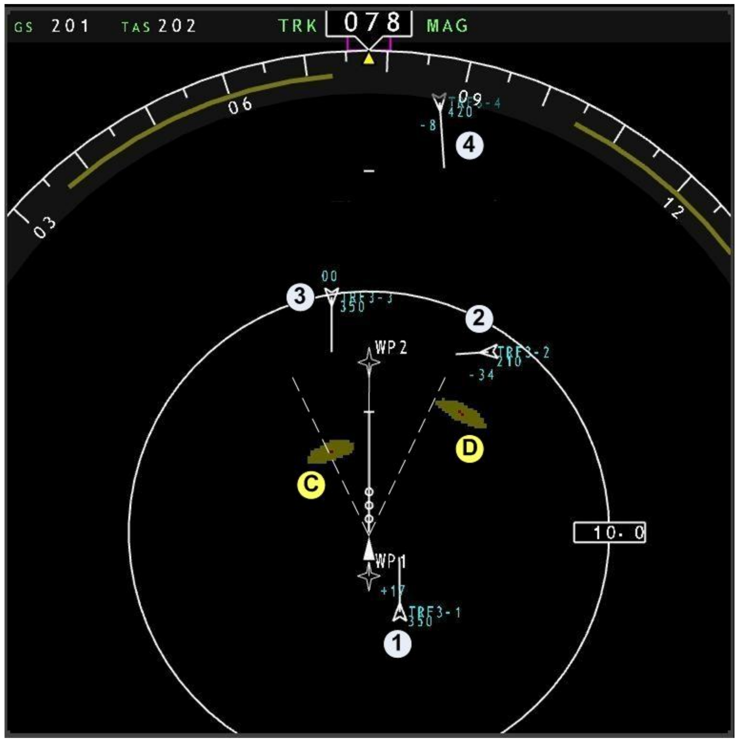

Figure 7. CDTI with integrated Track-Probe (1-D probe).

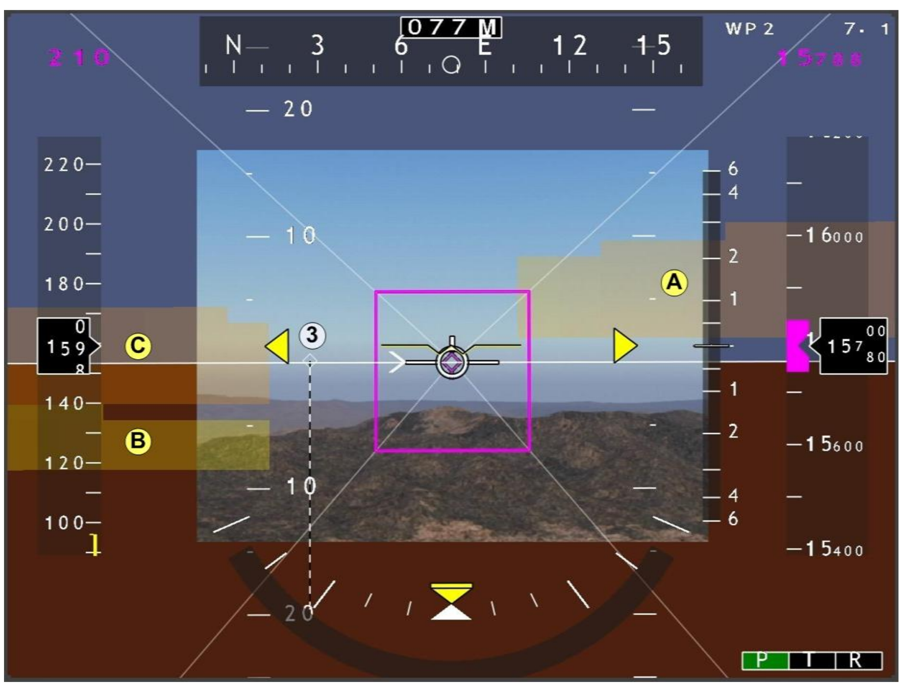

Figure 8. HUD with integrated Track-FPA probe (2-D probe).

