NASA/CR—2019–220156

Automated Collision Avoidance (ACA) and Automated Return to Course (ARTC)

Requirement and Guidance Review

Final

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November 2018

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Introduction

For this task order, the project objectives were to review regulatory and guidance documents to identify requirements and considerations for the design and operation of automated systems that perform the functions of automated collision avoidance (ACA) and/or automated return to course (ARTC). The RTCA committee SC-228 defines automated collision avoidance as when a system reacts to a Traffic Collision Avoidance System (TCAS) resolution advisory (RA) without input from the pilot in command (PIC). The information in this report is meant to be consistent with that definition. The automated collision avoidance function starts when it receives the RA indication from the TCAS / Airborne Collision Avoidance System (ACAS) that is part of the Unmanned Aircraft System (UAS).

Background

While organizations such as RTCA are working towards developing industry wide standards and requirements related to UAS integration into the National Airspace (NAS), to date, there has not been an inventory taken of what requirements and guidelines are currently available. All the while there is an increasing amount of automation being integrated into both ground and air based systems. Automated systems such as automatic collision avoidance has recently been tested at both the Alaska and Nevada UAS test sites for example. Also, while RTCA subcommittees are developing requirements for various types of automated systems, there are a host of other automation related requirements that have been in development by the FAA, Eurocontrol, Academia, the US Military (MIL-STDs), and NATO.

A case has been made where there is a need to inventory the requirements and guidelines currently available related to automated systems. These requirements will then need to be fleshed out to identify what are actual requirements that could be built and tested against. Finally, there needs to be a gap analysis to identify what requirements are not currently available and if possible, develop some initial requirements to support those identified gaps.

The importance of this work is twofold: 1) To help focus efforts addressing new automated collision avoidance and return to course systems requirements and considerations, and 2) In pulling together available requirements from multiple sources, generate a master resource for these automated system requirements and considerations.

Methodology

For this task, regulatory and guidance documents that may have information for requirements and considerations were identified and reviewed. Documents included regulations, industry standards and research papers that specifically address Automated Collision Avoidance (ACA) or Automated Return to Course (ARTC) systems or functionality, other automated control and guidance systems (autopilot, flight guidance, required navigation performance (RNP), ICAO, and Eurocontrol documents. The documents were reviewed to identify potentially relevant excerpts. The excerpts were then reviewed and categorized into whether they applied to requirements and considerations for general automated systems, automated collision avoidance (ACA), automated return to course (ARTC), general TCAS/ACAS, or general interface.

The main functions of ACA and ARTC were broken into sub-functions to use for grouping the requirements and considerations.

Identified gaps where information sources were not identified for requirements and consideration for one or more functions were also developed through a cross-examination of requirements and considerations against the functions that were identified and/or developed.

Vendors in the UAS automation space were also interviewed to gain further knowledge and insights into state of the present and state of the art UAS systems, as well as how existing requirements are currently being followed (and if they are being followed).

Vendor Interviews

The development of ACA and ARTC system requirements and considerations can support industry vendors as they develop their systems. As part of this work, several vendors were interviewed to obtain insight into their processes and needs in terms of automation requirements, as well as where they saw the future of automated technologies headed.

To gain an understanding for state of the present in terms of ACA and ARTC technologies project researchers attended AUVSI's Xponential 2018 symposium where they met with multiple technology vendors. From those connections, follow on interviews were scheduled with IRIS, Kutta, Echodyne, New Earth Autonomy, and SRC/Gryphon Sensors. Project researchers also attended RTCA's SC-228 committee meeting to further discuss Detect and Avoid (DAA).

Vendors were asked the following questions:

1. Tell me about your product. Who is your target audience?
2. How long has your product been on the market?
3. What are the differentiators between your product and that of your competition?
4. Tell me what it was like going through the air certification process?
5. What documentation did you rely on to meet the air certification process?
6. What was most helpful during the process?
7. What would have helped?
8. Knowing what you know now, if you were to go through the air certification process today, what would you do differently?
9. How do you see automation for collision avoidance evolving to meet the future needs of the NAS?

Vendors interviewed include Kutta (Bob Vallelonga), Echodyne (Mo Swanson), IRIS (Gabrielle Wain), Near Earth Autonomy (Sanjiv Singh), and SRC/Gryphon (Andrew Carter). By selecting these vendors there is a range of experience (some, like Kutta, being around for a decade, while others such as IRIS are startups that don't have a final product yet (it's in beta testing now). Additionally, some products fit the voids of other products. For instance, the Echodyne ground based radar can fill the low altitude, small object gaps that a larger system such as SRC/Gryphons might not be looking for.

A short description of each vendor is provided in the table below, followed by an interview summary.

Table 1 List of Vendors Interviewed

Vendor	Description
Echodyne	Located in Bellevue, WA, Echodyne makes compact solid-state beam-steering radar sensors for a range of existing and new applications for industry and government.
Iris	Located in San Francisco, California, Iris Automation makes a small, airborne automatic collision avoidance system currently undergoing beta testing at the Nevada UAS test site.
Kutta	Located in Tempe, Arizona and now a division of the Sierra Nevada Corporation, Kutta makes small, portable ground control stations (GCS) as well as an Air Traffic Control Reporting System (ATC-RS) which provides UAS with position reporting capabilities.
Near Earth Autonomy	Located in Pittsburgh, Pennsylvania, Near Earth Autonomy leverages its suite of sensors to create 3D visualizations. These visualizations are then used for system based automatic collision detection and avoidance.
SRC	Located in Syracuse, New York, SRC is an independent, not-for-profit, research and development company. They apply science, technology and information to solve challenges in the areas of defense, environment, and intelligence. We spoke with Andrew Carter who represented SRC/Gryphon. Note that while SRC is the branch that builds radars in support of the military and is a parent company to Gryphon, Gryphon is the branch which supports commercial radar endeavors.

A summary of the interviews with these vendors is below:

Tell us about your product? Who is your target audience?

Most of the vendors interviewed are working on small ground and air based detect and avoid systems. Some of which can provide automatic collision avoidance. One vendor is working on an automatic return to course capability as well. The typical market for these systems is commercial UAS, class 1 (small UAS) and class 2 (although Gryphon's radar has been used for class 3). Typical operations are in Class G airspace (although Gryphon's radar has been used in class E).

How long has your product been on the market?

Responses ranged from a decade to not on the market yet (currently in beta testing).

What are the differentiators between your products and that of your competition?

Vendor responses covered the gamut, where some systems are ground based, some airborne, some target small UAS detection while others look towards larger UAS and general aviation aircraft. Two system have automatic collision avoidance capabilities, one is also working on automatic return to course.

What guidelines did you use during your design process?

