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Abstract:
This study develops evaluation criteria for systems and technologies against the Cooperative Conflict Avoidance (CCA) requirements for unmanned flight at and above FL430 as part of Step 1 of the Access-5 program. These evaluation criteria are then applied to both current and future technologies to identify those which might be used to provide an Equivalent Level of Safety (ELOS) for CCA. This document provides the results of this analysis of various systems and technologies intended for evaluation as part of the CCA work package.

Status:

SEIT-Approved

Limitations on use:
This document is not intended to advocate a solution and instead should be used as guideline to trade current and future sensor technologies. All criteria and metrics were evaluated for enroute operations above FL430 and may not be completely applicable to all flight envelopes.

NASA ACCESS 5

Cooperative Conflict Avoidance

Sensor Trade Study Report

Version 2

30 November 2004

Prepared by:

NASA ACCESS 5
Work Package 2, CCA Team

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

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1 Scope

1.1 Identification

This document provides the results for an analysis of various systems and technologies intended for evaluation as part of the Cooperative Conflict Avoidance (CCA) work package. The CCA work package is one aspect of a larger program, entitled ACCESS-5, to develop technologies and certification criteria that would permit Remotely Operated Aircraft (ROA) to safely operate within the various classes of US national airspace alongside conventional air traffic.

1.2 Objectives

The objective of this study is as follows:

- To develop criteria to evaluate systems and technologies against the CCA requirements for unmanned flight at and above FL400 as part of Step 1 of the Access-5 program.
- To identify current and future technologies that might be used to provide Equivalent Level Of Safety (ELOS) for CCA and evaluate them against these criteria.
- To present various technology solutions that may be used in the design of the Air Vehicle Control Station (AVCS). These technologies when used together should create an environment that provides sufficient information for the ROA-Pilot to conduct flight operations/management to an Equivalent Level of Safety for collision avoidance.

2 Evaluation Methodology

2.1 Orthogonal Systems Information Domains

The analytical basis for system and technology evaluation applied in this trade study is derived from the Department of Defense Architecture Framework (DoDAF), as modified by IEEE-1220 (Standard for Application & Management of the Systems Engineering Process). The DoDAF recognizes 3 different domains of information related to any operational system and its supporting elements. The DoDAF refers to these as the “Operational View”, the “Systems View”, and the “Technical View”. However, upon examination one can identify that the information contained in the Systems View and the Technical view are somewhat overlapping, or non-orthogonal. IEEE-1220 resolves this issue and defines 3 distinct views of system information that are mutually orthogonal to each other: Operational, Functional, and Design (or Physical) views. These 3 views are truly orthogonal, and when taken together can describe all aspects of a system and its operating environment. Figure 1 illustrates the interrelationships of these 3 orthogonal information domains.

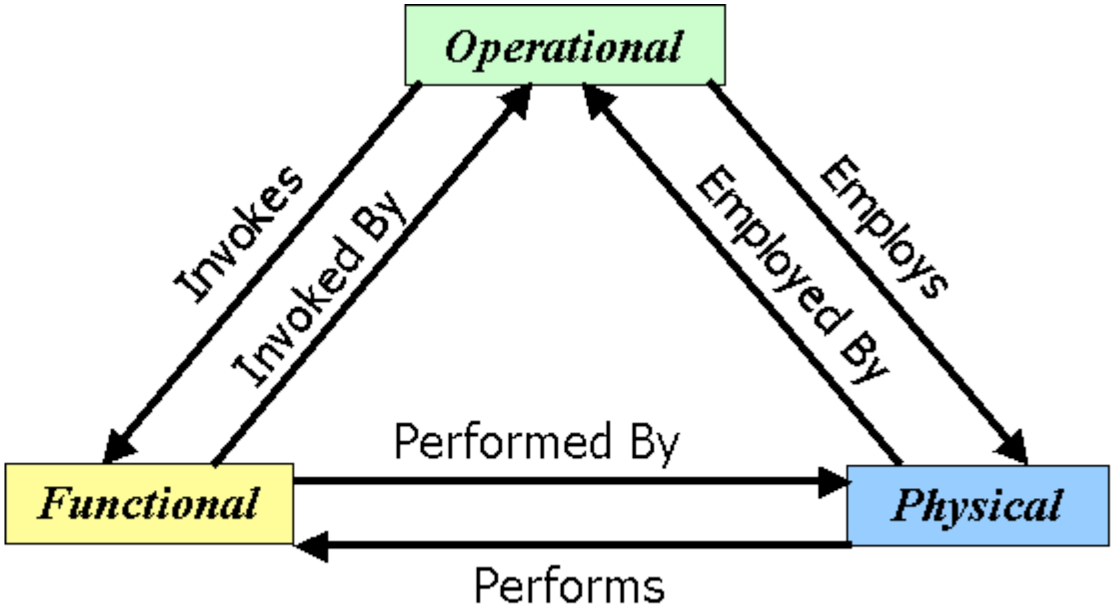


Figure 1 - Orthogonal System Information Domains & Their Relationships

Requirements and system metrics for the CCA sensor trade studies were allocated across these three domains. Trade study evaluations focused on analyzing each particular system with respect to its performance in each of the three orthogonal domains. The specifics of this process are described in the following sections.

2.2 Evaluation Metrics & Scoring Criteria

The operational-functional-physical analytical model begins by identifying appropriate and applicable measurable performance parameters for the target system in all three of the system information domains. These parameters are listed under their respective domains in Table 1 below.

Operational Domain		***Functional Domain***		***Physical Domain***	
Conflict Look-ahead Time	Sec	Field Of Regard (Azimuth)	Deg (+/-)	Total Weight	Lbs.
Trustworthy (G'tee of Accy)	NIC	Field Of Regard (Alt)	Deg (+/-)	Total Cost (Aquire Only)	$
Probability of Detection	%	Detection Range	Nmi	RMS Power Consumption	Watts
Probability of False Alarm	%	Refresh Rate	Sec.	Total Volume	In.^3
Operational Maturity	TRL	Azimuth Accuracy	Deg. (+/-)		
Availability	%	Elevation/Altitude Accuracy	Deg (+/-)		
Target Track Capacity	#	Range Accuracy	Nmi (+/-)		
Reliability	MTBF				
Coop or Non-Coop	C/N				
Env/Weather Susceptibility	Y/N				

Table 1 - Evaluation Parameters

Each of the chosen parameters is related to a quantifiable measure of effectiveness or performance associated with the system, its ultimate goals, and its functional and operational capabilities. Table 1 also defines the units of measure used to evaluate the actual metric value for the subject system.

2.2.1 Quantitative Scoring of Metrics

Each quantified metric is assigned a four-level qualitative scoring scheme as a means to compare relative performance of various trade study system or technology options. Numerical values of 0, 1, 2, and 3 are applied to the four qualitative scoring levels, with the colors red, yellow, green, and blue are respectively associated. The scoring value is of no importance when comparing individual performance parameters. Table 2 below provides a brief description for the levels.

LEGEND	Description
3	Extremely well-suited to CCA objectives
2	Meets/exceeds basic CCA needs
1	Potential value, but likely unacceptable
0	Clearly unacceptable to meet CCA objectives

Table 2 - Qualitative Scoring Legend

These scores must be referenced to appropriate ranges of each performance metric used to assess potential CCA solutions in the operational, functional, and physical domains. Table 3 shows the ranges used for each of the parameters of Table 1. The rationale behind each range is discussed in the *"CCA Functional Requirements Document"*.

Measurement Parameters		2.5	2	1	-1
Operational Domain	***Units***				
Conflict Look-ahead Time	Sec	> 30	>= 23.5	>= 12.5	< 12.5
Trustworthy (G'tee of Accy)	NIC				
Probability of Detection	%	> 99	>= 97	>= 90	< 90
Probability of False Alarm	%	< 0.5	<= 1	<= 3	> 3
Operational Maturity	TRL	>= 8	>= 6	>= 3	< 3
Availability	%	> 98	>= 95	>= 90	< 90
Target Track Capacity	#	> 20	>= 10	>= 5	< 5
Reliability	MTBF	> 12000	>= 8000	>= 5000	< 5000
Coop or Non-Coop	C/N	Non-Coop	Coop	NA	NA
Env/Weather Susceptibility	Y/N	NA	N	Y	NA
Functional Domain					
Field Of Regard (Azimuth)	Deg (+/-)	> 135	>= 110	>= 60	< 60
Field Of Regard (Alt)	Deg (+/-)	> 20	>= 15	>= 10	< 10
Detection Range	Nmi	> 10	>= 8	>= 4	< 4
Refresh Rate	Sec.	< 1	<= 2	<= 5	> 5
Azimuth Accuracy	Deg. (+/-)	< 1	<= 2	<= 4	> 4
Elevation/Altitude Accuracy	Deg (+/-)	< 1	<= 2	<= 4	> 4
Range Accuracy	Nmi (+/-)	< 0.05	<= 0.1	<= 0.2	> 0.2
Physical Domain					
Total Weight	Lbs.	< 25	<= 35	<= 50	> 50
Total Cost (Aquire Only)	$	< 20000	<= 90000	<= 120000	> 120000
RMS Power Consumption	Watts	< 60	<= 150	<= 200	> 200
Total Volume	In.^3	< 500	<= 650	<= 800	> 800

Table 3 - Parameter Evaluation Ranges

2.2.2 Operational Metrics

Metrics associated with the operational domain are typically related to time-based measures and/or mission phases where the system functionality is employed. However, operational metrics can also be associated with the operational environment within which the intended system must perform. The operational metrics shown in Table 3 were selected for this trade study, as they are all either directly or indirectly related to the CCA requirements.

2.2.3 Functional Metrics

Metrics associated with the functional domain are typically related to functional transformations of some measured system input into an output that is directly related to the system's intended function and performance. This includes not only those parameters produced by a system function, but also the accuracy of these parameters and any associated limits placed on their usefulness. The functional metrics shown in Table 3 were selected for this trade study, and are based on the CCA functional requirements

2.2.4 Physical Metrics

Metrics associated with the physical domain are all of those measures related to the physical needs of the system in order to be installed aboard the subject UAV. The physical metrics shown in Table 3 include principal physical constraints that all aircraft designs share in common with respect to systems and equipment.

2.2.5 Evaluation of Integrated System Solutions

Evaluating integrated systems is not as straightforward as presented in this document. An attempt was made to match sensor systems, which compliment one another. Sensors, which score low in a certain section, are matched with a system that scored well in that particular parameter.

In the Operational Domain each parameter is evaluated and the following data fusion logic is applied: The worse of the two individual scores is used to combine all parameters excluding Probability of Detection and the Probability of False Alarms. The reason for this is based on the assumption that for non-statistic based criteria the system can only be as good as its weakest component. The probability based parameters use the better of the two independent scores due to the assumption that, given the two systems are working properly, the overall performance of the system should not be worse than the individual sensor.