H. Technology maturity level

Probing in itself is a concept, not a technology. The data needed for the computations depends on the technology used to obtain information about other traffic and is the same as the data that is needed by comparable concepts such as proposed in [8]. The range of options in terms of display, level of integration and level of autonomy make it a scalable concept, and hence the possibility for implementation is influenced by the choices made regarding these options. The current research addresses a range of options, varying from current state-of-the-art digital avionics used in commercial aircraft to the anticipated open-systems approach used in future UAS Control Stations. The scalability allows for an evolutionary approach, where the level of integration with other hazard data can increased in a stepwise fashion.

Conflict probing is currently being considered as a means to integrate the alerts from multiple hazard detection systems in the context of research performed for the NASA IIFD program [13]. Figure 9 shows the integration of a two-dimensional (Track-FPA) probe into an existing Synthetic Vision System (SVS) Primary Flight Display (PFD) used in this research.

The functionality of the existing SVS PFD is represented by the blue block and the probe functionality by the green one. The inputs to the traffic probe comprise ownship and traffic data and the thresholds for the minimal required separation.

Several definitions for these thresholds exist. In [14], the threshold that is used to declare a loss of separation is the Assured Normal Separation Distance (ANSD). Regarding this threshold, it is stated that '*the ANSD may be altered by the flight crew to mimic the current airspace separation standards. The parameters determine the separation that the CD uses to define a conflict (i.e., violations of separation) and generate alerts*'. The Conflict Detection Zone (CDZ) alerts indicate an expected loss of separation and the Collision Avoidance Zone (CAZ) alerts indicate that a collision situation is imminent. Hence, a second threshold can be defined based on the CAZ criteria. In the UAV Sense and Avoid (SAA) concept being developed [1], a so-called Self Separation Threshold (SST) and a Collision Avoidance Threshold (CAT) are used. The SST is defined as '*the boundary at which the self separation function declares that action is needed to preclude a threat aircraft from penetrating the collision avoidance threshold, thereby maintaining "well clear"*'. The CAT is defined as '*the boundary at which the collision avoidance function declares that action is necessary to avoid a collision and prevent the threat aircraft from penetrating the collision volume*'. The 'collision volume' is defined as '*the volume of airspace around the UAS that, if penetrated results in a MAC or NMAC*' [1].

The Test matrix shown in Fig. 9 is filled with vectors comprising all combinations of Track and FPA specified in the block FPA range & Track range. These vectors are tested against the traffic in the conflict prediction functions, and the result (time to loss of separation for the particular Track-FPA) is used to update the probe matrix. Using a pre-defined color coding scheme, the values of time to loss of separation are translated into a color. The resulting object is conformally integrated into the SVS PFD.