All vendors were aware of the work being done by RTCA and specifically the SC-228 subcommittee on Detect and Avoid (with some of the vendors being RTCA members). Additionally, several of the RTCA DO requirement documents and DAA MOPS were followed. The most frequent guidelines used being DO 178 and DO 160. However, vendors felt that “it was the wild west out there” in terms of building actual systems and deriving performance requirements because in part they didn’t find solid performance parameters being covered in any of the available guidelines. There was a general feeling that not all the requirements are available in one document, and even if all the necessary requirements were available, there would still be gaps in basing a system off those requirements. To fill the gap, several vendors were looking to general aviation when developing automated systems, this includes small general aviation aircraft and even rotorcraft.

When developing your system what additional info/guidance would have been helpful?

Many of the vendors stated there just weren’t enough requirements available which is why they looked to manned aviation for requirement guidance. Others felt there should be a single set of requirements contained in one master document. During some of this conversation a discussion of relationships with the FAA came up. Some of the vendors were already talking with the FAA to help ensure their technologies would be or could be certified. Vendors felt that the FAA is interested in seeing UAS integration in the NAS and their technologies succeed, but they don’t have all the answers.

Knowing what you know now, if you were going through the design process today, what would have you done differently?

Vendors were unanimous in saying they wouldn’t do anything differently, but citing this response because nothing has changed. The requirements they needed at the time of building their system still aren’t available today.

How do you see automation evolving to meet the future needs of the NAS?

Vendors felt that there needs to be more testing, they want it to be easier to get UAS in the air for testing, and to test various scenarios including in higher traffic areas. They also felt there would need to be a combination of both ground based detect and avoid systems and airborne systems that worked together to identify all aircraft (including non-cooperatives) in the airspace and then automation would move the aircraft to avoid collisions. The thought was that in the future there would be minimal human piloting but rather telling the aircraft to fly from one location to another and the aircraft would then determine its most efficient and safest route.

Vendor interview takeaways

There were several key takeaways from the vendor discussions including:

There is a lack of automation related performance parameter requirements

There is no one stop shop document to gather all automation related requirements

While RTCA is working to develop automatic return to course (ARTC) requirements, very few vendors (and none of the UAS test sites) are currently incorporating ARTC technologies.

Vendors see the future of automation being a combination of ground and air based systems working together.

Document Review and Findings

An assessment was performed, looking at the regulatory and guidance documents currently available. The data gathering effort began by working through RTCA's library, selecting DOs and white papers covering collision avoidance, automation, return to course, autopilot, auto landing, Auto TCAS, and Required Navigation Performance (RNP). Advisory Circulars (ACs), EuroControl, FAA documentation, ICAO documents, MIL-STDs, and NATO Standards were also reviewed. A complete list of documents reviewed can be found in Appendix A of this report.

Well over 100 documents were reviewed. Of those, approximately half included relevant information that could be used to address ACA and ARTC requirements and considerations and associated general automation concepts. Additionally, some documents contained only general requirements (i.e., the system shall be usable). In those cases, the general requirements were not included. Requirements or guidelines that were testable, or at least contributed to providing information to a vendor or technologist where they could build a system against were the focus.

Functions

Through a review of the documentation several ACA and ARTC functional groups were identified and/or created. Requirements and guidelines were then cross-compared to these functions and where applicable requirements and considerations were then grouped under these functional groups. The results of this effort included identifying which functions were well supported via requirements and considerations and which functions were not.

Automated Collision Avoidance Functional Groups

ACA functional groups are as follows:

1. Receive ACAS/TCAS II RA flag and guidance for maneuver(s) to clear conflict
2. Provide warning/alert and maneuvers for ACA execution to remote pilot
3. Allow time for pilot intervention, if appropriate
4. Initiate avoidance maneuvers by sending control inputs to Flight Control System
5. Allow pilot to monitor accomplishment of ACA maneuvers
6. Send indication to PIC when ACA maneuvers are complete

Automated Return to Course Functional Groups

ARTC functional groups are as follows:

1. Receive ACAS/TCAS Clear of Conflict indication or determine that the encounter has been resolved and the ARTC maneuvers can be initiated
2. Send indication to PIC that conflict has been resolved and return to course can begin
3. Determine maneuver(s) necessary to return to original course or currently assigned course
4. Notify PIC of maneuver(s) necessary to return to course
5. Allow time for pilot intervention, if appropriate
6. Send control inputs to Flight Control System to execute maneuver(s)
7. Allow pilot to monitor accomplishment of ARTC maneuvers
8. Send indication to PIC when return-to-course maneuver is complete

All relevant documents were reviewed in detail to identify excerpts that could be useful in understanding and describing ACA and ARTC requirements and considerations. On the first round of reviews 793 potentially useful excerpts were identified. These were reviewed in more detail and evaluated for specific relevance to ACA and ARTC or related concepts. In the second review 235 useful excerpts were identified related to TCAS/ACAS, ACA, ARTC, and display interfaces for the PIC. A numerical breakdown of the excerpts is illustrated in Figure 1. The excerpts were then used to develop statements of requirements and considerations that may be useful in the future for designing and certifying new ACA and ARTC systems. Tables 2-6 list the requirements and consideration statements and the source document(s) that provided the information. Table 2 provides requirements and considerations for addressing general automation concepts that apply to ACA and ARTC. Table 3 provides requirements and considerations related to ACA and Table 4 for ARTC. General considerations for the TCAS/ACAS system that provides the RA to trigger the ACA system were identified in the review of documents, as well as general requirements and considerations for related to the interface. These are presented in Tables 5 and 6, respectively.