The functional domain also employs the philosophy that the overall system can only be as good as its weakest link and therefore uses the worse of the two systems for all raw data parameters including detection range and field of regard. If an intruder is outside a sensors protected volume, the corresponding accuracy of the sensor should not be used. With the use of the worst detection parameters between combined sensors it is acceptable to assume the accuracy of the smaller protection volume to be the better of the two sensors.

The physical domain is the simplest of the three domains to combine. Simple summations of the sensors parameters are used. It is noted that there are current technologies that already combine sensors and provide shared usages of equipment which should reduce some of these combined values.

3 Technology Evaluations

3.1 Individual Systems/Sensors

3.1.1 Traffic Alert & Collision Avoidance System (TCAS)

TCAS is designed to provide pilot advisories of proximate traffic by taking advantage of ICAO-compliant transponders already installed on aircraft to operate with ATC ground-based radars. On board TCAS equipment interrogates all aircraft transponders in the vicinity and, based on the replies, tracks relative bearing, range. Relative bearing is determined by use of a directional antenna and the range by the time between interrogation and receipt of the reply. These tracks are then used to calculate an estimated time to Closest Point of Approach (CPA) using a tau time concept, which divides slant range, by the closing speed (range/range rate) in the xy-plane. When altitude is contained in the transponder reply, (Mode C and Mode S Transponders) TCAS will also calculate the time to reach co-altitude.

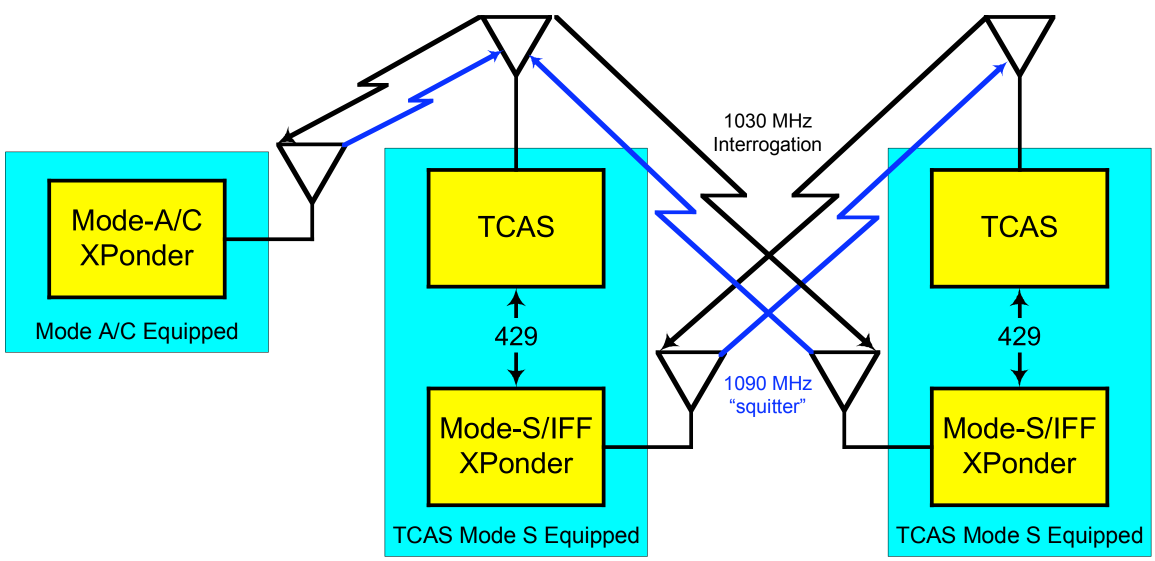


Figure 2 - TCAS Principal of Operation

As shown in Figure 2 above, the system consists of a TCAS processor, a directional antenna and an ICAO-compliant transponder. The TCAS sends out interrogations on the 1030 MHz frequency, which is received by a separate antenna connected to the transponders. The transponders then replies on the 1090 MHz frequency. The content of the response depends on the type of transponder the target aircraft is equipped with. Mode A responds only with a vehicle identification, Mode C responds with an altitude in increments of 100 ft, and Mode S responds with both identification and altitude in increments of 25 ft.

3.1.1.1 TCAS I

Principle of Operation: TCAS I is the first generation of TCAS developed to provide pilots with ATC-like situational awareness. The system interrogates all vehicles with Mode A, Mode C or Mode S transponders and displays the received information to the pilot via a visual display. It tracks up to 35 vehicles and determines projected traffic alerts based on the time to CPA, as described in the previous section. When a possible near miss or collision is detected, the pilot is alerted with a Traffic Advisory or TA. The system does not provide an advisory maneuver to de-conflict. The pilot must use the situational awareness provided to visual acquire the intruder vehicle and respond accordingly.

Operational Availability: TCAS I is fully operational and certified in the US only (TCAS I is not recognized outside the US). It currently is mandated as minimal equipment for passenger aircrafts with seats for 10-30. RTCA has published MOPS, DO-197A which provides the requirements definition and test procedures while the FAA TSO C118A defines the certification requirements for TCAS I equipment.

Equipment Availability: TCAS I is commercially available off the shelf from multiple manufacturers. The functionality amongst the systems evaluated (Honeywell CAS 66A, KTA 970 and Goodrich TCAS I) all had similar capabilities and are summed up in the evaluation metrics shown below in Table 4.

Measurement Parameters		Quantitative Measures	Qualitative Scoring
Operational Domain	***Units***		
Conflict Look-ahead Time	Sec	90	3
Trustworthy (G'tee of Accy)	NIC		1
Probability of Detection	%	>99	3
Probability of False Alarm	%	8	0
Operational Maturity	TRL	9	3
Availability	%	95	2
Target Track Capacity	#	35	3
Reliability	MTBF	8700	2
Coop or Non-Coop	C/N	C	2
Env/Weather Susceptibility	Y/N	N	2
Functional Domain			
Field Of Regard (Azimuth)	Deg (+/-)	180	3
Field Of Regard (El)	Deg (+/-)	20	2
Detection Range	Nmi	30	3
Refresh Rate	Sec.	1	2
Azimuth Accuracy	Deg. (+/-)	5	0
Elevation/Altitude Accuracy	Deg (+/-)	1	2
Range Accuracy	Nmi (+/-)	0.05	2
Physical Domain			
Total Weight	Lbs.	22	3
Total Cost (Aquire Only)	$	$40,000	2
RMS Power Consumption	Watts	80	2
Total Volume	In.^3	630	2

Table 4 - TCAS I Evaluation Metrics

Evaluation Overview: Overall TCAS I is shown to either meet or exceed the CCA needs for most parameters. In the Operational Domain the Trustworthy parameter is depicted as yellow or likely unacceptable due to the fact that the system relies on the integrity of the other vehicle. There is no way to verify the validity of the data. The probability false alarm rate is estimated to be on the order of 8%. This high occurrence has been documented in the percentage of pilots ignoring the TCAS I TA's or determining it to be a nuisance. The main cause for high false alarm rates is the poor azimuth accuracy, which is shown in the Functional Domain metrics.

3.1.1.2 TCAS II

Principle of Operation: TCAS II provides all of the capabilities of TCAS I with the addition of a Resolution Advisories or RA. The RA provides the pilot with a recommended vertical escape maneuver to maintain or increase the vertical separation with intruding aircraft. While TCAS II interrogates all modes of transponders, it must be equipped with a Mode S transponder. The requirement for a Mode S transponder allows coordination messages to be sent between two maneuvering aircraft equipped with TCAS II. It is designed to operate in traffic densities of up to 0.3 aircraft per square nautical mile (nmi), i.e., 24 aircraft within a 5 nmi radius, which is the highest traffic density envisioned over the next 20 years.

Operational Availability: TCAS II is fully operational and certified in the US and internationally. It currently is mandated as minimal equipment for passenger aircrafts with more than 30 seats or above 15,000 kg (Public Law 100-223) in the US. TCAS II Version 7 complies with ICAO Standards and Recommended Practices (SARPs) for ACAS II and was mandated for carriage by 2003. RTCA has published MOPS, DO-185A that provides the requirements definition and test procedures while the FAA TSO C119B and Advisory Circular 20-131a defines the certification requirements for installation of TCAS II equipment. Advisory Circular 120-55a defines the procedures for obtaining operational approval for use of TCAS II.

Equipment Availability: Certified TCAS II is commercially available off the shelf from three separate manufacturers (L-3 ACSS, Honeywell, Rockwell Collins). Each has distinguishing characteristics but overall has similar parameters with respect to this evaluation and is shown in Table 5 below.

Measurement Parameters		Quantitative Measures	Qualitative Scoring
Operational Domain	***Units***		
Conflict Look-ahead Time	Sec	120	3
Trustworthy (G'tee of Accy)	NIC		1
Probability of Detection	%	>99	3
Probability of False Alarm	%	1.5	1
Operational Maturity	TRL	9	3
Availability	%	95	2
Target Track Capacity	#	35	3
Reliability	MTBF	8700	2
Coop or Non-Coop	C/N	C	2
Env/Weather Susceptibility	Y/N	N	2
Functional Domain			
Field Of Regard (Azimuth)	Deg (+/-)	180	3
Field Of Regard (El)	Deg (+/-)	22	3
Detection Range	Nmi	40	3
Refresh Rate	Sec.	1	2
Azimuth Accuracy	Deg. (+/-)	2	2
Elevation/Altitude Accuracy	Deg (+/-)	0.25	3
Range Accuracy	Nmi (+/-)	0.05	2
Physical Domain			
Total Weight	Lbs.	19.5	3
Total Cost (Aquire Only)	$	$100,000	1
RMS Power Consumption	Watts	80	2
Total Volume	In.^3	515	2

Table 5 - TCAS II Evaluation Metrics

Evaluation Overview: TCAS II improves on the two major aspects of TCAS I. The first upgrade results from improved directional antennas that provide a much more accurate azimuth reading. The second upgrade is that TCAS II requires a Mode-S transponder, which provides altitude data at 25 ft increments instead of the 100 ft increment of Mode-C. These two improvements result in a much lower probability of false alarm and an overall higher rating than TCAS I. Although there were no red sores for TCAS II there are a few parameters that stand out as not quite meeting CCA requirements. The two metrics in the operational domain in question are the Trustworthy and Probability of

False Alarm. The trustworthiness of the system is put into question primarily due to the fact that the system is completely reliant on the proper operation of outside equipment. It is impossible to have complete confidence that the responding transponder is providing correct altitude. The probability of false alarm may be lowered with the assumption that all vehicles are equipped with Mode-S transponders. The 1.5% used in the evaluation is the percentage observed with all types of transponders. Isolating only Mode-S transponders more precise 25 ft altitude increments should result in a reduction of false alarms. Whether this would result in adequate false alarm rates for Step 1, where the assumption of a Mode-S transponder onboard is much higher, has not been completely evaluated. There is a significant increase in cost between the TCAS I and II systems and depending on the platform this may become an issue.