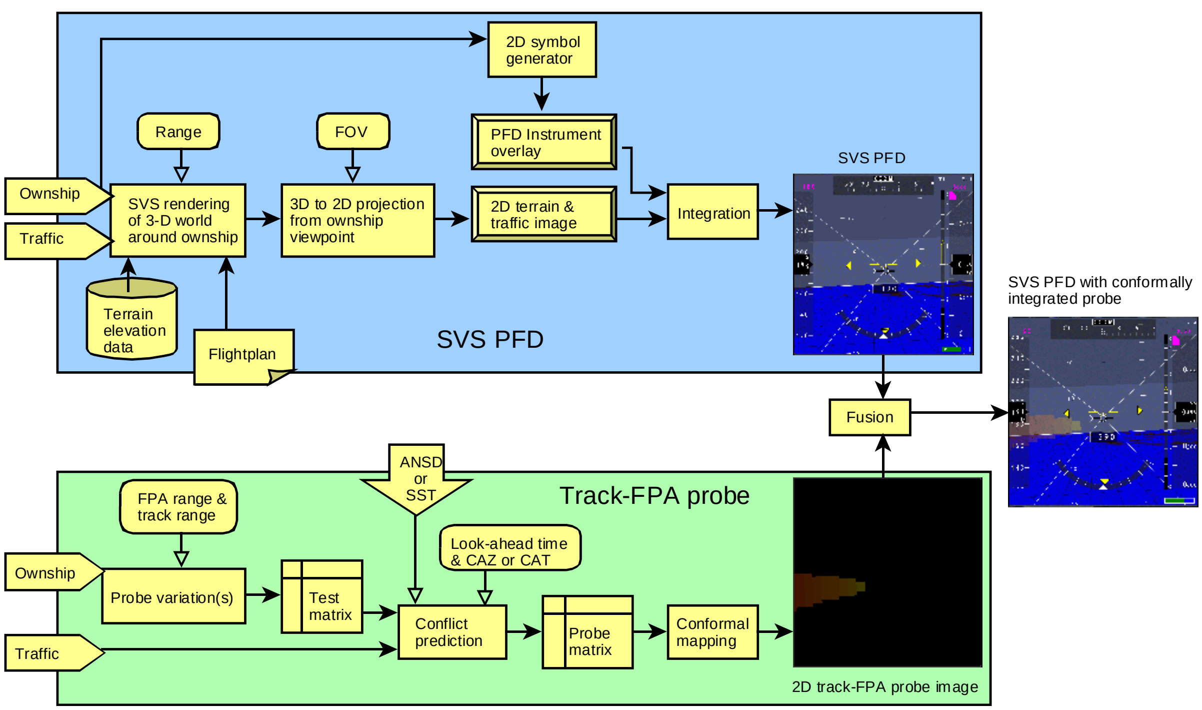

Figure 9. Implementation and integration of directional traffic probe data into an SVS PFD.

Figure 10 shows how the one-dimensional Track probe is integrated into a CDTI. The inputs to the traffic conflict probe are the same as those in Fig. 10. The test matrix now only comprises a range of Tracks for the current FPA.

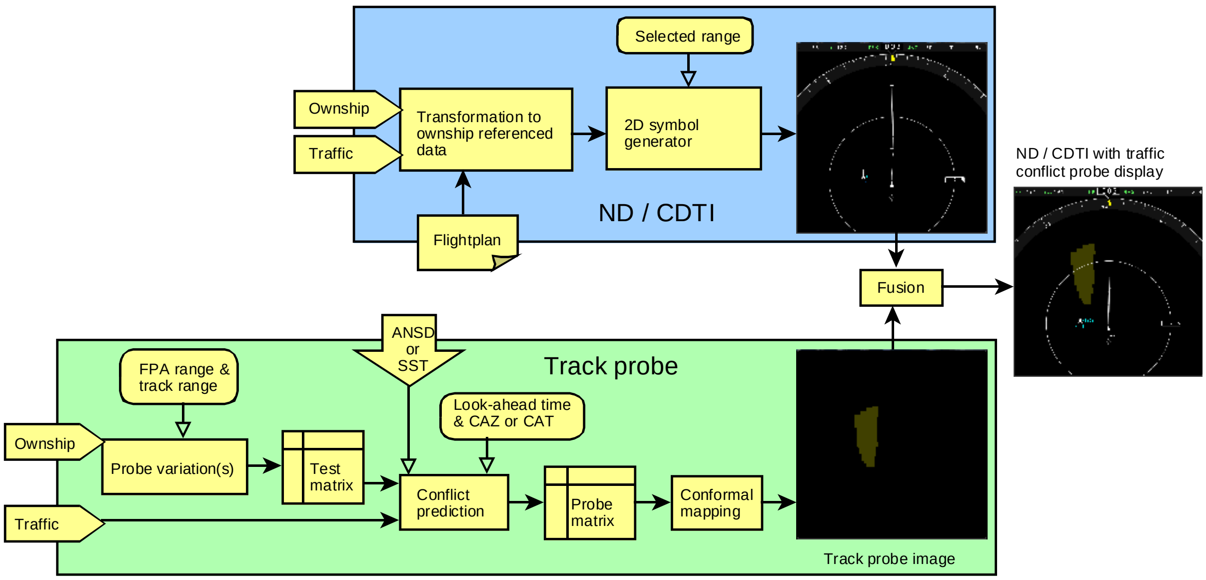

Figure 10. Implementation and integration of Track traffic probe data into an ND or CDTI.