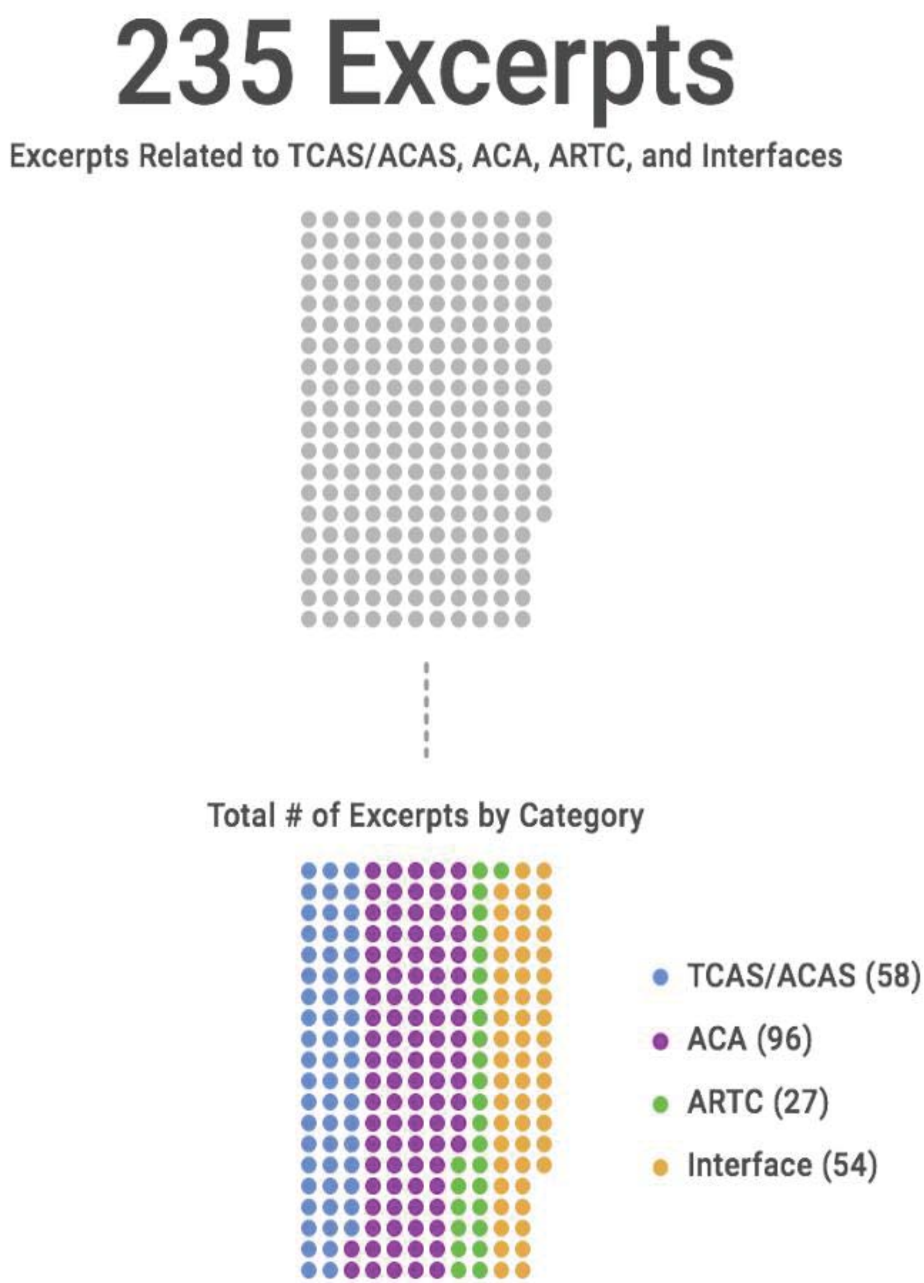

Figure 1. Breakdown of Excerpts

Table 2 below lists general automated system related excerpts as well as which document(s) they were derived from. Table 3 lists ACA related excerpts and their related documents, Table 4 lists ARTC related excerpts and their related documents, Table 5 lists TCAS/ACAS related excerpts and their related documents, and Table 6 lists Interface related excerpts and their related documents.

Table 2 General Automated System Requirements and Considerations

General Automated System Requirements and Considerations	Sources of Information
System performance-based requirements should be defined in terms of system accuracy, integrity, continuity, and functionality.	ICAO 9613 Performance-Based Navigation Manual, 4th Edition, Executive Summary; paragraph 1.1.1.1
System Independence	
Ensure the independence of systems to avoid common mode failures.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.2.2.2
System Integrity	
Ensure the integrity of common data.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.2.2.2
Identify all of the receiver errors that can cause hazardly misleading information to be displayed and estimate their associated probability - compare results to the integrity and continuity requirements.	DO-236C, Minimum Aviation System Performance: Required Navigation Performance for Area Navigation, paragraph B.1
Each mode of operation must have sufficient integrity (low enough undetected failure rate) to meet the performance requirement for which it is proposed to qualify.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph B.2.4
Containment indicates the added integrity required of aircraft systems and is intended to support the performance assurance necessary for more demanding or critical operations.	DO-201A Standards for Aeronautical Information, April 19, 2000, paragraph 1.2.1
System Reliability	
Achieve a level of reliability that is equal to, or exceeds, that achieved by ACAS in a known traffic environment.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.6.3.1, 5.6.5

Achieve a level of reliability that is equal to, or exceeds, that achieved by flight crew of manned aircraft in encounters with manned aviation.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.6.5
Ensure the reliability of common components.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.2.2.2
System Accuracy	
Provide accuracy and performance monitoring and alerting.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016, Chapter 1
Total System Error	
Consider using total system error (TSE) to allow accurate prediction of installed system performance. Analysis of algorithms, sensors, and their performance characteristics can be used to theoretically determine the 95th percentile point of the TSE distribution for operating modes of the system. This point can be validated by flight demonstration or an equivalent approved method.	DO-236C, Minimum Aviation System Performance: Required Navigation Performance for Area Navigation, paragraph 4.2.1
Provide information to enable the remote pilot to have situation awareness of total system error parameters necessary to understand and conduct the operation. Information may include cross track deviation, estimated positioning uncertainty, and allow operating modes.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph 4.2
Provide an alert when the total system error exceeds the required threshold.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016, Chapter 1
Data Validity	
Consider providing a means for the remote pilot to confirm the validity of input data prior to the utilization of the data by the automated system.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph 2.2.2.2.1

Table 3 Automated Collision Avoidance (ACA) Requirements and Considerations

Automated Collision Avoidance (ACA) Requirements and Considerations	Sources of Information
General Requirements and Considerations	

Perform collision avoidance maneuvers in regard to other aircraft and airborne objects that present a hazard to flight safety.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 1.1.3
Perform in ways that are operationally compatible with the associated TCAS/ACAS.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraphs 1.1.3, 5.6.3.1, 5.6.4.2
Enable a reduction in collision risk with fast moving objects equal to, or exceeding, that achieved by flight crew of manned aircraft using see and avoid.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.6.3.1, 5.6.5
Enable a reduction in collision risk with transponder equipped aircraft equal to, or exceeding, that achievable by the correct response to ACAS RAs by pilots in manned aircraft.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.6.3.1, 5.6.3.2, 5.6.4.2, 5.6.5
Execute an effective avoidance maneuver at the maximum likely closing speed.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraphs 5.6.3.2, 5.6.4.2, 5.6.5
The ACA system must perform at least as well as collision avoidance through see and avoid by flight crew of manned aircraft.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraphs 5.3.4, 6.2.1
Ensure the collision avoidance capability is equal to or exceeds that of manned aircraft in the same environment (known ATC environment or unknown ATC environment) and conditions (IMC or VMC50).	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 6.1.4
The design characteristics of the display system should support error avoidance and error management.	AC 23.1309-1C - Equipment, Systems, and Installations in Part 23 Airplanes, March 12, 2009
Ensure that all information, no matter the prioritization, can be recovered when needed.	AC 25-11B - Electronic Flight Deck Displays, Oct 7, 2014
Receive ACAS/TCAS II RA flag and guidance for maneuver(s) to clear conflict	
Receive RA alert and guidance so that there is sufficient time to initiate any required maneuvers and achieve the desired miss distance from the intruder aircraft.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.3
Provide warning/alert and maneuvers for ACA execution to remote pilot	
Ensure that the timing of CA warnings incorporate the delay associated with the UA conducting the CA maneuver.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.3.2
Ensure that the ACA system achieves the CA	Eurocontrol, Unmanned Aircraft Systems -