3.1.2 Automatic Dependent Surveillance - Broadcast (ADS-B)

Principal of Operation: ADS-B is a new technology that relies on the Global Positioning System (GPS) and onboard systems to determine the aircraft's position in space. ADS-B provides a broadcast of ownship position, velocity, heading, altitude, identification, and aircraft intent data. What's unique about ADS-B is that unlike TCAS it does not rely on radar for its position information and unlike TCAS equipped aircraft, ADS-B equipped aircraft broadcast their ownship information, without being interrogated, for other ADS-B equipped aircraft to receive and utilize for conflict avoidance. ADS-B was designed to have a reception range of greater than 100 nmi and has the capability of rebroadcasting other vehicles data to extend the range of situational awareness. This is shown in Figure 3, where an intruder vehicle outside the range of ADS-B has its data relayed via an intermediate vehicle. Currently there are three data links being used by ADS-B. These data links consist of the same Mode-S Transponder used for TCAS (1090 Mhz), Universal Access Transceiver or UAT (978 Mhz) or VDL-VHF. Due to the high usage of VHF, this data link is only being used in Asia and Europe. The FAA has announced a link decision which utilizes a combination of 1090 MHz Extended Squitter and UAT. Mode-S 1090 Mhz will be used as the initial ADS-B link to support near term commercial and transport operation capabilities while UAT will be used to support general aviation. Communication across data links will require a ground station rebroadcast of information as described in section 3.1.4. If the long range air-to-air ADS-B applications cannot be satisfied by 1090 ES alone, UAT would be a leading candidate to support these requirements.

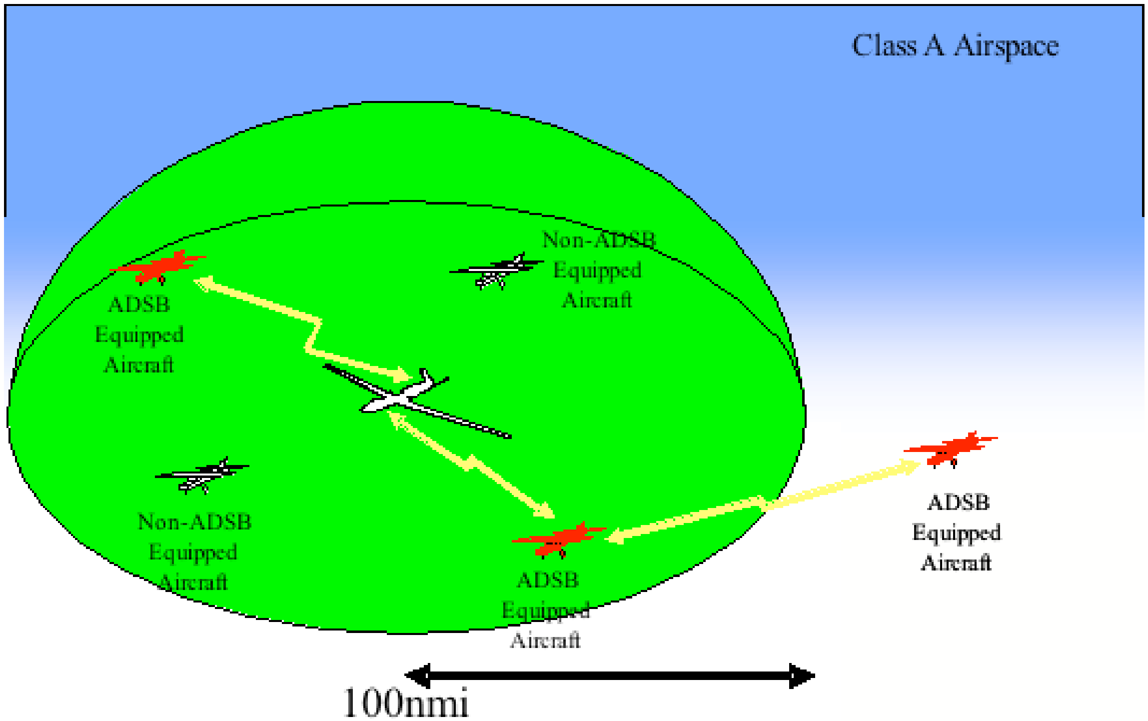


Figure 3 - ADS-B Principal of Operation

ADS-B is a cooperative system and therefore any non-ADS-B equipped aircraft will not be seen by ADS-B equipped aircraft.

Operational Availability: ADS-B is currently undergoing preliminary demonstrations. There are many projects collecting data, including the Alaska Capstone Project where the FAA has approved the use of UAT/ADS-B to support "radar-like services" for equipped aircraft in areas of Western Alaska without radar coverage. Currently, there are over 180 UAT equipped aircraft, involved in the FAA's Capstone program. Given the current flight demonstration level an assumed TRL of 4-6 is used. The current expected full deployment date is 2013. Currently there are issues with data integrity and the data provided by ADS-B is only allowed to provide situational awareness and may not be used to provide TCAS Resolution Alerts. The degraded integrity of ADS-B compared to TCAS is due to the reliance of all data from an external device. TCAS only receives altitude from the target vehicle. It then determines relative range and bearing based on the response time and the direction it came from, respectfully. ADS-B relies completely on the data being sent to it for all 3 degrees of position.

Equipment Availability: There are multiple manufacturers of ADS-B transceivers. The original ADS-B developer UPS AT, now Garmin AT, produce multiple types and configurations, including boxes that can send and receive on both Mode-S and UAT frequencies. They, along with multiple TCAS manufacturers have begun combining the two systems into a single unit, which provides both functionalities. As stated above, ADS-B data is not allowed to be used with the TCAS TA/RA algorithm. It can only be used for additional situational awareness.

Measurement Parameters		Quantitative Measures	Qualitative Scoring
Operational Domain	***Units***		
Conflict Look-ahead Time	Sec	300	3
Trustworthy (G'tee of Accy)	NIC	NIC	1
Probability of Detection	%	>99	3
Probability of False Alarm	%	0.1	3
Operational Maturity	TRL	4	1
Availability	%	95	2
Target Track Capacity	#	35	3
Reliability	MTBF	10000	2
Coop or Non-Coop	C/N	C	2
Env/Weather Susceptibility	Y/N	N	2
Functional Domain			
Field Of Regard (Azimuth)	Deg (+/-)	180	3
Field Of Regard (El)	Deg (+/-)	90	3
Detection Range	Nmi	100	3
Refresh Rate	Sec.	1	2
Azimuth Accuracy	Deg. (+/-)	0.62	3
Elevation/Altitude Accuracy	Deg (+/-)	0.25	3
Range Accuracy	Nmi (+/-)	0.01	3
Physical Domain			
Total Weight	Lbs.	7.6	3
Total Cost (Aquire Only)	$	$17,000	3
RMS Power Consumption	Watts	18	3
Total Volume	In.^3	327	3

Table 6 - ADS-B Evaluation Metrics

Evaluation Overview: The ADS-B evaluation resulted in very promising scores. The obvious negatives, which have been mentioned in previous sections, are the trustworthiness and the technology maturity of the system.

3.1.3 Traffic Advisory Systems (TAS)

3.1.3.1 Passive

Principal of Operation: Passive TAS works as a standalone traffic processor which listens in on transponder responses to ground radar and other vehicles TCAS interrogations. Due to this passive nature it is impossible to get accurate range from response times. This limits the capability of the system and results in the inability to provide TCAS type resolution advisories. These systems are intended to bring situational awareness to the general aviation pilot and therefore are inexpensive and portable. The portability of the system removes the need of FAA certification since it is not intended for air vehicle installation.

Operational Availability: Currently TAS passive systems are available on the market. FAA will not issue a TC or STC for the installation of this equipment and can only be installed via Field Approval Form 337.

Equipment Availability: There are many manufacturers of this type of technology but the two representative products evaluated in this study are SureCheck Traffic Scope (VR and VRX) and Proxalert – R5. Neither has FAA certification and cost approximately $1000.

Measurement Parameters		Quantitative Measures	Qualitative Scoring
Operational Domain	***Units***		
Conflict Look-ahead Time	Sec	15	1
Trustworthy (G'tee of Accy)	NIC		1
Probability of Detection	%	99	2
Probability of False Alarm	%	8	0
Operational Maturity	TRL	7	2
Availability	%	95	2
Target Track Capacity	#	10	2
Reliability	MTBF	8700	2
Coop or Non-Coop	C/N	C	2
Env/Weather Susceptibility	Y/N	N	2
Functional Domain			
Field Of Regard (Azimuth)	Deg (+/-)	180	3
Field Of Regard (El)	Deg (+/-)	12	1
Detection Range	Nmi	5	1
Refresh Rate	Sec.	1	2
Azimuth Accuracy	Deg. (+/-)	5	0
Elevation/Altitude Accuracy	Deg (+/-)	1.5	2
Range Accuracy	Nmi (+/-)	1	0
Physical Domain			
Total Weight	Lbs.	13.06	3
Total Cost (Aquire Only)	$	$1,500	3
RMS Power Consumption	Watts	2	3
Total Volume	In.^3	43	3

Table 7 - TAS Passive Evaluation Metrics

Evaluation Overview: The poor range and azimuth angle accuracy are the main limiters of this system and result in downgrades of the false alarm probability and trustworthiness. This is apparent in the red scores shown in the Table 7. The limited detection range also negatively impacts the performance in respect to CCA requirements. At closing rates of 1200 knots, the system only will provide 15 seconds of look-ahead time. The physical domain evaluation results in a perfect score, as would be expected for a system designed for the general aviation community.

3.1.3.2 Active

Principal of Operation: The TAS active systems act similarly to the passive system with the inclusion of an active interrogating transponder. This transponder interrogates vehicles in a similar way to TCAS and removes the need to be in an actively covered radar zone to perform. Overall the system acts very similar to TCAS I without the official TCAS TA's. It does provide similar alerts that do not use the certified TCAS algorithms.

Operational Availability: Active TAS is currently available off the shelf and is FAA certified flight equipment under TSO-C147.

Equipment Availability: As with the passive systems, there are many manufacturers of active systems. The products used in this evaluation include Skywatch HP and Bendix/King KTA 870. The price for this product ranges from 20-30K, which still is accessible for the general aviation public.

