

Cockpit Display of Traffic Information Using GPS - Design of a Low Cost System for General Aviation

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Abstract - This paper describes the need for, and the development of, an avionics device to provide cockpit display of proximate traffic. The device is targeted at general aviation (GA), and is designed to address the needs of this unique market; namely pilot utility and low cost. Traffic Alert and Collision Avoidance Systems (TCAS) are currently in use by the commercial airlines and are being installed by the commuter airlines, but high cost has virtually excluded their use by GA. This paper describes the requirements for surveillance and collision avoidance equipment in the national airspace system, the current avionics equipage by the U.S. aircraft fleet, and the GA avionics market. The operational and functional requirements for the new general aviation traffic alert system are presented accompanied by design, development, and schedule information. The paper also presents the issues and challenges of designing a system that will satisfy the needs of GA and the TCAS community. This paper contains only the understanding and views of the authors and is not intended to reflect the official position or view of the U.S. Government or Federal Aviation Administration (FAA).

I. INTRODUCTION

With the equipage of TCAS mandated by Congress, the chances of a near mid-air collision (NMAC) between air carrier aircraft has been reduced considerably, but this has effectively done very little to reduce the chances of an NMAC between an air carrier aircraft and a GA aircraft that does not have an ATC transponder. In recognizing these limitations, the FAA has been seeking effective ways to integrate the non-transponder equipped GA aircraft into the TCAS system with minimal expense on the part of the GA owner. In the past, this has taken the form of encouraging, or even mandating where safety is of concern, that GA aircraft be equipped with a Mode C transponder when operating in certain types of airspace. Unfortunately, the transponder offers little or no direct benefit to the GA pilot and so is more of a cost burden than a desirable item of avionics equipment.

With the deployment of the Mode S ground sensor and transponder, there have been several innovative ideas employing the datalink capability provided by Mode S that attempt to offer the GA owner an incentive to equip with Mode S. These incentives take the form of services to which the GA pilot did not previously have access, such as weather and traffic information services. The ability to provide such services has been proven, but for a practical service they require modifications to all Mode S ground sensors and therefore are limited in their timeliness and constrained to the Mode S sensor coverage region. Also, pilot charges for such services are uncertain. Due to the cost of the avionics and the low pilot utility, the GA owner has not equipped with Mode S. The current high cost of TCAS I avionics - the least expensive TCAS system selling for approximately \$50K - makes the probability of most GA owners equipping with TCAS I extremely unlikely.

The following sections of the paper describe the requirements for collision avoidance equipage, federal initiatives to revitalize the GA industry, the GA avionics market, and TAS operation and development.

A. *The TAS Concept*

The U.S. Department of Transportation has awarded a Small Business Innovation Research contract to Rannoch for the development of a small, low cost general aviation cockpit device aimed at enhancing air safety by combining Mode S and GPS technology. The system is called TAS - for traffic alert system. TAS offers the GA pilot a cockpit display of nearby traffic (assuming sufficient levels of TAS equipage), a capability traditionally reserved for the larger aircraft equipped with TCAS or sophisticated airborne radar. The TAS concept is also compatible with the idea of a small, inexpensive terminal surveillance sensor for low traffic GA terminals.