maneuver within the required response times, vertical acceleration requirements, and vertical rates.	ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.3.5
Present relative track of intruder aircraft.	AC 20-151 - Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) Version 7.0 and Associated Mode S Transponders, paragraph 2.3.7.1
Provide to the remote pilot a clear indication of the path and planned speed that will be followed when the CA maneuver is initiated.	NATO Standard AEP-80, Rotary Wing Unmanned Aerial Systems Airworthiness Requirements, September 2014
Use a prioritization scheme to prioritize alerts and advisory/status messages. Alerts requiring pilot awareness or action should be given the highest priority.	AC 23-17B - Systems and Equipment Guide for Certification of Part 23 Airplanes, April 12, 2005; DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5
Consistently use alerts and advisory/status messages.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5
All message nomenclature should be easily understood by the flight crew.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5
Allow time for pilot intervention, if appropriate	
If pilot intervention in the CA maneuver is allowed, ensure that the warning time incorporates the delay associated with pilot performance (noticing the alert, determining the required response, initiating the response, and the round trip latency of communicating the alert and maneuver to the remote pilot and then the pilot response back to the UA).	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.3.2.1
Consider including a means for the remote pilot to manually override or abort the maneuver.	NATO Standard AEP-80, Rotary Wing Unmanned Aerial Systems Airworthiness Requirements, September 2014; DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013, paragraph 3.7.2.1.3.1, DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015 paragraph 2.2.1.2.1.2.1; DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph 4.3
Provide the remote pilot a ready means to	SC-228 Automated RA Execution and

disarm/re-arm the ACA mode so that the current mode of the autopilot/flight director is unaffected.	Return-to-Course Requirements, June 28, 2018
Ensure that override of autopilot or autothrust cannot create a hazardous situation.	14 CFR 25.1329 Flight Guidance System
Initiate avoidance maneuvers by sending control inputs to Flight Control System	
ACA must comply with RAs from the TCAS/ACAS promptly and accurately.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 6.2.1
Initiate avoidance maneuvers only in case of a real threat.	Fasano et al (2008). Multi-Sensor-Based Fully Autonomous Non-Cooperative Collision Avoidance System for Unmanned Air Vehicles. Journal of Aerospace Computing, Information, and Communication, Vol 5, October 2008
Minimize the deviation from the nominal trajectory due to executing the avoidance maneuver.	Fasano et al (2008). Multi-Sensor-Based Fully Autonomous Non-Cooperative Collision Avoidance System for Unmanned Air Vehicles. Journal of Aerospace Computing, Information, and Communication, Vol 5, October 2008
Collision avoidance maneuver must be initiated at a time and range to allow execution of the maneuver maintaining the minimum safe distance to the intruder.	Airborne Collision Detection and Avoidance for Small UAS Sense and Avoid Systems, Laith Rasmi Sahawneh, Brigham Young University - Provo, January 1, 2016
Collision avoidance maneuver must be executed no later than 5 seconds upon issuance.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Perform the avoidance maneuver in such a way that the distance at the closest point of approach to the intruder is equal or greater than a minimum required miss distance.	Airborne Collision Detection and Avoidance for Small UAS Sense and Avoid Systems, Laith Rasmi Sahawneh, Brigham Young University - Provo, January 1, 2016
Perform collision avoidance maneuvers so as to guarantee a miss distance of at least 500 feet.	Fasano et al (2008). Multi-Sensor-Based Fully Autonomous Non-Cooperative Collision Avoidance System for Unmanned Air Vehicles. Journal of Aerospace Computing, Information, and Communication, Vol 5, October 2008
Perform the CA maneuver well within the 25 second warning time predicted by the. TCAS/ACAS RA to the closest point of approach .	AC 20-131A - Airworthiness and Operational Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders, Section 2, March 29, 1993
Display to the remote pilot the commanded flight or navigation parameters sent to the UA.	NATO Standard AEP-83, Light Unmanned Aircraft Systems Airworthiness Requirements, September 2014
Ensure that the UA remains within a flight envelope sufficiently protected by the flight control system.	NATO Standard AEP-83, Light Unmanned Aircraft Systems Airworthiness Requirements, September 2014

Consistent with that assumed for flight director operation and manual operation allow a maximum horizontal position estimation error of .08 NM.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph 2.2.1.5.1.1
Engagement, disengagement, or switching of the flight guidance system, mode, sensor, or automatic control function may not cause a transient response of the flight path any greater than a minor transient.	14 CFR 25.1329 Flight Guidance System
Provide access to a navigation database with resolution to achieve required track keeping accuracy, protected against pilot modification of stored data.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016
Allow pilot to monitor accomplishment of ACA maneuvers	
Provide a means for the remote pilot to monitor compliance with the CA guidance maneuvers.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Continue to follow the RA maneuver guidance unless one of the following conditions is met: a. a mode disengagement is received b. a clear of conflict indication is received c. an RA inhibit region is reached d. other priority alerts are presented (e.g. stall warning, windshear alert).	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Receive mode disengagement commands.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Receive clear of conflict indications.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Receive RA inhibit indications.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Receive other priority alerts (e.g. stall warning, windshear alert).	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Indicate to the PIC that the ACA system cannot achieve or maintain its target guidance due to UA performance limitations.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
ACA actions must not lead to loss of LOC capture or loss of Nav mode.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Clearly and unambiguously indicate to the remote pilot the state(s), mode(s), and status of the autopilot, flight director, and TCAS/ACAS before, during, and following an autopilot/flight director coupled RA maneuver.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018; 14 CFR 25.1329 Flight Guidance System
Continuously present to the remote pilot	NATO Standard AEP-80, Rotary Wing

during the performance of the avoidance maneuver the UA flight path and any deviation between the UA flight path and the planned flight path.	Unmanned Aerial Systems Airworthiness Requirements, September 2014; DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013, paragraph 3.7.5.2.1
Indicate selected altitude if mode logic permits flight through or away from any AP/FD selected altitude.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Clearly indicate mode disengagements or transitions (including from automated collision avoidance mode to another AP/FD mode).	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018; 14 CFR 25.1329 Flight Guidance System
Present desired path and UA position relative to the path.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016
Send indication to PIC when ACA maneuvers are complete	
Use a prioritization scheme to prioritize alerts and advisory/status messages. Alerts requiring pilot awareness or action should be given the highest priority.	AC 23-17B - Systems and Equipment Guide for Certification of Part 23 Airplanes, April 12, 2005; DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5
Consistently use alerts and advisory/status messages.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5
All message nomenclature should be easily understood by the flight crew.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5

Table 4 Automated Return to Course (ARTC) Requirements and Considerations

Automated Return to Course (ARTC) Requirements and Considerations	**Sources of Information**
General Requirements and Considerations	
The ARTC function must not lead to loss of LOC capture or loss of Nav mode.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Provide an indication to the remote pilot if the ARTC mode is inhibited.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Receive ACAS/TCAS Clear of Conflict indication or determine that the encounter has been resolved and the ARTC maneuvers can be initiated	
Receive Clear of Conflict alert to initiate the ARTC action.	No specific information sources were identified for this requirement/consideration.
Send indication to PIC that conflict has been resolved and return to course can begin	
Use a prioritization scheme to prioritize alerts and advisory/status messages. Alerts requiring pilot awareness or action should be given the highest priority.	AC 23-17B - Systems and Equipment Guide for Certification of Part 23 Airplanes, April 12, 2005; DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5
Consistently use alerts and advisory/status messages.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5
All message nomenclature should be easily understood by the flight crew.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5
Determine maneuver(s) necessary to return to original course or currently assigned course	
Determine maneuvers to return to course.	No specific information sources were identified for this requirement/consideration.