Measurement Parameters		Quantitative Measures	Qualitative Scoring
Operational Domain	***Units***		
Conflict Look-ahead Time	Sec	105	3
Trustworthy (G'tee of Accy)	NIC		1
Probability of Detection	%	99	2
Probability of False Alarm	%	8	0
Operational Maturity	TRL	9	3
Availability	%	95	2
Target Track Capacity	#	35	3
Reliability	MTBF	8700	2
Coop or Non-Coop	C/N	C	2
Env/Weather Susceptibility	Y/N	N	2
Functional Domain			
Field Of Regard (Azimuth)	Deg (+/-)	180	3
Field Of Regard (El)	Deg (+/-)	20	2
Detection Range	Nmi	35	3
Refresh Rate	Sec.	1	2
Azimuth Accuracy	Deg. (+/-)	5	0
Elevation/Altitude Accuracy	Deg (+/-)	1.5	2
Range Accuracy	Nmi (+/-)	0.05	2
Physical Domain			
Total Weight	Lbs.	9	3
Total Cost (Aquire Only)	$	$29,259	2
RMS Power Consumption	Watts	56	3
Total Volume	In.^3	340	3

Table 8 - TAS Active Evaluation Metrics

Evaluation Overview: It is determined that in all functional and operational domain metrics the TAS acts very similarly to TCAS I and is basically indistinguishable in this trade study.

3.1.4 Traffic Information System – Broadcast (TIS-B)

Principal of Operation: TIS-B is a ground-based system which integrates multiple ground surveillance radar and transponder returns and uplinks the data via the L-band 978 Mhz frequency and 1090 MHz ES to the vehicles in the same format used for ADS-B. Aircraft flying at high altitude already equipped with a Mode-S transponder would use the 1090 ES. General Aviation aircraft are equipped with UAT. Interoperability between the links is provided within coverage of the ground ADS-B infrastructure using the multilink gateway service provided via the TIS-B uplink (ground-to-air). TIS-B is also used to provide "ADS-B reports" on aircraft that are not transmitting ADS-B information. This data is used as a "gap filler" for situational awareness. The ground system filters out ADS-B responding vehicles from the uplinked data to avoid double reporting at the vehicle level. RTCA DO-286 defines the minimum aviation system performance standards for TIS-B including the service volume, traffic information volume and the surveillance quality parameters.

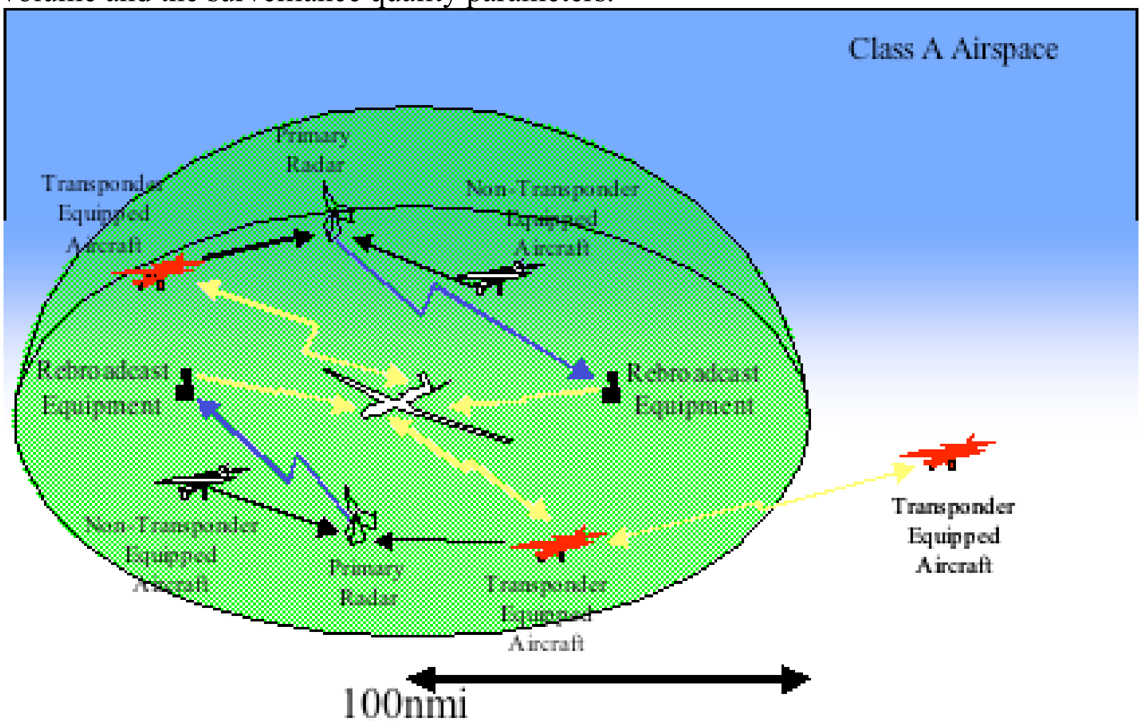


Figure 4 - TIS-B Principle of Operation

Operational Availability: Currently the ground-based rebroadcast infrastructure is not in place and is full deployment is not expected until 2013. The FAA Capstone project in Alaska has 10 ground stations rebroadcasting ADS-B only (no primary radar integration). There are also plans in place for 36 East coast installations. FAA plans to create dual ground station installation reducing down time and therefore implies that the airborne receiver unit will limit the MTBF of the system.

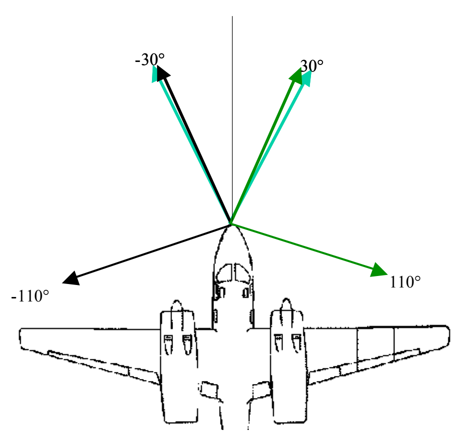
Equipment Availability: The same transceiver equipment used for ADS-B is used for TIS-B. For more equipment availability information see the ADS-B section 3.1.2. As for the ground station availability there is a dual installation operating at ERAU in Prescott, Az along with the Sensis ground stations installed in Western Alaska. The overall cost to each aircraft is negligible, if already equipped with ADS-B. The ground infrastructure development will require a much greater investment.

Measurement Parameters		Quantitative Measures	Qualitative Scoring
Operational Domain	***Units***		
Conflict Look-ahead Time	Sec	90	3
Trustworthy (G'tee of Accy)	NIC		2
Probability of Detection	%	>99	3
Probability of False Alarm	%	1	2
Operational Maturity	TRL	3	1
Availability	%	95	2
Target Track Capacity	#	25	3
Reliability	MTBF	10000	2
Coop or Non-Coop	C/N	N	3
Env/Weather Susceptibility	Y/N	N	2
Functional Domain			
Field Of Regard (Azimuth)	Deg (+/-)	180	3
Field Of Regard (El)	Deg (+/-)	90	3
Detection Range	Nmi	30	3
Refresh Rate	Sec.	5	1
Azimuth Accuracy	Deg. (+/-)	0.07	3
Elevation/Altitude Accuracy	Deg (+/-)	3	1
Range Accuracy	Nmi (+/-)	0.05	2
Physical Domain			
Total Weight	Lbs.	0	3
Total Cost (Aquire Only)	$	$17,000	3
RMS Power Consumption	Watts	0	3
Total Volume	In.^3	0	3

Table 9 - TIS-B Evaluation Metrics

Evaluation Overview: The TIS-B metrics shown in Table 9 projects an overall excellent rating. The only yellow scores are present in the elevation angle accuracy, the refresh rate and the operational maturity. A fully developed and deployed system seems to present a promising solution to CCA. Since TIS-B is an add on to the ADS-B air-to-air infrastructure it cannot be evaluated properly as an individual system. It is important to note that the numbers used in the evaluation are dependent on the source, given that the TIS-B broadcasts both ground radars and Air-to-Ground ADS-B data, and may affect some of the scoring results.

3.1.5 CCD Vision Sensor



Principal of Operation: The vision sensor system being evaluated consists of multiple fixed starring CCD cameras arranged to meet the +/- 110-degree azimuth and +/- 15-degree elevation field of regard requirements (Figure 11). Along with the cameras the system consists of on-board image processing for moving target detection and tracking at 30 Hz. The image processor provides a detected threat's elevation and bearing angle, along with the image size to be downlinked to the AVCS (Section 0). There are some techniques including maneuver based passive ranging being developed to generate 3-D information from the 2-D sensed data provided by the CCD Camera. The cameras should provide a detection range of 3-5 nmi for a general aviation aircraft which will decrease with degrading atmospheric conditions. The option to provide the ROA with video data exists if permitted by the bandwidth of the data link.

Operational Availability: The CCD cameras evaluated in this study are currently in the flight test state and are considered to be at TRL 5-6. There are prototypes available including the Field Programmable Gate Arrays or FPGA used to perform the image processing.

Equipment Availability: The two manufacturers evaluated are DRA and Boeing SVS. Both have current prototypes being flight-tested.

Measurement Parameters		Quantitative Measures	Qualitative Scoring
Operational Domain	***Units***		
Conflict Look-ahead Time	Sec	15	1
Trustworthy (G'tee of Accy)	NIC		2
Probability of Detection	%	95	1
Probability of False Alarm	%	1	2
Operational Maturity	TRL	5	1
Availability	%	90	1
Target Track Capacity	#	35	3
Reliability	MTBF	8000	2
Coop or Non-Coop	C/N	N	3
Env/Weather Susceptibility	Y/N	Y	1
Functional Domain			
Field Of Regard (Azimuth)	Deg (+/-)	110	2
Field Of Regard (El)	Deg (+/-)	15	2
Detection Range	Nmi	5	1
Refresh Rate	Sec.	0.033	3
Azimuth Accuracy	Deg. (+/-)	0.07	3
Elevation/Altitude Accuracy	Deg (+/-)	0.03	3
Range Accuracy	Nmi (+/-)	0.75	0
Physical Domain			
Total Weight	Lbs.	20	3
Total Cost (Aquire Only)	$	$75,000	2
RMS Power Consumption	Watts	140	2
Total Volume	In.^3	400	3

Table 10 - CCD Vision Evaluation Metrics

Evaluation Overview: The CCD camera alone does not provide adequate conflict avoidance. The main plus this system has is that it is completely non-cooperative in that it does not rely on any information from an outside system. In Step 1 cooperative vehicles can be assumed and the true benefits of this system may not be realized until later steps. The main drawback of the system is the fact that the camera is a 2-D sensor and the Range accuracy is very poor. This is shown as the only red score in the evaluation metrics shown in Table 10.

3.1.6 Infra-Red Sensor

Principal of Operation: The IR sensor has the same concept of operation as the CCD camera with an increase in detection range. The use of IR also reduces the susceptibility of the sensor to atmospheric conditions. After preliminary research it was determined that a mid-wave IR sensor provided the optimal balance between detection range and atmospheric sensitivity.

Operational Availability: The mid-wave IR sensors used in this evaluation are at a similar stage of development as the CCD camera. The technology is at about TRL 5-6 and there are prototypes currently available.