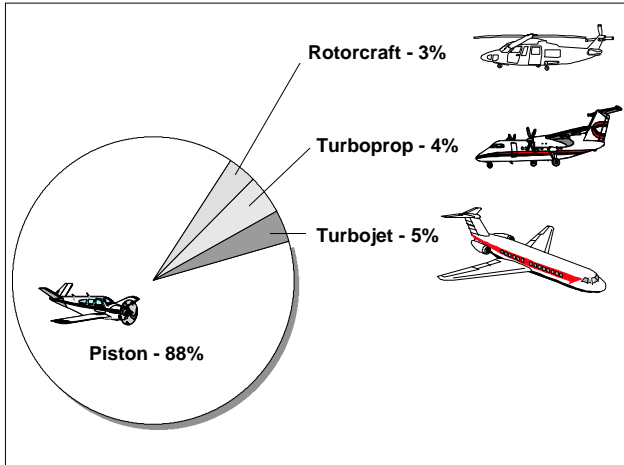


Fig 1. U.S. Civil Aircraft

TAS represents an avionics device that is intended to bring the GA owner under the protection umbrella of the traffic alert/collision avoidance concept in a way that is less costly to GA, but which is compatible, or at least could be made compatible with the existing TCAS technology. Achieving this goal, even partially, will improve ATC safety overall and should appeal to GA users by offering a capability that traditionally has not been available to them. The ideal GA TAS should be compatible with the next generation of the TCAS system (TCAS IV) and be comparatively inexpensive to acquire.

B. Collision Avoidance Equipage

The FAA has mandated the installation of TCAS in commercial, air carrier type aircraft [1]. The functionality, and therefore the complexity of the TCAS unit that must be installed is dependent on the size of the aircraft. Aircraft with 10-30 passenger seats must equip with TCAS I, which provides only a traffic alert capability, or Traffic Advisories in the cockpit. For aircraft with more than 30 seats, TCAS II must be installed, which provides both a Traffic Advisory (TA) and a Resolution Advisory (RA) capability. TCAS I installation is currently planned for February 1995, although relief for this date is under consideration. At this time TCAS II installation is complete. The mandatory equipage date was December 1993.

For a better understanding of the TCAS concept and its current limitations we should consider the make up of the U.S. civil aircraft fleet. As shown in Fig. 1, 88% of the approximately 192,000 U.S. registered civil aircraft are piston engine aircraft [2]. The TCAS mandate applies to less than 5% of the total number of aircraft in the United States. Many of the non TCAS equipped aircraft

do have some type of transponder on board, allowing them to be detected by TCAS equipped aircraft. Fig. 2 is a breakdown of aircraft transponder and TCAS equipage.

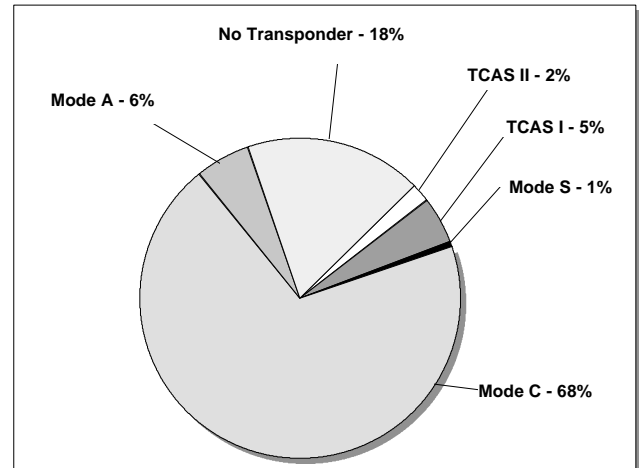


Fig 2. TCAS Equipage (from FAA 1992 statistics)

The estimate for TCAS I is based on 1500 commuter aircraft and an estimate of high-end GA aircraft. Since 18% of all aircraft have no transponder, TCAS provides air carrier aircraft with improved safety protection against 82% of U.S. civil aircraft. However, all of the non TCAS equipped aircraft (93%) do not have proximate traffic information available to them, regardless of transponder equipage. The gross potential market for TAS is Mode A/C equipped aircraft and non equipped aircraft, representing over 80% of all U.S. registered civil aircraft.

C. Federal GA Initiatives

GA users eagerly await the availability of affordable avionics that can provide real-time weather, situational awareness, flight management, and improved navigation and communications information in the cockpit. This has been articulated by many individual users, user groups, and the federal government. Furthermore, GA represents a considerable industry and is recognized as an economic and national asset. The number of GA users far exceeds the number of commercial users, and as the NAS becomes busier, and users seek greater access, more flexibility and autonomous operations, it is increasingly more important that GA users be an integral part of the system. The federal government has several initiatives underway to revitalize the GA industry. Both NASA and FAA have GA programs evaluating the development of a fully integrated GA avionics system, including [3]:

- integration of weather, navigation, (moving map), terrain and obstacle database, and traffic situation information into one primary flight display; databases for display design guidelines, communications (datalink) systems standards, and hardware certification criteria.
- integration of simplified flight controls with flight guidance displays; databases for simplified controls operations, design guidelines, and certification criteria.