Notify PIC of maneuver(s) necessary to return to course	
Provide to the remote pilot a clear indication of the path and planned speed that will be followed when return-to-course maneuver is initiated.	NATO Standard AEP-80, Rotary Wing Unmanned Aerial Systems Airworthiness Requirements, September 2014
Allow time for pilot intervention, if appropriate	
Provide a means for the PIC to inhibit, disengage, or manually override the ARTC mode.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018; NATO Standard AEP-80, Rotary Wing Unmanned Aerial Systems Airworthiness Requirements, September 2014; DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013, paragraph 3.7.2.1.3.1, DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015 paragraph 2.2.1.2.1.2.1; DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph 4.3
Receive mode disengagement indications.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
If pilot intervention in the RTC maneuver is allowed, ensure that the warning time incorporates the delay associated with pilot performance (noticing the alert, determining the required response, initiating the response, and the round trip latency of communicating the alert and maneuver to the remote pilot and then the pilot response back to the UA).	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.3.2.1
Provide the remote pilot a ready means to disarm/re-arm the ACA mode so that the current mode of the autopilot/flight director is unaffected.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Ensure that the override of autopilot or autothrust cannot create a hazardous situation.	14 CFR 25.1329 Flight Guidance System
Send control inputs to Flight Control System to execute maneuver(s)	
Initiate the return to course maneuver when the clear of conflict condition has been met.	Fasano et al (2008). Multi-Sensor-Based Fully Autonomous Non-Cooperative Collision Avoidance System for Unmanned Air

	Vehicles. Journal of Aerospace Computing, Information, and Communication, Vol 5, October 2008
ARTC must accomplish maneuvers promptly and accurately.	No specific information sources were identified for this requirement/consideration
Implement a means for predictable, immediate positive guidance and control of the UA upon one of following conditions being satisfied a. A mode disengagement is commanded either by the remote pilot or another higher priority UAS system b. An indication is received that course convergence is achieved.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Display to the remote pilot the commanded flight or navigation parameters sent to the UA.	NATO Standard AEP-83, Light Unmanned Aircraft Systems Airworthiness Requirements, September 2014
Ensure that the UA remains within a flight envelope sufficiently protected by the flight control system.	NATO Standard AEP-83, Light Unmanned Aircraft Systems Airworthiness Requirements, September 2014
Consistent with that assumed for flight director operation and manual operation allow a maximum horizontal position estimation error of .08 NM..	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph 2.2.1.5.1.1
Engagement, disengagement, or switching of the flight guidance system, mode, sensor, or automatic control function may not cause a transient response of the flight path any greater than a minor transient	14 CFR 25.1329 Flight Guidance System
Provide access to a navigation database with resolution to achieve required track keeping accuracy, protected against pilot modification of stored data.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016
Allow pilot to monitor accomplishment of ARTC maneuvers	
Provide an indication to the PIC when an automated RTC maneuver is underway and that indication shall persist until one of the following conditions is met a. A mode disengagement is commanded either by the remote pilot or another higher priority UAS system (e.g. terrain alert, windshear alert, stall warning, automatic RA mode, etc.) b. An indication is received that course convergence is achieved.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Present desired path and UA position relative to the path.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016

Receive mode disengagement commands.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Receive course convergence indications.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Receive indication that course convergence has been achieved.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Clearly and unambiguously indicate to the remote pilot the state(s), mode(s), and status of the autopilot, flight director, and TCAS/ACAS before, during, and following an autopilot/flight director coupled maneuver.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018; 14 CFR 25.1329 Flight Guidance System
Continuously present to the remote pilot during the performance of the RTC maneuver the UA flight path and any deviation between the UA flight path and the planned flight path.	NATO Standard AEP-80, Rotary Wing Unmanned Aerial Systems Airworthiness Requirements, September 2014; DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013, paragraph 3.7.5.2.1
Indicate selected altitude if mode logic permits flight through or away from any AP/FD selected altitude.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018
Clearly indicate mode disengagements or transitions.	SC-228 Automated RA Execution and Return-to-Course Requirements, June 28, 2018; 14 CFR 25.1329 Flight Guidance System
Send indication to PIC when return-to-course maneuver is complete	
Use a prioritization scheme to prioritize alerts and advisory/status messages. Alerts requiring pilot awareness or action should be given the highest priority.	AC 23-17B - Systems and Equipment Guide for Certification of Part 23 Airplanes, April 12, 2005; DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5
Consistently use alerts and advisory/status messages.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5
All message nomenclature should be easily understood by the flight crew.	DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015, paragraph F.2.2.5

Table 5 TCAS/ACAS Requirements and Considerations

Traffic Collision Avoidance System (TCAS) / Airbone Collision Avoidance System (ACAS) Requirements and Considerations	Sources of Information
General Requirements and Considerations	
Ensure ACAS surveillance is not negatively impacted by siting of the UAS antennae.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.3.5
Ensure ACAS algorithms are not impaired by UAS flight dynamics.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.3.5
Ensure that CA function performs at least as well as See and Avoid exercised by flight crew of manned aircraft.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 6.2.1
Enable a reduction in collision risk with fast moving objects equal to, or exceeding, that achieved by flight crew of manned aircraft using see and avoid.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.6.3.1
Ensure the collision avoidance capability is equal to or exceeds that of manned aircraft in the same environment (known ATC environment or unknown ATC environment) and conditions (IMC or VMC50).	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 6.1.4.
Use the standard collision avoidance algorithms so that they coordinate well with other systems.	AC 20-151 - Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) Version 7.0 and Associated Mode S Transponders, February 7, 2005.
Detect Aircraft and Determine Separation and Collision Risk	
Identify risk of impending collision and determine need for collision avoidance.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraphs 1.1.3, 1.2.5
Identify potential and predicted collision threats.	AC 20-145 - Guidance for Integrated Modular Avionics (IMA) that Implement TSO-C153 Authorized Hardware Element, February 25, 2003.