IV. Implementation Options

The SVS PFD and ND implementation presented in the previous section require the presence of an SVS as a baseline system and assume the availability of accurate speed and directional data of other traffic. As illustrated in Fig. 5, the probing concept is scalable in terms of probe dimensions, types of hazards, prediction algorithms and look-ahead times. The scalability enables a range of possible implementations, specifically matched to the available data, interfaces and displays. The implementation of the conflict probing concept does not require an SVS as a baseline system. In order to determine the possibilities to integrate a conflict probe function and display into an existing system, it must be determined:

1. Whether and if so, how the required data can be obtained;
2. How the results from the conflict probe can be integrated into the existing PFD/HUD and ND.

I. Obtaining the data

Most algorithms for future conflict detection and separation assurance require speed and directional information of the intruders. Typically the availability of ADS-B information is assumed [8]. The FAA's proposed deadline for mandatory equipage of an ADS-B out capability is 2020, but there is a bill being debated in US congress to mandate ADS-B OUT as early as 2015 [15]. For near term implementation of a conflict probe display as a situation awareness aid this raises the question to what extent basic TCAS information, possibly augmented with information from passive EO or IR sensors can be used.

When obtained through an ARINC 735 bus, the TCAS range data has a resolution of 1/16 nmi [16]. Also, the relative bearing is rather inaccurate, only 9 degrees RMS is required [17]. Hybrid systems that combine output from an EO sensor with TCAS provide a better bearing accuracy. In [18] it is reported: '*The real value of sensor fusion of EO and TCAS tracks can be seen in the improved relative bearing estimate of the EKF, where the fusion of the EO-based line-of sight information eliminates the nearly 10 degree bearing error that was reported by TCAS*'. With the availability of range and bearing measurements from a hybrid system, it becomes possible to estimate the velocity and track of the intruder. The limited range resolution and the bearing inaccuracy will yield a 95% containment interval for the velocity and track estimates that is considerably larger than when this data is obtained through ADS-B. Furthermore, the 95% containment interval will be influenced by conflict geometry. Yet, with adequate filtering, it may be possible to use this concept for the computation of the conflict probe areas. To evaluate the impact of the limited range resolution and bearing inaccuracy on the location of the conflict probe areas, the setup shown in Fig. 11 has been created.

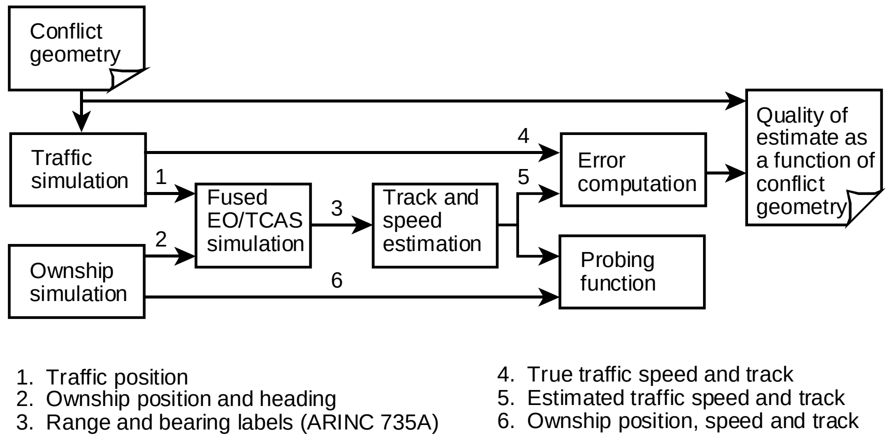

Figure 11. Simulation setup used to determine impact of conflict geometry on accuracy of intruder Speed and Track estimates.