TABLE 1
1991 Levels of GA Avionics Equipage

Avionics	GA Equipage %
<i>Transponder Equipment</i>	
Mode A	6.6
Mode C	82.2
Mode S	0.6
<i>Precision Approach Equipment</i>	
Localizer	64.6
Marker Beacon	60.9
Glideslope	59.1
<i>Navigation Equipment</i>	
100 Channel VOR	26.3
200 Channel VOR	62.2
ADF	59.8
LORAN	52.0

The TAS development program plays a part in these initiatives.

II. THE GA MARKET

Designing avionics for the GA market requires a thorough understanding of the potential volume of sales, the amount of development required, and the cost of the materials, components and assembly.

A. The Market

To plan for production of an avionics unit it is imperative that a practical estimate is made of the market size. The current U.S. GA fleet consists of over 180,000 aircraft, over 175,000 of which are equipped with electrical systems. Table 1 is a summary of 1991 GA avionics equipage compiled by FAA [4]. Over 50% of GA users have equipped with some form of transponder, precision approach, and navigation equipment. 82% of GA users have equipped with Mode C transponders, whereas only 0.6% have equipped with Mode S. This

serves as a starting point to estimate the size of the market, and can be used to target/identify relevant parts of the industry. It may also be appropriate to conduct a survey of user requirements for parts of the industry. At the time of this publication Rannoch is in the process of conducting a comprehensive market survey to estimate the need for cockpit display of traffic information avionics. Results of this survey will be available at a later date.

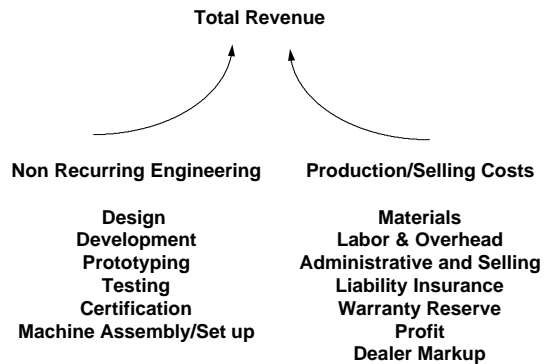


Fig. 3. Relationship Between Total Revenue, Design Costs and Production Costs

B. Development & Manufacturing Costs

Fig. 3 is a summary of the relationship between the non recurring engineering costs and the manufacturing costs associated with production. It is clear that the total revenue from any particular product, or set of products, should exceed the total costs, thereby rendering a profit to the manufacturer. More detail on the costs, commonly interpreted as *mark-ups*, is provided in Table 2, from the work of John Beukers [5]. This table shows an overall mark-up of 350%, (i.e., the cost to the user divided by the cost of the components), and is based on the manufacturing and distribution costs of commercial marine Loran-C receivers. Avionics manufacturers have told us that mark-ups can be as high as 500%—a factor of five.

We quickly came to the realization, during our research, that the key cost driver for an avionics market, of any considerable size, is the cost of the equipment components. To bring the user costs down, the main areas that must be focused on are component reduction and component cost reduction.

III. TAS OPERATION & DEVELOPMENT

Fig. 4 illustrates the TAS concept of operation which is based on the Mode S/Automatic Dependent

Surveillance (ADS) squitter concept. The TAS equipped aircraft determines its own position using an integrated GPS receiver and broadcasts this information to other TAS equipped aircraft in the local vicinity. The other TAS equipped aircraft also broadcast their positions so that the TAS unit can detect and display proximate traffic. There are three main components to the TAS system: surveillance, proximate traffic processing, and pilot alerting and display.