Detect other aircraft.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 1.1.3
Detection must be accomplished at a time and range to allow the system to track the intruder, identify a collision threat, and plan an avoidance path to allow execution of the maneuver maintaining the minimum safe distance to the intruder.	Airborne Collision Detection and Avoidance for Small UAS Sense and Avoid Systems, January 1, 2016, page 21.
Ensure a detection range commensurate with an effective avoidance maneuver considering maximum closing speed of traffic.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraphs 5.6.3.1, 5.6.5, 5.6.6.
Resolve multiple aircraft encounters.	AC 20-151 - Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) Version 7.0 and Associated Mode S Transponders, February 7, 2005.
Ensure surveillance and tracking of transponder replies using active interrogation where necessary.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.6.3.2.
Sense and present relative track of nearby transponder-equipped aircraft.	AC 20-151 - Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) Version 7.0 and Associated Mode S Transponders, February 7, 2005.
Ensure that estimates of intruder positions and motion are reliable.	AC 25-11A - Electronic Flight Deck Displays, June 21, 2007, Section IV; Fasano et al (2008). Multi-Sensor-Based Fully Autonomous Non-Cooperative Collision Avoidance System for Unmanned Air Vehicles. Journal of Aerospace Computing, Information, and Communication, Vol 5, October 2008, Section IV.
Display traffic	
Display relative positions of other aircraft.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 1.2.5
Display potential and predicted collision threats.	AC 20-145 - Guidance for Integrated Modular Avionics (IMA) that Implement TSO-C153 Authorized Hardware Element, February 25, 2003.

Display of traffic should consider different altitude reporting modes.	AC 20-151 - Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) Version 7.0 and Associated Mode S Transponders, February 7, 2005.
Create RA and Trigger Collision Avoidance System	
Trigger the collision avoidance system when the self-separation mode fails to maintain the well-clear distance.	Airborne Collision Detection and Avoidance for Small UAS Sense and Avoid Systems, January 1, 2016, page 21.
Create a RA to provide vertical avoidance maneuver to increase separation when a threat aircraft is predicted to be within approximately 25 seconds from the closest point of approach.	AC 20-131A - Airworthiness and Operational Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders, March 29, 1993.
Generate and Provide Guidance for Collision Avoidance	
Use an algorithm to create the collision avoidance maneuver in such a way that the distance at the closest point of approach to the intruder is equal to, or greater than, a minimum required safe distance.	Airborne Collision Detection and Avoidance for Small UAS Sense and Avoid Systems, January 1, 2016, page 148.
Create a collision avoidance maneuver to prevent a threat aircraft from entering the near mid-air collision (NMAC) volume: the area surrounding the UA that is defined by a horizontal radius of 500 feet and a vertical height of 200 feet (100 feet above and below).	An Investigation of Minimum Information Requirements for an Unmanned Aircraft System Detect and Avoid Traffic Display, June 2017, page 1.
Provide collision avoidance guidance that guarantees a miss distance of at least 500 feet.	Fasano et al (2008). Multi-Sensor-Based Fully Autonomous Non-Cooperative Collision Avoidance System for Unmanned Air Vehicles. Journal of Aerospace Computing, Information, and Communication, Vol 5, October 2008, Section B.
Consistent with that assumed for flight director operation and manual operation allow a maximum horizontal position estimation error of .08 NM.	RTCA DO-283B, December 15, 2015, Paragraph 2.2.1.5.1.1.
Calculate and develop guidance for an effective avoidance maneuver at the maximum likely closing speed.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.6.3.1, 5.6.3.2, 5.6.6
Produce suitable avoidance maneuver.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.2.2.5

Produce maneuver that accommodates possible movements of UAS and intruder aircraft.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.2.2.5
Generate collision avoidance maneuver that minimizes the deviation from the nominal trajectory.	Fasano et al (2008). Multi-Sensor-Based Fully Autonomous Non-Cooperative Collision Avoidance System for Unmanned Air Vehicles. Journal of Aerospace Computing, Information, and Communication, Vol 5, October 2008, Section IV.
Develop CA avoidance maneuvers that ensure that the UA remains within a flight envelope sufficiently protected by the flight control system.	NATO Standard AEP-83, September 2014, Section UL.57.
Generate collision avoidance guidance and maneuvers that is compatible with the UA flight performance characteristics.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraphs 5.3.5, D.3.2.1; D.3.2.2; Airborne Collision Detection and Avoidance for Small UAS Sense and Avoid Systems, January 1, 2016, page 21; AC 20-131A - Airworthiness and Operational Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders, March 29, 1993.
Know aircraft performance beforehand so strategy can be changed and alternative RA issued.	AC 20-151 - Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) Version 7.0 and Associated Mode S Transponders, February 7, 2005.
Consider right-of-way rules when developing collision avoidance guidance maneuvers.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.4.4; Airborne Collision Detection and Avoidance for Small UAS Sense and Avoid Systems, January 1, 2016, page 21.
Coordinate avoidance maneuvers with other aircraft so that complementary maneuvers are chosen.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 1.2.5, 6.1.4, 6.2.1
Develop collision avoidance guidance that is compatible with other ACAS.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 5.6.6
Consider coordination with ATC for separation maneuvers, but ATC coordination does not have to be considered for collision avoidance	An Investigation of Minimum Information Requirements for an Unmanned Aircraft System Detect and Avoid Traffic Display,

maneuvers.	June 2017, page 1.
Ensure interoperability and compatibility with other ACAS and the ability to coordinate avoidance maneuvers.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraphs 1.1.3, 5.6.3.1
Provide collision avoidance guidance to the collision avoidance function or system and to the flight crew.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraphs 1.2.5, 5.3.5
Provide Separation Alerts and Collision Avoidance Warnings	
Provide appropriate aural and visual alerts when a penetration of protected airspace is predicted to ensure adequate separation.	AC 20-131A - Airworthiness and Operational Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders, March 29, 1993; AC 20-145 - Guidance for Integrated Modular Avionics (IMA) that Implement TSO-C153 Authorized Hardware Element, February 25, 2003.
Issue alerts of impending collision.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 1.2.5
Generate alerts in a timely manner so that there is sufficient time to initiate any required maneuvers and achieve the desired miss distance from the intruder aircraft.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.3
Warning times must incorporate pilot delay and maneuver delay.	Eurocontrol, Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements, May 17, 2010, paragraph 4.3.1; 4.3.2
Issue RAs on pilot displays.	AC 20-151 - Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) Version 7.0 and Associated Mode S Transponders, February 7, 2005.
Prioritize aural alerts with an aural prioritization scheme.	AC 23-17B - Systems and Equipment Guide for Certification of Part 23 Airplanes, April 12, 2005.
The design characteristics of the display system should support error avoidance and error management.	AC 23.1309-1C - Equipment, Systems, and Installations in Part 23 Airplanes, March 12, 2009.
Ensure that all information, no matter the prioritization, can be recovered when needed.	AC 25-11B - Electronic Flight Deck Displays, October 7, 2014.