Equipment Availability: There are many developers of the mid-wave IR sensors evaluated in this study. These include Northrop Grumman, Indigo, Raytheon, DRA and Boeing SVS.

Measurement Parameters		Quantitative Measures	Qualitative Scoring
Operational Domain	***Units***		
Conflict Look-ahead Time	Sec	18	1
Trustworthy (G'tee of Accy)	NIC		2
Probability of Detection	%	95	1
Probability of False Alarm	%	1	2
Operational Maturity	TRL	5	1
Availability	%	90	1
Target Track Capacity	#	35	3
Reliability	MTBF	5000	1
Coop or Non-Coop	C/N	N	3
Env/Weather Susceptibility	Y/N	Y	1
Functional Domain			
Field Of Regard (Azimuth)	Deg (+/-)	110	2
Field Of Regard (El)	Deg (+/-)	15	2
Detection Range	Nmi	6	1
Refresh Rate	Sec.	0.033	3
Azimuth Accuracy	Deg. (+/-)	0.07	3
Elevation/Altitude Accuracy	Deg (+/-)	0.03	3
Range Accuracy	Nmi (+/-)	0.75	0
Physical Domain			
Total Weight	Lbs.	50	1
Total Cost (Aquire Only)	$	$300,000	0
RMS Power Consumption	Watts	500	0
Total Volume	In.^3	1000	0

Table 11 - IR Evaluation Metrics

Evaluation Overview: The increased range of the IR sensor did not affect the scoring when compared to the CCD camera. The reduced MTBF actually downgrades the overall Operational Domain score. The increased size, cost, and volume degrade performance in the Physical Domain.

3.1.7 RADAR

For avoidance of collision with cooperative and uncooperative air traffic, Radar technology could represent a possible solution. EM waves are generated and transmitted, and usually scanned, either mechanically or electronically, in a raster or circular pattern, and the energy reflected from the intruder received. The phase difference of the return signal or the time of flight is then used to calculate intruder range. As design wavelengths increase over the EM spectrum, from X-rays through visible light and infrared to "radio" wavelengths, several effects occur. Atmospheric and obscurant penetration capability increases with increasing wavelength, power required increases, and spatial resolution decreases. In applications that benefit from longer range detection, but where precise target location is not required, conventional Radar is appropriate. If a significant probability of collision is indicated, logic similar to the TCAS systems can advise or initiate avoidance maneuvers.

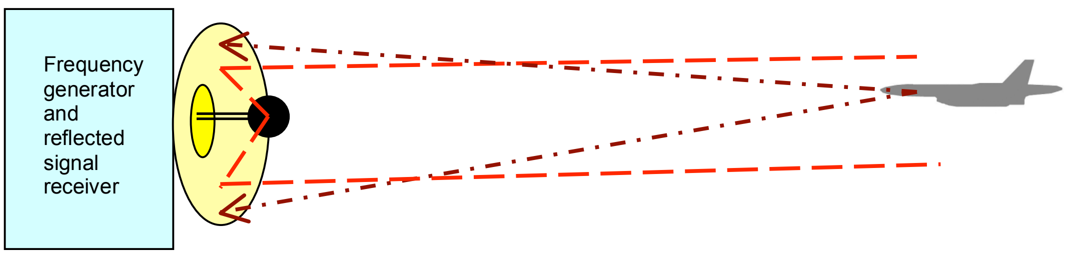


Figure 5 – Radar Principal of Operation

As shown in Figure 5 above, the simplified system consists of a transmitter, a scanning mechanism, a receiver and signal processing logic. Any EM wavelength can be used, although certain bands are more common due to having lower atmospheric attenuation, and for this application, the higher (Ka, ~35 GHz) wavelengths provide better location and tracking capability. Also as an advantage for UAV applications, the shorter wavelengths can use smaller antennas. The system can also be designed to interpret the Doppler shift of the reflected signal and determine approach speed, if this would be of value. The range of effectiveness is a function of optical power provided, with about 8 miles typical within practical airborne weight and power limitations.

Principal of Operation: The system is self-contained and requires no input from any outside source in order to detect and track other aircraft. Most aircraft are made of EM reflective materials, and a portion of the transmitted radar signal is reflected back to the source. Being a two-path concept, the inverse square signal strength law is multiplied to become a function of RCS (Radar cross section) of the aircraft and the inverse fourth power of the transmission. Regarding RCS, in general the larger the aircraft the greater the detection range possible, with variations due to aspect angle of the intruder presented, and where stealth aircraft are concerned, some absorption of the signal rather than reflection.

Operational Availability: Radar systems have been built and flown in production aircraft for civilian and military use over the past 50 years. Typical applications are weather detection, terrain warning, altimetry, and detection of other aircraft for targeting. While many similar systems are currently available COTS, and while systems are presently in development that could be used, none are presently configured for this application.

Equipment Availability: There is currently no Radar system in production that would meet all of these requirements. Systems in development would need to be completed and tested before production. When the functional requirements for ROA detect and avoid are finalized and the basis for certification established, it is possible that a Radar system could be available to meet the need. The manufacturers of these systems include Northrop Grumman, Ampithec, Raytheon and BAE.

Measurement Parameters		Quantitative Measures	Qualitative Scoring
Operational Domain	***Units***		
Conflict Look-ahead Time	Sec	24	2
Trustworthy (G'tee of Accy)	NIC		2
Probability of Detection	%	95	1
Probability of False Alarm	%	1	2
Operational Maturity	TRL	6	2
Availability	%	90	1
Target Track Capacity	#	35	3
Reliability	MTBF	1000	0
Coop or Non-Coop	C/N	N	3
Env/Weather Susceptibility	Y/N	N	2
Functional Domain			
Field Of Regard (Azimuth)	Deg (+/-)	110	2
Field Of Regard (El)	Deg (+/-)	15	2
Detection Range	Nmi	8	2
Refresh Rate	Sec.	2	2
Azimuth Accuracy	Deg. (+/-)	1	2
Elevation/Altitude Accuracy	Deg (+/-)	1	2
Range Accuracy	Nmi (+/-)	0.0009	3
Physical Domain			
Total Weight	Lbs.	60	0
Total Cost (Aquire Only)	$	$300,000	0
RMS Power Consumption	Watts	500	0
Total Volume	In.^3	1200	0

Table 12 - RADAR Evaluation Metrics

Evaluation Overview: Overall a Radar system configured for this application would meet most operational and functional requirements, exceptions including MTBF, weight, power consumption and cost. A note on MTBF: the single unit MTBF of the Radar must be compared to the combined MTBF of the two units in TCAS-like cooperative detection, since two such units are required to complete the detection loop. Its detection range is adequate for collision avoidance with autonomous response and possibly pilot in the loop as well. Compared to TCAS, the Radar false alert rate is better, and would be advantageous even for cooperative intruders. . A Radar system for this application could probably be designed specifically for airborne intruder detection and flight-tested within the Access 5 time frame.

3.1.8 Scanning Laser Rangefinder

For avoidance of collision with cooperative and uncooperative air traffic, a scanning laser rangefinder is a version of the LADAR/LIDAR. LADAR and LIDAR create an image and determine very accurately the range to each pixel, but their full imaging capability is not necessary to the ROA. The scanning LASER only needs to detect a signal return and track the intruder to calculate intruder flight path. If a significant probability of collision is indicated, logic similar to the TCAS systems can advise or initiate avoidance maneuvers. Ground based systems have been developed that can track up to 50 aircraft at a time.

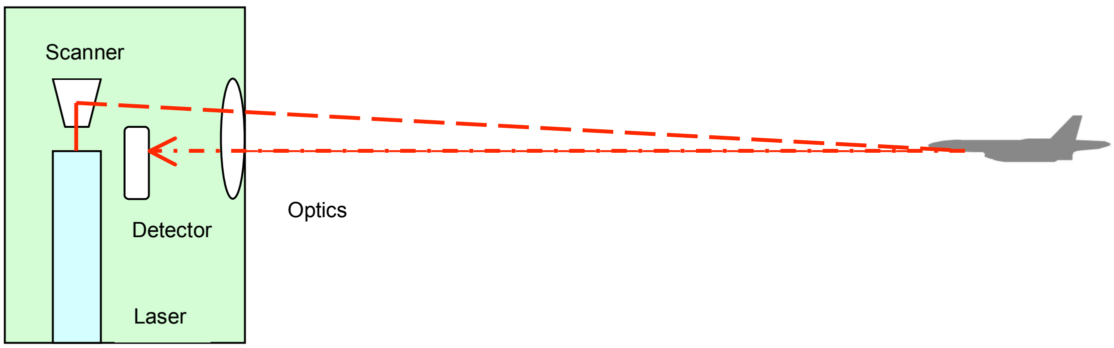


Figure 6 – Scanning Laser Rangefinder Principal of Operation

As shown in Figure 6 above, the system consists of a Laser transmitter, an agile scanning mechanism, a receiver and signal processing logic. Any Laser wavelength can be used, although IR wavelengths provide some atmospheric obscuration penetration. Some systems have passive IR pixel-colocated detectors for longer-range cuding. Eye safety is easily satisfied since the platform is moving and the system is scanning, rather than dwelling on a specific point. The Laser average power levels at the intruder are well below eye damage thresholds. The range of effectiveness is a function of optical power provided, with 2 to 4 miles typical for airborne applications.

3.1.8.1 LADAR

Principle of Operation: The system is self-contained and requires no input from any outside source in order to detect and track other aircraft. Existing systems operate in two modes, pulsed or continuous wave. The pulsed mode sends pulses, receives reflected energy from the intruder, and determines range from time-of-flight of the pulse. The continuous wave mode sends a modulated beam and measures range as a function of the phase shift of the return. In both cases the lat/long precision comes from the narrow beam that is possible with optical wavelengths, and the range precision is due to the high frequency of the pulses or wave peaks.

Operational Availability: Many LADAR systems have been built and tested in aircraft for military use over the past 25 years by both military labs and aerospace companies. While the concept has been proven in many applications including wire detection for

NOE flight, Laser altimetry, battlefield target detection and recognition, and while several similar systems are currently COTS, none are configured for this application and certified by the FAA for commercial use

Equipment Availability: There is currently no LADAR system in production that would meet these requirements. Existing prototypes will need to be configured for this specific application, and tested before production, which will only occur when the commercial ROA market matures. When the functional requirements for ROA detect and avoid are finalized and the basis for certification established, a Ladar system could be available to meet the need.