TABLE 2
Percentage Cost of Materials

Item	%	%
Materials	28	
Labor and Overhead	14	
Total Manufacturing Cost		42
Administrative & Selling	10	
Liability Insurance	2	
Warranty Reserve	5	
Total Factory Cost		59
Manufacturing Profit, 20%	12	
Selling Price to Dealer		71
Dealer Markup, 40%	29	
List Price		100
Discount, 20%	20	
Discounted/Mail Order Price		80

An effective collision avoidance system needs position information, not only on the threat/intruder aircraft, but also on the aircraft in which the system is installed (*own-aircraft*). In the TAS system, *own-aircraft* absolute-position and heading information are both determined using GPS. The *own-aircraft* information is used to transmit (squitter) position to other aircraft in the vicinity and is used in the traffic alert processing. To minimize the cost of the system, its design is oriented toward that of a situational awareness display for the pilot. Consequently, there are no controls or pilot selectable functions for the system except that of a simple on/off switch.

GPS position coordinates coupled with an aircraft identification (ID) are periodically transmitted - squittered - using a "Mode-S look-a-like" message format. Aircraft ID is provided so that the receiving aircraft can associate successive position messages emanating from the same aircraft. Similarly, position/ID messages squittered by the intruder aircraft (*other-aircraft*) are received and processed by *own-aircraft*. The traffic alert function is derived by processing *other-aircraft's* relative position and *own-aircraft's* position to determine whether the intruder is within or outside a defined volume of airspace surrounding the position of *own-aircraft*. Relative positions computed to be within the volume are considered traffic alerts and are displayed on the control/display unit. The possibility of TAS system

compatibility with future TCAS systems is achieved through the use of a standardized Mode-S type message format. This will require the next generation of TCAS to be able to process the extended TAS squitters, but would require little or no additional hardware since the system radiates on the Mode-S downlink channel frequency of 1090MHz.

The functional requirements for TAS are derived from the operational requirements, i.e., what information the pilot needs for situational awareness, and the TAS design goals, i.e., features of TAS that are not operational requirements but may affect cost or marketability. The process of determining the TAS functional requirements is illustrated in Fig. 5.

The following sections describe the source and justification for the preliminary TAS system level requirements and design goals. The requirements are presented in each category followed by an explanation or description as necessary. Each requirement has been italicized.

A. Operational Requirements

The TAS system shall provide situational awareness to the GA pilot in the form of location and heading trend of nearby TAS (and possibly TCAS) equipped aircraft, i.e., the system shall assist the pilot in visually acquiring other traffic during VFR.

The system range shall be sufficient to provide general aviation aircraft pilots with adequate time to visually acquire targets and change course or altitude as necessary. Based on existing TCAS performance measures, this should be no less than 30 seconds [6].

The TAS system shall be compatible with the more sophisticated TCAS system. To achieve the stated goals it is recommended that the systems be made compatible through long term refinements to the TCAS system functionality.

The TAS system shall have a surveillance positioning accuracy (navigation) performance that is at least as good as the existing TCAS surveillance accuracy performance. This will ensure compatibility with the logic and advisory functions of TCAS.

The TAS system shall alert the pilot when new, not previously displayed traffic have encroached upon own-aircraft and are within the airspace protection volume.

The system shall be capable of being installed and used effectively by small to medium-sized GA aircraft including, single-/multi-engine propeller, single-/multi-engine turboprop, and light helicopters. Larger helicopters and large multi-engine turboprop commuter aircraft are assumed to equip with the more sophisticated TCAS I system.

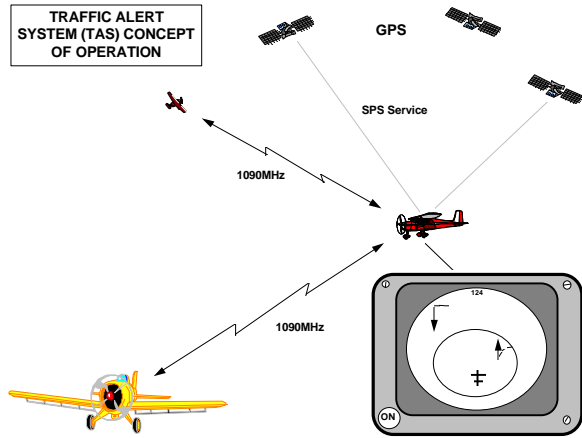


Fig. 4. TAS Concept of Operation

The TAS system performance shall not be adversely affected by variations in own aircraft speed and attitude. It is expected that typical GA aircraft will operate with: airspeeds up to 250 kts; continuous bank angles up to 40°; aircraft pitch angles between 10° nose down and 25° nose up; and rate 3 turns.