Table 6 Interface Requirements and Considerations

Interface Requirements and Considerations	Sources of Information
General Requirements and Considerations	
Minimize reliance on flight crew memory for any system operations procedures or task.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.1 General.
Clearly and unambiguously display system modes and mode changes.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.1 General.
Display context-sensitive error messages.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.1 General.
Use fault tolerant data entry methods.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.1 General.
Minimize nuisance alerts.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.1 General.
Displays and Controls	
Displays should be located where they are clearly visible.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Each display element used as a primary flight instrument in the guidance and control of the aircraft, for maneuver anticipation, or for failure/status/integrity annunciation, shall be located in the pilot's primary field of view.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.2 Displays and Controls.
Horizontal (and vertical) deviation(s), display(s), and failure annunciations should be located within the pilot's primary field of view, as should any indication requiring immediate aircrew action.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
All displays, controls, and annunciators must be easily readable under all expected lighting conditions.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.2 Displays and Controls; RTCA DO-283B, Minimum Operational Performance Standards for Required

	Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.3 Readability; AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Orient labels to facilitate readability.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.1.1.1 Controls.
Pilots should have an unobstructed view of displayed data.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
The effect of failure of one system must not result in misleading information.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Controls and displays shall be designed to maximize operational suitability and minimize pilot workload.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.2 Displays and Controls.
Controls shall be readily accessible with standardized labeling as to their function.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.2 Displays and Controls; MIL-HDBK-454B, General Guidelines for Electronic Equipment, April 15, 2007. Guideline 28, Controls.
Controls used most frequently should be most accessible.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Controls shall be designed to minimize errors.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.2 Displays and Controls.
Provide feedback for operation of all controls.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.1 Controls; AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
In general, movement of a control forward, clockwise, to the right, or up, should turn the equipment on, cause the quantity to increase, or cause the equipment to move forward, clockwise, to the right, or up.	MIL-HDBK-454B, General Guidelines for Electronic Equipment, April 15, 2007. Guideline 28, Controls.
If a control can be used for multiple functions, the current function should be indicated either on the display or on the control.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.1.1.1 Controls.

Current and active functions should be clear and distinguishable.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Mode logic should be consistent across systems.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Provide a continuous and unambiguous indication of current, armed, and enabled modes whether modes are armed manually or by the system.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
All controls should be marked, indexed, sized, and located so that the control position can be readily identified.	MIL-HDBK-454B, General Guidelines for Electronic Equipment, April 15, 2007. Guideline 28, Controls.
Control labels should clearly communicate control functions.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.1.1.1 Controls.
Indicate the method for actuating the control.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.1.1.1 Controls.
Labels should be adjacent to the controls they identify.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.1.1.1 Controls.
Controls and their labels should be identifiable in all expected lighting conditions.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Control function must be understandable.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Controls shall be arranged to provide adequate protection against inadvertent system shutdown.	DO-236C, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, June 19, 2013. Paragraph 3.6.2 Displays and Controls.
Prevent inadvertent operation of controls.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.1 Controls; AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Control labels and related information should not be obstructed by the control.	MIL-HDBK-454B, General Guidelines for Electronic Equipment, April 15, 2007. Guideline 28, Controls; RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area

	Navigation, December 15, 2015. Paragraph F.2.1.1.1 Controls; AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Controls should be organized in logical groups.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
All controls that have sequential relations, are related to a particular function or operation or are operated together, should be grouped together along with their associated displays.	MIL-HDBK-454B, General Guidelines for Electronic Equipment, April 15, 2007. Guideline 28, Controls.
Controls should be organized according to the following principles: • Collocate the controls with associated displays. • Partition the controls into functional groups. • Place the most frequently used controls in the most accessible locations. • Arrange the controls according to the sequence of use.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.1 Controls.
Ensure that the location of soft controls are consistent across all systems.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.1 Controls.
Symbology and mode annunciations should be used consistently and be consistent with general use and established standards whenever possible.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016; RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.1.1.2 Data Fields and Other Symbology.
Force required for operating a control should be consistent with its intended function.	AC 20-138D Change 2, Airworthiness Approval of Positioning and Navigation Systems, April 7, 2016.
Formatting	
Use fonts consistently on all pages such that the meaning of information is preserved.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.3 Fonts and Highlighting.
Highlighting can be used to bring attention to a field or to convey that an action is required.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.3 Fonts and Highlighting.
Use the same highlighting scheme across all pages.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation,

	December 15, 2015. Paragraph F.2.2.3 Fonts and Highlighting.
Establish a consistent use of color throughout all displays that complies with accepted practices and standards.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.4 Color.
Only use the color red for actions requiring immediate flight crew awareness and immediate flight crew response.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.4 Color.
Only use the colors amber or yellow for actions requiring immediate flight crew awareness and subsequent flight crew response.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.4 Color.
Ensure that all colors used are discernable the full range of lighting conditions.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.4 Color.
Pure (e.g. "royal") blue should be avoided for text, small symbols, other fine detail, or as a background color because it is difficult for the human eye to bring blue symbols into focus and to distinguish the blue from yellow when the symbols are small.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.4 Color.
Avoid the following color combinations: -- saturated red and green, -- saturated blue and green, -- saturated yellow and green, -- yellow on purple -- yellow on green -- yellow on white -- magenta on green -- magenta on black (may be acceptable for lower criticality items) -- green on white -- blue on black -- red on black	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.4 Color.
Color-coded information should be accompanied by another distinguishing characteristic such as shape, location, or text.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.4 Color.
Use consistent page formats and display layouts.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.1 Page Format and Display Layout.
Use consistent positioning of information and data fields.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation,

	December 15, 2015. Paragraph F.2.2.1 Page Format and Display Layout.
Consistently group information.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.1 Page Format and Display Layout.
Display the most essential information as the most prominent.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.1 Page Format and Display Layout.
Minimize clutter and density of information.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.1 Page Format and Display Layout.
Consistently format data and information across pages.	RTCA DO-283B, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation, December 15, 2015. Paragraph F.2.2.1 Page Format and Display Layout.

Conclusions and Observations

Automated collision avoidance (ACA) and automated return to course (ARTC) are fairly new. A review of the current seven FAA UAS test sites found that only two (Alaska and Nevada) of the seven utilized ACA and none were working with ARTC. Therefore, it is not surprising that information specifically addressing ACA and ARTC was sparse. However, there is a lot of information available addressing collision avoidance in general that could be used to extrapolate to an ACA system. Very little was found in a similar way related to any type of return to course system however.

The ACA requirements and considerations shown in the ACA table seem to be fairly complete in coverage of general requirements and coverage of concepts that will need to be addressed. There is more work however that will need to be done for ARTC. We did not find any source information for two of the functional groups for ARTC: that addressing the initiation of the ARTC function when the system receives an indication that the UA is clear of the conflict and the function of generating the return to course maneuvers. ACA has functions related to these that could possibly be used as models, but no document in the review addressed these for ARTC.