Measurement Parameters		Quantitative Measures	Qualitative Scoring
Operational Domain	***Units***		
Conflict Look-ahead Time	Sec	9	0
Trustworthy (G'tee of Accy)	NIC		2
Probability of Detection	%	95	1
Probability of False Alarm	%	1	2
Operational Maturity	TRL	6	2
Availability	%	90	1
Target Track Capacity	#	35	3
Reliability	MTBF	1000	0
Coop or Non-Coop	C/N	N	3
Env/Weather Susceptibility	Y/N	N	2
Functional Domain			
Field Of Regard (Azimuth)	Deg (+/-)	110	2
Field Of Regard (El)	Deg (+/-)	15	2
Detection Range	Nmi	3	0
Refresh Rate	Sec.	1	2
Azimuth Accuracy	Deg. (+/-)	0.1	3
Elevation/Altitude Accuracy	Deg (+/-)	0.1	3
Range Accuracy	Nmi (+/-)	0.0003	3
Physical Domain			
Total Weight	Lbs.	40	1
Total Cost (Aquire Only)	$	$300,000	0
RMS Power Consumption	Watts	600	0
Total Volume	In.^3	1100	0

Table 13 - Laser Evaluation Metrics

Evaluation Overview: Overall a Ladar system configured for this application would meet most operational and functional requirements, with the exception of those reflecting maturity levels, such as MTBF and cost. A note on MTBF: the single unit MTBF of the Ladar must be compared to the combined MTBF of the two units required for a TCAS-like cooperative detection. Also the precision of the Ladar intruder path prediction can to some extent offset its detection range, which is in any case adequate for collision avoidance with autonomous response. Compared to TCAS the Ladar false alert rate is superior, and would be advantageous even for cooperative intruders.

3.1.9 Rejected Technologies

3.1.9.1 Acoustic Sensors

The principal of the sensor is to use acoustic beam-shaping to detect sounds of proximate air traffic. After initial research, it was found that the signal-to-noise ratio at high speeds would prove to be problematic. Another problem found was that the directional nature of target aircraft sound waves makes head on detection difficult. These issues, along with the under 2 nmi range limitations, constituted the removal of this system from the trade study.

3.1.9.2 Micro-EARTS

Micro-EARTS is the ground-based microcomputer replacement for the legacy ATC EARTS equipment. Lockheed Martin - Transportation and Security Systems, developed the system and the initial understanding was that Micro-EARTS only feeds target track data to ATC. There currently is no capacity to transmit Micro-EARTS tracks via an uplink to an aircraft. The possible usage of land-lines to provide track data directly to a ground based ROA may require a re-evaluation of the system.

3.2 Integrated System Solutions

3.2.1 TCAS II & ADS-B

Concept of Operation: Multiple manufacturers have already realized the benefits of combining TCAS II and ADS-B. This system provides dual, independent capabilities for sensing all cooperative traffic. Both the individual TCAS and ADS-B reports are available to the ROA pilot and can be displayed as desired (combined or separate). There are options for the processing of the track reports. The track fusion process can be performed onboard and downlink the fused tracks to the ROA or each individual sensors track can be made available to the ROA pilot for display with data fusion performed on the ground.

Benefits of Blended Solution: The integrated system provides an increased CCA system integrity resulting from dual dissimilar sensing sources. This provides a fault tolerance not present in the individual systems. ADS-B extends the detection range provided by TCAS II. The constant position accuracy associated with ADS-B's use of GPS along with the range dependent angle accuracy of TCAS provides a complimentary bearing accuracy. The GPS precision for ADS-B results in more accurate bearing angles at long range, while the TCAS II bearing precision increases as the range decreases. The result of this combined system is a larger protection volume with overall better accuracies.

Measurement Parameters		Quantitative Measures			Qualitative Scoring		
Operational Domain	***Units***	**TCAS**	**ADS-B**	**Comb**	**TCAS**	**ADS-B**	**Comb**
Conflict Look-ahead Time	Sec	120	300	120	3	3	3
Trustworthy (G'tee of Accy)	NIC	0	NIC		2	2	2
Probability of Detection	%	>99	>99	>99	3	3	3
Probability of False Alarm	%	1.5	0.1	0.1	1	3	3
Operational Maturity	TRL	9	4	4	3	1	1
Availability	%	95	95	95	2	2	2
Target Track Capacity	#	35	35	35	3	3	3
Reliability	MTBF	8700	10000	8700	2	2	2
Coop or Non-Coop	C/N	C	C	C	2	2	2
Env/Weather Susceptibility	Y/N	N	N	N	2	2	2
Functional Domain							
Field Of Regard (Azimuth)	Deg (+/-)	180	180	180	3	3	3
Field Of Regard (El)	Deg (+/-)	22	90	22	3	3	3
Detection Range	Nmi	40	100	40	3	3	3
Refresh Rate	Sec.	1	1	1	2	2	2
Azimuth Accuracy	Deg. (+/-)	2	0.62	0.62	2	3	3
Elevation/Altitude Accuracy	Deg (+/-)	0.25	0.25	0.25	3	3	3
Range Accuracy	Nmi (+/-)	0.05	0.01	0.01	2	3	3
Physical Domain							
Total Weight	Lbs.	19.5	7.6	27.1	3	3	2
Total Cost (Aquire Only)	$	100000	17000	117000	1	3	1
RMS Power Consumption	Watts	80	18	98	2	3	2
Total Volume	In.^3	515	327	842	2	3	0

Table 14 - TCAS II & ADS-B Evaluation Metrics

Evaluation Overview: The overall system evaluation resulted in all parameters meeting or exceeding the CCA requirements in both the Functional and Operational Domains except for operational maturity, which is affected by the TRL of ADS-B. This evaluation may be a bit conservative based on the combined TCAS/ADS-B boxes being developed and result in a few poor marks in the physical domain.

3.2.2 TCAS II & ADS-B & TIS-B

Concept of Operation: The addition of TIS-B to the TCAS II / ADS-B combined system provides the additional capability of tracking non-cooperative traffic.

Benefits of Blended Solution: See section 3.2.1.

Measurement Parameters		Quantitative Measures				Qualitative Scoring			
Operational Domain	***Units***	**TCAS**	**ADS-B**	**TIS-B**	**Comb**	**TCAS**	**ADS-B**	**TIS-B**	**Comb**
Conflict Look-ahead Time	Sec	120	300	90	90	3	3	3	3
Trustworthy (G'tee of Accy)	NIC	0	NIC	0		2	2	2	2
Probability of Detection	%	>99	>99	>99	>99	3	3	3	3
Probability of False Alarm	%	1.5	0.1	1	0.1	1	3	2	3
Operational Maturity	TRL	9	4	3	3	3	1	1	1
Availability	%	95	95	95	95	2	2	2	2
Target Track Capacity	#	35	35	25	25	3	3	3	3
Reliability	MTBF	8700	10000	10000	8700	2	2	2	2
Coop or Non-Coop	C/N	C	C	N	N	2	2	3	3
Env/Weather Susceptibility	Y/N	N	N	N	N	2	2	2	2
Functional Domain									
Field Of Regard (Azimuth)	Deg (+/-)	180	180	180	180	3	3	3	3
Field Of Regard (El)	Deg (+/-)	22	90	90	22	3	3	3	3
Detection Range	Nmi	40	100	30	30	3	3	3	3
Refresh Rate	Sec.	1	1	5	1	2	2	1	2
Azimuth Accuracy	Deg. (+/-)	2	0.62	0.07	0.07	2	3	3	3
Elevation/Altitude Accuracy	Deg (+/-)	0.25	0.25	3	0.25	3	3	1	3
Range Accuracy	Nmi (+/-)	0.05	0.01	0.05	0.01	2	3	2	3
Physical Domain									
Total Weight	Lbs.	19.5	7.6	0	27.1	3	3	3	2
Total Cost (Aquire Only)	$	100000	17000	17000	134000	1	3	3	0
RMS Power Consumption	Watts	80	18	0	98	2	3	3	2
Total Volume	In.^3	515	327	0	842	2	3	3	0

Table 15 - TCAS II & ADS-B & TIS-B Evaluation Metrics

Evaluation Overview: The inclusion of TIS-B does not truly affect the evaluation of systems in Step 1 due to the cooperative assumption above FL400. The benefit of TIS-B becomes more apparent as a non-cooperative traffic is introduced.

3.2.3 TCAS II & CCD Vision Sensor

Concept of Operation: Similar to the TCAS/ADS-B combination, this system provides dual, independent capabilities for sensing all cooperative traffic along with the added capability of sensing non-cooperative traffic.

Benefits of Blended Solution: In addition to the benefits described in the TCAS/ADS-B section, the vision sensor provides enhanced bearing and elevation accuracy when within its detection range. The vision sensor also provides the all-important "see" aspect of "see and avoid" missing in all other sensors. TCAS false alarms may be resolved by the ability to visually confirm threats.

Measurement Parameters		Quantitative Measures			Qualitative Scoring		
Operational Domain	***Units***	**TCAS**	**Vision**	**Comb**	**TCAS**	**Vision**	
Conflict Look-ahead Time	Sec	120	15	15	3	1	1
Trustworthy (G'tee of Accy)	NIC	0	0		2	2	2
Probability of Detection	%	>99	95	>99	3	1	3
Probability of False Alarm	%	1.5	1	1	1	2	2
Operational Maturity	TRL	9	5	5	3	1	1
Availability	%	95	90	90	2	1	1
Target Track Capacity	#	35	35	35	3	3	3
Reliability	MTBF	8700	8000	8000	2	2	2
Coop or Non-Coop	C/N	C	N	C	2	3	2
Env/Weather Susceptibility	Y/N	N	Y	Y	2	1	1
Functional Domain							
Field Of Regard (Azimuth)	Deg (+/-)	180	110	110	3	2	2
Field Of Regard (El)	Deg (+/-)	22	15	15	3	2	2
Detection Range	Nmi	40	5	5	3	1	1
Refresh Rate	Sec.	1	0.033	0.033	2	3	3
Azimuth Accuracy	Deg. (+/-)	2	0.07	0.07	2	3	3
Elevation/Altitude Accuracy	Deg (+/-)	0.25	0.03	0.03	3	3	3
Range Accuracy	Nmi (+/-)	0.05	0.75	0.05	2	0	2
Physical Domain							
Total Weight	Lbs.	19.5	20	39.5	3	3	1
Total Cost (Aquire Only)	$	100000	75000	175000	1	2	0
RMS Power Consumption	Watts	80	140	220	2	2	0
Total Volume	In.^3	515	400	915	2	3	0

Table 16 - TCAS II & CCD Vision Evaluation Metrics

Evaluation Overview: The benefits of adding a vision sensor do not truly become apparent until non-cooperative vehicles are entered into the equation. While combining TCAS with a CCD camera lowers the overall score of the system due to the integrated evaluation methods described in section 2.2.5, it does improve the one sub par parameter of TCAS II – Probability of False Alarm.