The system coverage and the position quality of the surveillance function shall not be adversely affected by weather, e.g., heavy rain.

As far as practical, the design of the display-to-pilot interface shall be geared toward simplicity and standardization. The system should provide display information that is easily interpreted by the pilot and aids visual acquisition of target aircraft.

The system shall be capable of tracking and displaying intruder aircraft position for the maximum number of aircraft that can be expected to be within the surveillance range at any given instant. This is estimated to be 30 aircraft, equivalent to a traffic density of 0.38/NM².

B. Design Goals

The system should cost around \$2,000. To ensure the potential safety benefits of TAS are fully realized, a reasonably high level of GA equipment is necessary. Consequently, to ensure the widest possible market the

cost of the avionics to be purchased by the owner shall be designed to be as low as practical.

The TAS nominal surveillance range shall be 5 NM. The range at which other TAS/TCAS equipped aircraft are identified and displayed is a compromise between providing adequate time for the pilot to acquire the target and perform an evasive maneuver and the need to minimize the impact that TAS has on the 1090 MHz RF channel [7].

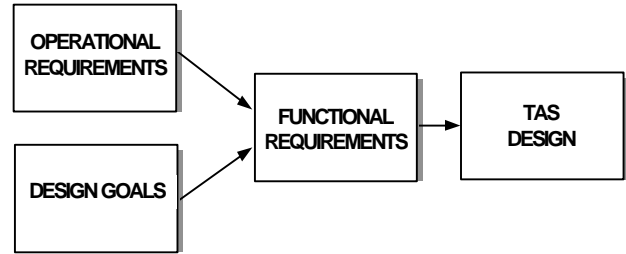


Fig. 5. Process for Developing TAS Requirements

The TAS shall require cooperative targets. A cooperative target is a target that is equipped with an identical or functionally similar device that permits the target to be detected and tracked. Non-cooperative target acquisition systems based on radar are impractical for this application and costly. Target acquisition systems based on ground radar data require Mode S equipment and do not provide protection in non-coverage regions.

Aircraft position shall be determined using GPS. GPS provides positioning performance that is at least equal, if not better than the TCAS surveillance performance and provides the common aircraft vertical position frame of reference needed for collision avoidance on a worldwide basis. GPS also offers receivers that are compatible with the cost goal for TAS.

The TAS datalink shall use the Mode S radar 1090 MHz downlink channel. The 1090 MHz channel provides the datalink to other TAS units and to the existing TCAS units. Although the TAS system will use the Mode S downlink channel, to reduce costs it will not employ a full capability Mode S transponder. This feature makes it possible for TCAS I, II, and III systems to receive and be able to process the TAS signals without additional hardware, however, a software modification would be necessary.

The TAS unit shall provide for simplicity of aircraft installation. The unit shall minimize the need for external, or existing avionics equipment interfaces and employ only a single antenna installation. The TAS unit

will be panel mounted with an integrated display—a scaled relative position indicator along with an altitude displacement indication for aircraft within the defined protection volume of airspace.

C. System Design Issues

Salient design issues are discussed in this part of the paper. Further technical details on the design of TAS are contained in a previous paper presented at the Institute of Navigation [8].