Finding ways to address the requirements and considerations related to automating these systems was challenging, as well. The approaches taken in designing and certifying other automated systems were reviewed (e.g. autopilot, autothrust, autoland, flight guidance system), but all of those systems we designed considering that the flight crew would likely set their parameters and turn them off if necessary. Documents related to Required Navigation

Performance (RNP) were also reviewed to consider the requirements for when systems need to show a minimum level of precision to be able to perform certain operations.

Moving forward, the design and certification approach to ensuring minimum standards of system accuracy, integrity, reliability, and data validity will need to be clarified. The requirements and considerations in the Automation Tables can be used as a start for future development in this area.

APPENDIX A: Documents Reviewed

Note that while we reviewed well over 100 documents, the following were the ones that contained information on automation such as ACA and ARTC that were able to leveraged for the above work.

Reference #	Title	Date
AC 20-130A	Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors	June 14, 1995
AC 20-131A	Airworthiness and Operational Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders	March 29, 1993
AC 20-145	Guidance for Integrated Modular Avionics (IMA) that Implement TSO-C153 Authorized Hardware Element	February 25, 2003
AC 20-151	Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) Version 7.0 and Associated Mode S Transponders	February 7, 2005
AC 20-151A	Airworthiness Approval of Traffic Alert And Collision Avoidance Systems (TCAS II), Versions 7.0 & 7.1 and Associated Mode S Transponders	September 25, 2009
AC 20-172A	Airworthiness Approval for ADS-B In Systems and Applications	March 23, 2012
AC 23-8B	Flight Test Guide for Certification of Part 23 Airplanes	August 14, 2003
AC 23-16A	Powerplant Guide for Certification of Part 23 Airplanes and Airships	February 23, 2004
AC 23-17B	Systems and Equipment Guide for Certification of Part 23 Airplanes	April 12, 2005
AC 23-18	Installation of Terrain Awareness and Warning System (TAWS) Approved for Part 23 Airplanes	June 14, 2000
AC 23-26	Synthetic Vision and Pathway Depictions on the Primary Flight Display	December 22, 2005
AC 23.1309-1C	Equipment, Systems, and Installations in Part 23 Airplanes	March 12, 2009
AC 23.1311-1B	Installation of Electronic Displays in Part 23 Airplanes	June 14, 2005
AC 23.1523	Minimum Flight Crew	January 12, 2005
AC 25-7A	Flight Test Guide for Certification of Transport Category Airplanes	March 31, 1998
AC 25-11A	Electronic Flight Deck Displays	June 21, 2007
AC 25-23	Airworthiness Criteria for the Installation Approval of a Terrain Awareness and Warning System (TAWS) for Part 25 Airplanes	May 22, 2000
AC 25.773-1	Pilot Compartment View for Transport Category Airplanes	January 8, 1993
AC 25.1329-1B	Pilot Compartment View for Transport Category Airplanes	October 27, 2014

AC 25.1329-1B	Automatic Pilot Systems Approval	July 14, 1997
AC 25.1581-1	Airplane Flight Manual	October 16, 1980
AC 43-2B	Minimum Barometry for Calibration and Test of Atmospheric Pressure Instruments	August 14, 2002
AC 43-6B	Altitude Reporting Equipment and Transponder System Maintenance and Inspection Practices	April 19, 2016
AC 90-48D	Pilots' Role in Collision Avoidance	April 19, 2016
AC 103-6	Ultralight Vehicle Operations-Airports, ATC, and Weather	June 23, 1983
AC 120-29A	Criteria for Approval of Category I and Category II Weather Minima for Approach	August 12, 2002
AC 120-53	Crew Qualification and Pilot Type Rating Requirements for Transport Category Aircraft Operated Under FAR Part 121	May 13, 1991
AC 120-55B	Air Carrier Operational Approval and Use of TCAS II	October 22, 2011
AC 120-86	Aircraft Surveillance Systems and Applications	September 16, 2005
Research Paper	Airborne Collision Detection and Avoidance for Small UAS Sense and Avoid Systems, Laith Rasmi Sahawneh, Brigham Young University - Provo	January 1, 2016
CMU-RI-TR-08-03	Avoiding Collisions Between Aircraft: State of the Art and Requirements for UAVs operating in Civilian Airspace, by Christopher Geyer, Sanjiv Singh, Lyle Chamberlain.	January 1, 2008
Research Paper	Survey on Unmanned Aerial Vehicle Collision Avoidance Systems, Hung Pham, Scott A. Smolka, Scott D. Stoller, Dung Phan, Junxing Yang	2015
	NBAA Automated Flight Deck Training Guidelines	September 2000
	Operational Use of Flight Path Management Systems	September 5, 2013
DOT-VNTSC-FAA-12-10; DOT/FAA/TC-12/8	Chandra, D. C., Grayhem, R.J., and Butchibabu, A.. Area Navigation and Required Navigation Performance Procedures and Depictions	September, 2012
RTCA	SC-228 Automated RA Execution and Return-to-Course Requirements	June 28, 2018
	Fasano et al. Multi-Sensor-Based Fully Autonomous Non-Cooperative Collision Avoidance System for Unmanned Air Vehicles. Journal of Aerospace Computing, Information, and Communication, Vol 5, October 2008	October 2008
	Automation in Aviation: A Human Factors Perspective	1999
	sUAS Flight Testing of Enabling Vehicle Technologies for the UAS Traffic Management Project	April 2018
	sUAS Flight Testing of Enabling Vehicle Technologies for the UAS Traffic Management Project	April 2018

Eurocontrol	Unmanned Aircraft Systems - ATM (Air Traffic Management) Collision Avoidance Requirements	May 17, 2010
ICAO 9613	Performance-Based Navigation Manual	4th Edition
MIL-HDBK-454B	General Guidelines for Electronic Equipment	April 15, 2007
MIL-HDBK-516C	Airworthiness Certification Criteria	December 12, 2014
7-1-001	Test Operations Procedure (TOP) Unmanned Aircraft Systems (UAS) Navigation System Test	June 27, 2010
07-2-032	Test Operations Procedure (TOP) Unmanned Aircraft Systems (UAS) Navigation System Test	June 27, 2010
NATO Standard AEP-80	Rotary Wing Unmanned Aerial Systems Airworthiness Requirements	Sept 2014
NATO Standard AEP-83	Light Unmanned Aircraft Systems Airworthiness Requirements	Sept 2014
RTCA DO-200B	Standards for Processing Aeronautical Data	June 18, 2015
RTCA DO-236C	Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation	June 19, 2013
RTCA WP-1	Detect and Avoid (DAA) Whitepaper	March 18, 2014
RTCA WP-3	Detect and Avoid (DAA) White Paper Phase 2	September 21, 2014
RTCA DO-201A	Standards for Aeronautical Information	April 19, 2000
RTCA DO-283B	Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation	December 15, 2015
RTCA DO-366	Minimum Operational Performance Standards (MOPS) for Air-to-Air Radar for Traffic Surveillance	2017