4 Air Vehicle Control Station

4.1 Main Elements

4.1.1 Air Vehicle Control Station (AVCS)

The Aircraft Vehicle Control Station (AVCS) will provide an environment where the ROA-Pilot has the capability to conduct flight management. Flight management will consist of either direct aircraft control through a control device such as a keyboard or set of flight controls (stick, throttle, etc.) or simply monitoring aircraft systems and navigation through a set of flight information displays. The AVCS will contain the proper radio equipment in order to communicate with ATC.

The AVCS may contain the following:

- Flight Information Displays
- Radio Communications
- Flight Control Capabilities
- Out-The-Window View Capabilities

The AVCS has to provide the ROA-Pilot with the equivalent types of information that a pilot gets from the real cockpit. This information is fused together by the pilot to create a mental model of the world outside the cockpit and therefore enhances the pilot's SA.

Figure 7 shows the basic connectivity that might exist among the various elements that make up the AVCS.

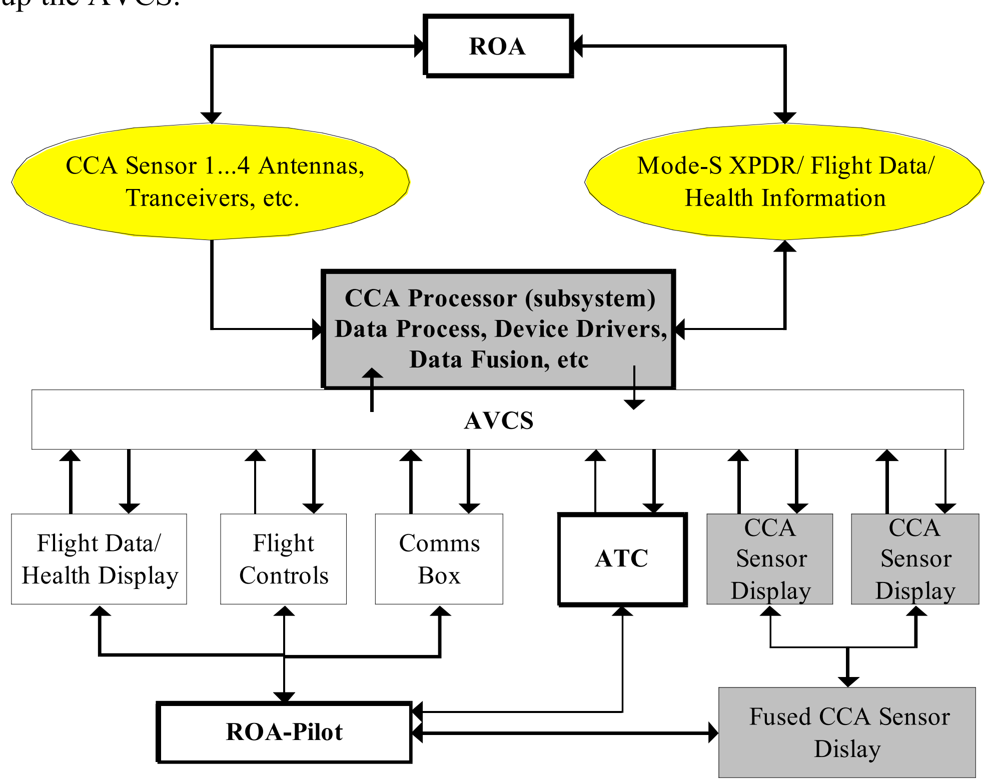


Figure 7 - AVCS Diagram

4.1.2 Remotely Operated Aircraft (ROA)

The Remotely Operated Aircraft (ROA) has not been completely defined at this point. Suffice to say that it will be something akin to what is being used today or a variation thereof; the vehicle will contain some type of sensor package that will provide a sufficient level of information to the ROA-Pilot.

4.1.3 CCA AVCS Processor (Subsystem)

The CCA AVCS Processor (subsystem) is a part of (attached to) the AVCS. It will receive input from the CCA sensor packages. The CCA subsystem will then process the sensor package data and provide the requisite information needed by the CCCA sensor displays and controls.

4.1.4 Air Traffic Control (ATC)

As stated in the DSA ELOS Definition document,

*"**Airspace Procedures***
The first lines of defense in the prevention of mid-air collisions are the existing rules, regulations, and procedures already in place. If adhered to, these procedures should prevent most accident scenarios from ever occurring.

Air Traffic Management
The second line of defense is the services provided by Air Traffic Management (ATM). If an aircraft is under positive control, it will receive separation information from ATM for other cooperative aircraft within the surrounding airspace. The air traffic authority assumes responsibility for providing separation for all IFR traffic and directs the participating aircraft to either maintain or change their flight path.

Figure 8 - Mid-Air Collision Lines of Defense

Cooperative Traffic Avoidance
Another capability used to avoid mid-air accidents employs the use of on-board traffic advisory systems that provide situational awareness to the pilot concerning all cooperative traffic within a certain range and relative altitude. These systems, mandatory on all aircraft that carry 10 or more passengers, also provide a traffic advisory to the pilot of an impending collision or even a resolution advisory directing them to execute an optimal avoidance maneuver.

See and Avoid
See and avoid is the last line of defense used by pilots to avoid collisions with other aircraft and obstacles located in the air and on the surface. The effectiveness of this method for collision avoidance depends entirely on the ability of the human pilot inside the cockpit to detect and track potential collision threats. The discussions contained within this paper focus on on-board or off-board sensing means and aircraft control required for ROA to provide this layer of collision avoidance without an on-board pilot."

Specific ATC requirements that need to be met are:
FAR 91 – General Operating Rules

- 91.111 – Operating near other aircraft
- 91.113 – Right-of-Way Rules: Except water operations
- 91.123 – Compliance with ATC clearances and instruction

FAA Order 7610.4k – Special Military Operations

- "Method of pilotage and proposed method to avoid other traffic"

4.1.5 ROA-Pilot (ROAP)

There is an ongoing debate in the UAV community as to whether or not a "pilot" as we understand it in the classic definition is needed to operate an ROA. This debate has impassioned supporters on both sides. Some suggest that we do not need a "pilot" to fly or manage the ROA during its mission. Others maintain that a "pilot" in the loop is needed for unforeseen contingencies. One might even argue that if ROA start operating within the NAS that whoever controls/manages the flight will need to be well versed in the operations, procedures, and language of ATC. Table 17 presents some options that may need to be considered are:

Certification	**Ratings**	**Currency Level**
Private Commercial ATP Military certification Special ROA certification?	Instrument Multi-Engine Military ratings Special ROA rating?	3 Take offs/3 Landings Every 90 Days Military currency Special ROA currency?

Table 17 - ROA-Pilot Certification (Assumptions)

4.1.6 CCA Sensor / Pilot Interaction

The CCA sensor package will be required to provide the ROA-Pilot with timely and accurate information. This information must adhere to the requirements that will be outlined by ELOS. We will examine the types of information each sensor provides the pilot individually. We will then combine sensor information and examine whether or not a particular combination of sensor inputs provides the critical information required by ELOS.

The sensor types discussed will be:

- TCAS II
- ADS-B
- TIS-B
- Vision

The sensor combinations to be examined are:

- TCAS II + ADS-B
- TCAS II + Vision
- TCAS II + ADS-B + TIS-B

4.2 Connectivity

Connectivity among various modules will be required in order to provide the ROA-Pilot with the information necessary to conduct safe flight operations/management. These pieces will consist of the following:

- Remotely Operated Aircraft (ROA)
- Air Vehicle Control Station (AVCS)
- Air Traffic Control (ATC)
- Remotely Operated Aircraft Pilot (ROAP)

Figure 9 shows how the different parts might be connected. The AVCS, ATC, and ROA-Pilot interconnect in order to provide ELOS, which is then connected, to the ROA. Each connection provides critical information to ELOS. If one connection fails to provide the required information then ELOS is degraded or compromised.

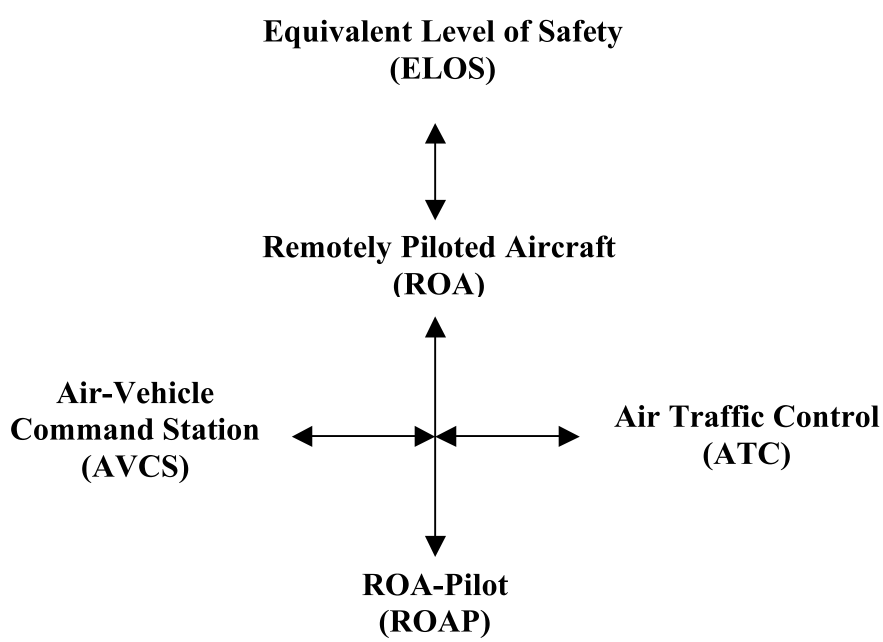


Figure 9 - Basic Module Connectivity

4.2.1 TCAS II

Figure 10 shows the connectivity of TCAS II to the AVCS.