Using this setup in the simulation environment, the 95% containment interval of estimated intruder speed and track is determined for a range of conflict geometries. The impact of an error in speed and/or track will increase with an increase in prediction time. To be able to evaluate the effect, the plan-view conflict probe display has been enhanced with the capability to compute the contour of the area for given 95% containment intervals of speed and track. Figures 12 and 13 show a research CDTI with a configuration panel to change the values of the 95% containment interval for the intruder tracks and speeds. An example scenario involving two other aircraft (TCAS symbols and labels) is depicted. In Fig. 12, the 95% containment interval for the intruder track errors is 1 degree and for speed 1 kts. In Fig. 13, these values have been increased to 5 degrees and 5 kts.

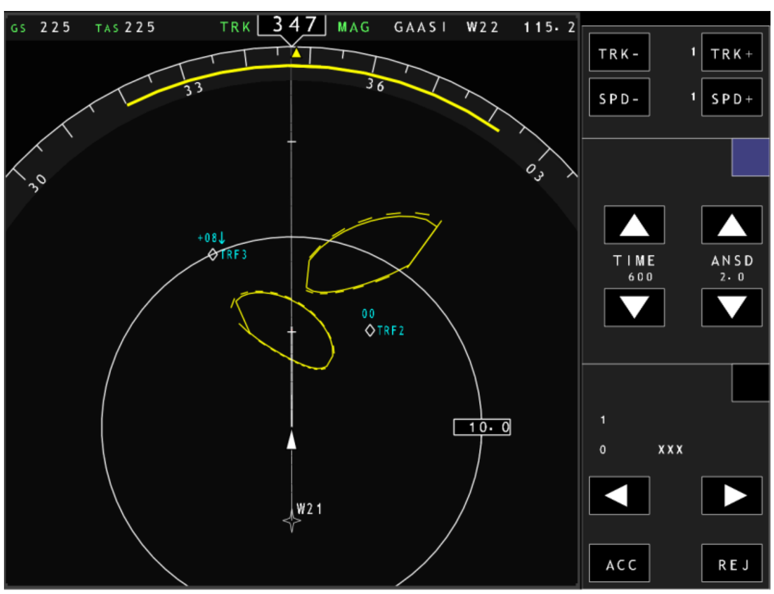

Figure 12. Impact of sensor inaccuracy (dashed) on the predicted conflict area (solid); intruder data uncertainty interval: 1 deg, 1 kts.

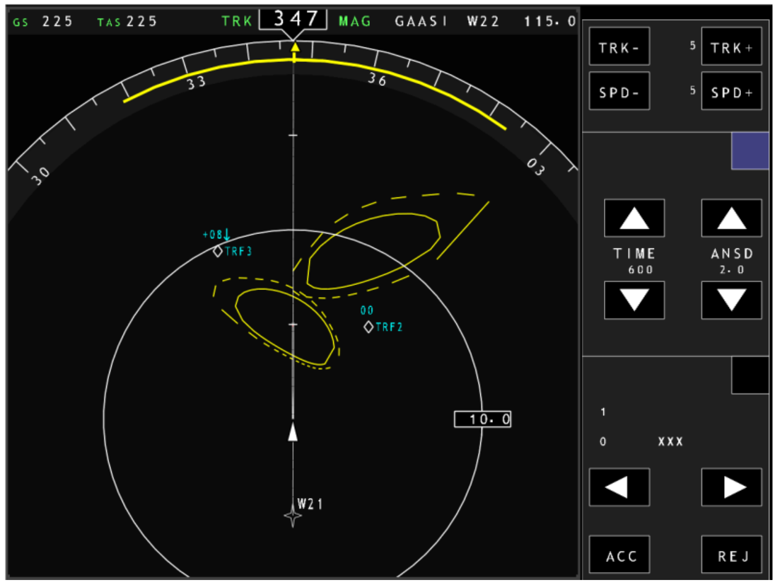

Figure 13. Impact of sensor inaccuracy (dashed) on the predicted conflict area (solid); intruder data uncertainty interval: 5 deg, 5 kts.