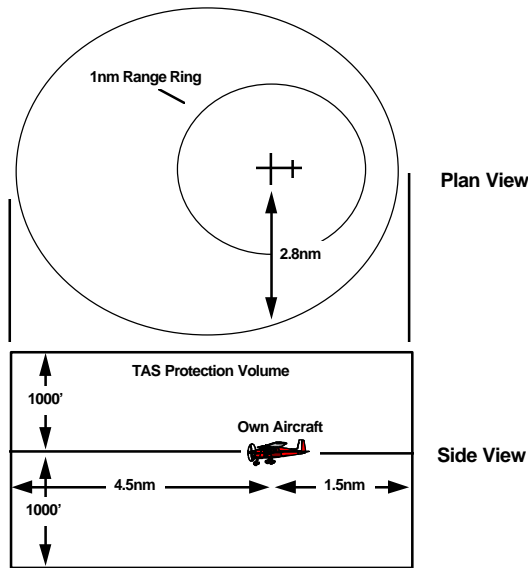


Fig. 7. Nominal TAS Protection Volume

On average, the TAS unit can be considered to offer a TA protection volume similar to sensitivity level 5 for TCAS II, although it is not designed to provide a constant warning threshold, or TAU. Fig. 6 illustrates the volume of airspace that TAS will monitor for encroaching aircraft. The volume of protected airspace is +4.5 NM, -1.5 NM in the longitudinal plane of *own-aircraft* and ± 2.8 NM in the lateral plane. The vertical dimension of the protected airspace is $\pm 1,000$ ft. The dimensions of the volume of protected airspace are selected based on the closure speeds expected in practice (head-to-head, head-to-tail etc.) and the need for simplicity of the processing and display. The dimensions chosen represent a simple circle with a displaced center.

The CDU situation display will have a display format that is based on *own-aircraft's* heading with respect to the aircraft's magnetic groundtrack. This ensures that the situation display is correctly oriented to the pilots' perspective and targets can be located using the

traditional 'clock face' reference for angular displacement from the aircraft's nose.

Single engine, single pilot aircraft typically do not have much panel space to install new avionics. Consequently, the unit's physical configuration is designed to minimize space and fit into the radio stack (Fig. 7).

IV. SUMMARY

Most industry sources believe there is a real need for a device that provides proximate traffic information to the pilot. There is a well defined market and the technology is available to develop equipment at an acceptable cost to the user. Detailed TAS requirements and a functional design are scheduled to be complete by April 1994. Assuming an acceptable outcome to the Phase I work and availability of appropriate funding, the Phase II effort will proceed to developing two prototypes for testing and flight trials. Assuming a timely Phase II award, a prototype could be available for trials by late 1995. Results of the market survey will also be available in the near future.

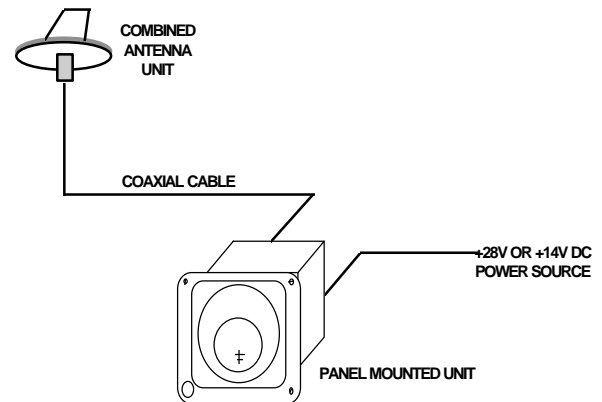


Fig. 7. TAS System Physical Configuration

V. BIOGRAPHIES

Alexander Smith and Jonathan Baldwin founded Rannoch Corporation in 1991 and have been providing systems engineering expertise to the Volpe Center and FAA. Rannoch has been supporting the FAA's Traffic Alert and Collision Avoidance System (TCAS) program since Mid-1992, and is currently studying the issues and problems of extending the "safety net" of TCAS to the GA community.

Mr. Smith received his MSEE in Aerospace Systems from Cranfield Institute of Technology in 1983 and his MBA from London Management Center in 1987. He is a Registered Professional Engineer, Member of the Institute of Electrical Engineers (IEE), and a Chartered Member of the Engineering Council, U.K.

Mr. Baldwin received his BSEE and MSEE from the University of Wales in 1985 and 1988 respectively. He is a private pilot, Registered Professional Engineer, Member of the Institute of Electrical Engineers, and a Chartered Member of the Engineering Council, U.K.

VI. ACKNOWLEDGMENTS

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