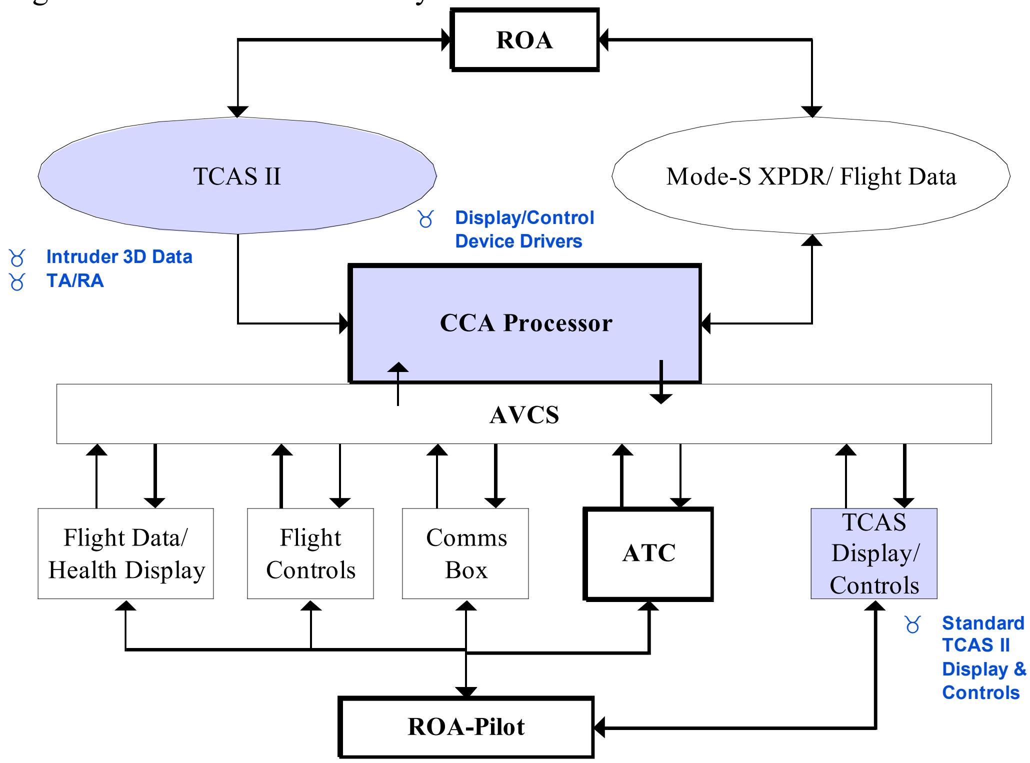


Figure 10 - TCAS II Connectivity

Table 18, shows what types information TCAS II would provide for cooperative and non-cooperative traffic.

ROA-Pilot Ownship Equipment	Intruder Aircraft Equipment	Sensed Parameters	Independent Verification Options (Ownship)	Independent Verification Options (Intruder)
TCAS II Mode S	None	None	ATC	ATC Pilot Visual ID
TCAS II Mode S	Mode C Only	Altitude + Range + Bearing	ATC TCAS Display	ATC Pilot Visual ID
TCAS II Mode S	Mode S	Altitude + Range + Bearing + ID	ATC TCAS Display	ATC Pilot Visual ID
TCAS II Mode S	TCAS II Mode S	Altitude + Bearing + ID + Range + Coordinated RA (Both Aircraft)	ATC TCAS Display	ATC TCAS Display Pilot Visual ID

Table 18 - TCAS II Data Provided

4.2.2 ADS-B

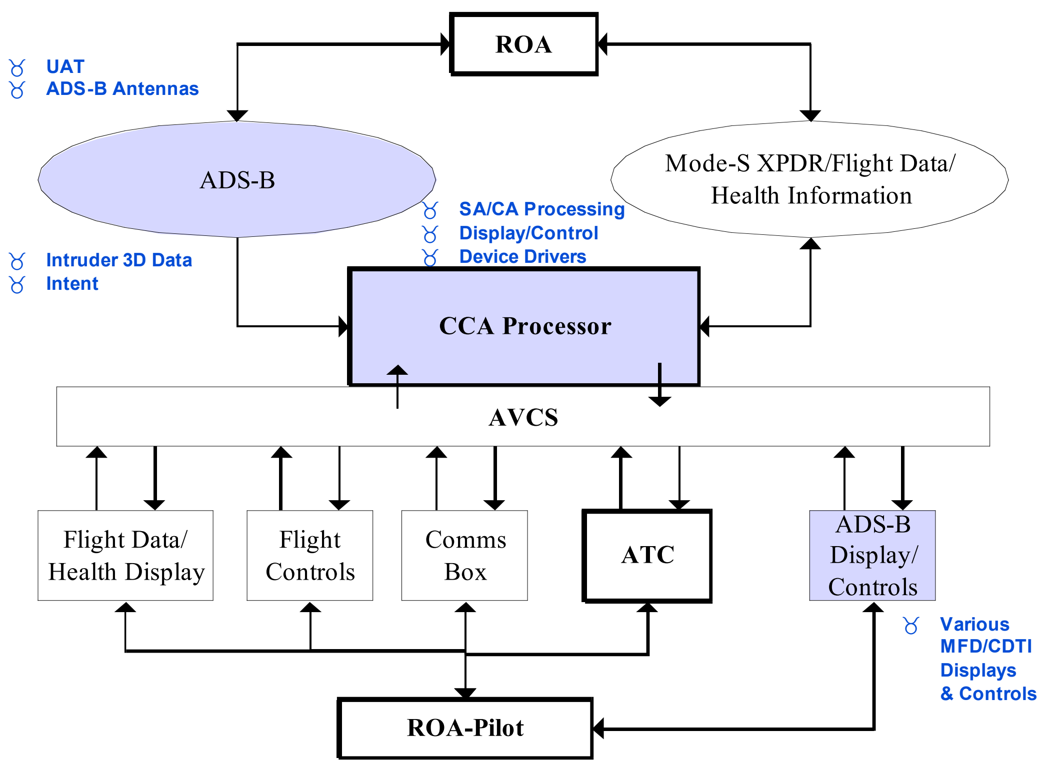


Figure 11 - ADS-B Connectivity

ROA-Pilot Ownship Equipment	Intruder Aircraft Equipment	Sensed Parameters	Independent Verification Options (Ownship)	Independent Verification Options (Intruder)
ADS-B Mode S	None Mode C/S	None	ATC	ATC Pilot Visual ID
ADS-B Mode-S or UAT	ADS-B Mode-S or UAT	Altitude + Bearing + ID + Range + Intent (Both Aircraft)	ATC ADS-B Display	ATC ADS-B Display Pilot Visual ID

Table 19 - ADS-B Data Provided

4.2.3 TIS-B

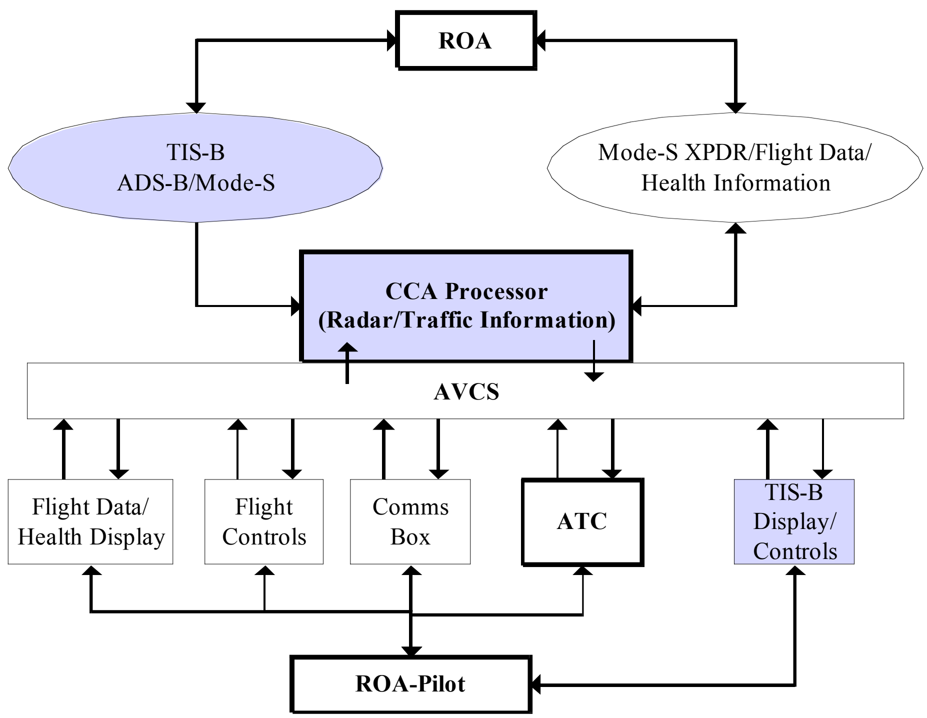


Figure 12 -TIS-B Connectivity

4.2.4 Vision

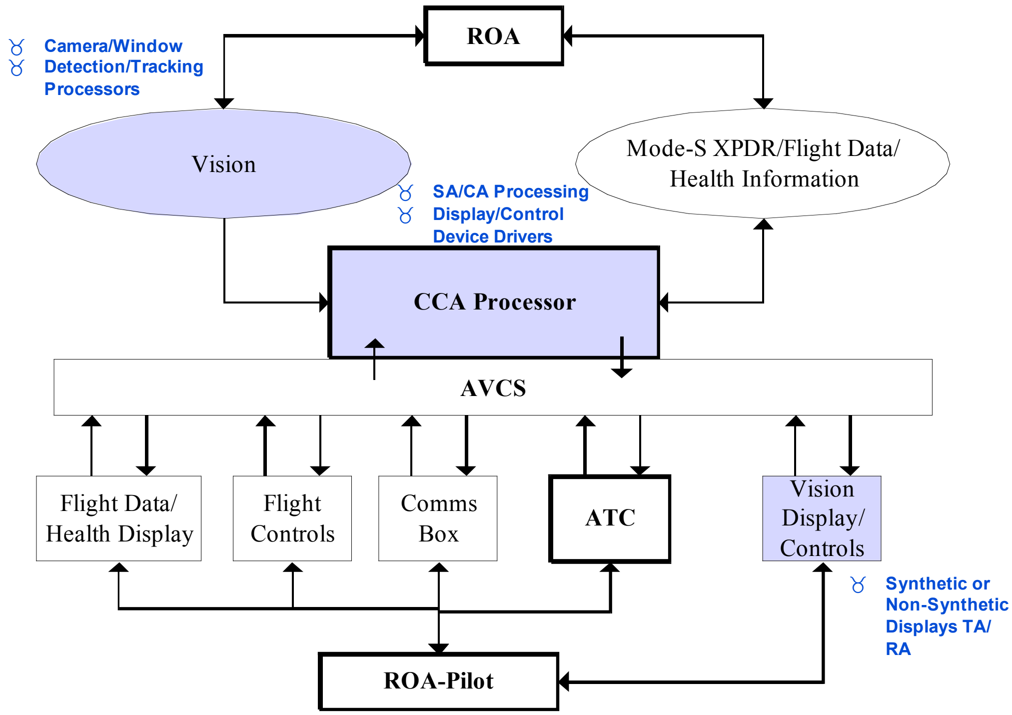


Figure 13 - Vision Connectivity

5 Reference Documents

1. ACCESS 5, *"DSA ELOS Definition Document"*, 2004
2. ACCESS 5, *"CCA Functional Requirements Document"*, 2004
3. IEEE Std. 1220-1998: IEEE Standard for Application and Management of the Systems Engineering Process, 1998.
4. United States, Department of Defense Architecture Framework Version 1.0, *Volume I: Definitions and Guidelines*, February 9, 2004.
5. United States, Federal Aviation Administration, *"How to Avoid a Midair Collision"*, FAA-P-8740-51 AFS-800-0687
6. United States, Department of Transportation, Federal Aviation Administration, *"Introduction to TCAS II Version 7"*, November 2000