The solid contours in Figs 12 and 13 depict the area where loss of separation is predicted based on the true state of the intruder. The dashed line indicates the contour that contains all possible areas that result from different combinations of track and speed that lie within the predefined 95% containment interval. As can be seen from Fig. 13, the impact of the uncertainty is asymmetrical. During the next phase of the research it will be determined whether it is possible to use a look-up table containing the data which relates the magnitude of the 95% containment interval to the particular conflict geometry to compute the conflict area.

J. Integrating the presentation

The demonstrator that has been created using the SVS setup shown in Fig. 9 performs the fusion in memory by translating the probing data into a texture which subsequently is conformally mapped into the SVS format. This was possible because the software of the SVS prototype could be enhanced with the required functionality. Alternatively, an SVS or HUD that has the capability to integrate live sensor video can use such a capability to integrate a probing image.

Similar to how the output from TAWS can be used on the weather radar input of an ND for depiction of terrain, the output that contains the probe data as a function of Track angle and Range can be translated to ARINC 708A [19], as depicted in Fig.14. In this way, the probe function depicted in Fig. 10 can be integrated as a separate device, using only existing interfaces for input and output, enabling a one-dimensional traffic probe to be displayed on a conventional ND.

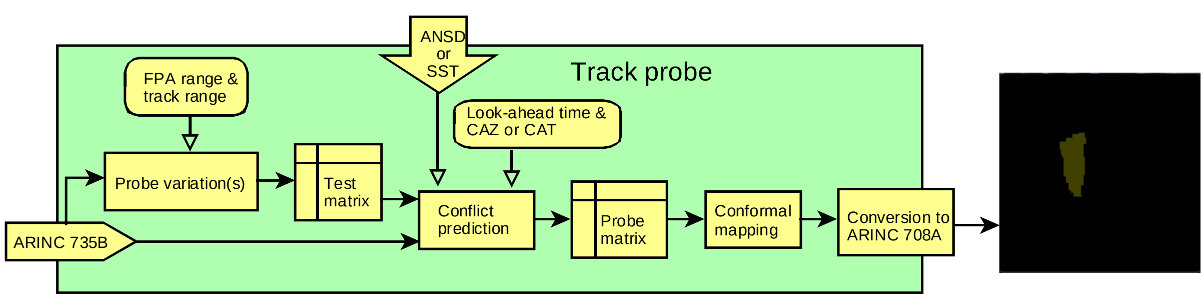

Figure 14. Depiction of conflict probe on ND using WXR input.

K. Integration into UCS Architecture

Historically, UAS Control Systems (i.e., the components necessary to control and manage UA operations in the air and at launch/recovery sites) have been closed systems, utilizing proprietary interfaces and software modules developed by the prime contractor. In order to promote innovation and software reuse, mitigate obsolescence, and enable incremental capability upgrades, future UCS architectures are adopting a Modular Open System Approach (MOSA) that can be scaled according to the individual UAS needs. By adopting this approach, the UCS is partitioned into numerous software modules -agnostic to specific hardware or operating systems- that contain services where "best of breed" solutions can be inserted.

This architectural approach lends itself well to the integration of a future Sense and Avoid (SAA) system given the multiple components and services that may contribute to Sense and Avoid as depicted in Fig. 15. As shown in the figure, the MOSA architecture features standard protocols and interfaces, and promotes third party Service Oriented Architecture (SOA) services as common plug-ins to the architecture. Additionally, the multiple SAA software modules, depicted in red, are all candidates for competitive development.

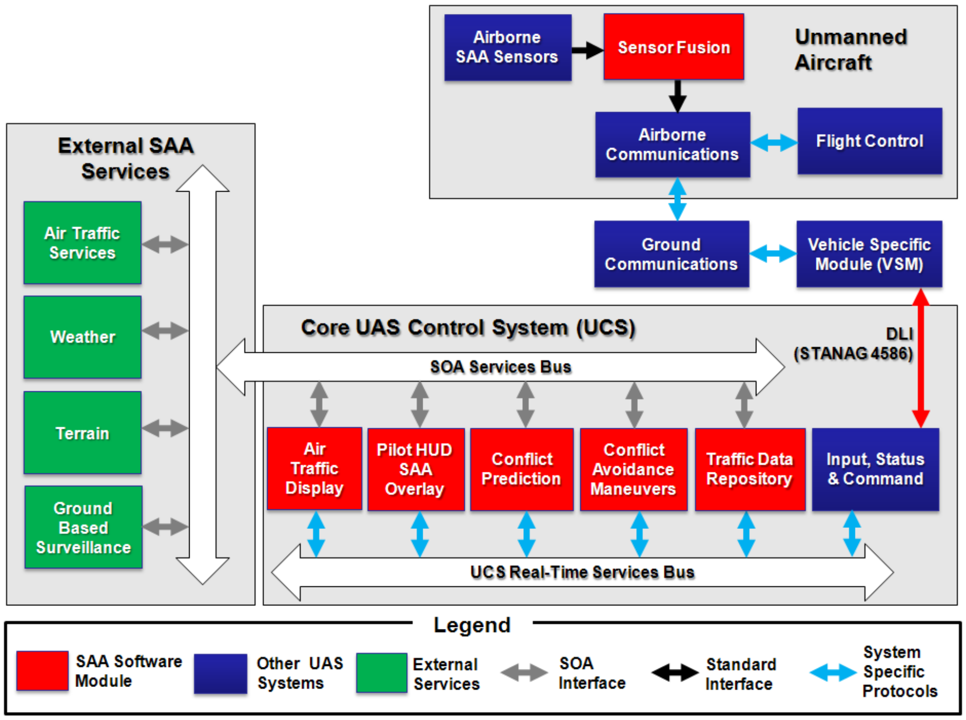

Figure 15. MOSA based integration of a future Sense and Avoid (SAA) system.

V. Summary and Conclusions

In this paper, conflict probing has been proposed as an element of a UAS self separation concept. Conflict probing consists of predicting the future separation between ownship and hazards for a set of ownship velocity vectors -representing possible combinations of Track, Flight Path Angle (FPA) and Speed- up to a predefined prediction horizon or look-ahead time.

The potential solution space generated by conflict probing comprises all possible vectors that will prevent a loss of separation with a pre-defined time within the particular probing dimension. The dimensionality of the solution space is determined by the dimensionality of the probe. The conflict avoidance vector is obtained through a search in the solution space using a set of pre-defined criteria which can include a cost function, rules of the road and thresholds in time or space. The solutions that can be obtained from the proposed conflict probing concept include those that would be generated by the NEXTCAS system described in [8]. The ability to generate conflict avoidance vectors which remain conflict free for a specified amount of time is obtained through appropriate selection of the alerting time and the look-ahead time.

Possible implementations range from the depiction of status information (the conflict areas) to the computation of a single conflict prevention command. At the lowest level of system autonomy, the pilot can derive the maneuvering decision from the location of the conflict areas and other constraints. At a higher system autonomy level, the identified avoidance maneuvers can either be used as suggestions, serving to support the pilot's decisions, or they can be executed automatically based on predefined authority criteria. This allows a gradual increase in separation system authority as these systems mature and the complexities associated with automatic maneuver selection and execution are better understood.

The probing concept is scalable in terms of probe dimensions, types of hazards, prediction algorithms and look-ahead times. This scalability enables a range of possible implementations, specifically matched to the available data, interfaces and displays.

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