Altimetry Aspects of Automatic Altitude Reporting

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The purpose of automatic altitude reporting is to reduce the amount of communication between the pilot and the controller. Nowhere in the recommendations for Project Beacon is better altitude measuring equipment, nor means for obtaining better vertical separation, recommended. An analysis of the accuracies to be expected, both in altimetry and in the automatically reported altitude, shows that systems installed under current rules and regulations could cause more communication between the controller and the pilot than now exists. This is because the combined tolerances of the altitude reporting equipment and of the current altimeters are such that one could even question the now-legal separations that are used. The conclusions are that certain ground rules must be established to make the program of automatic altitude reporting a success. These are 1) the tolerances for altimetry systems must be considerably tightened, 2) the pilot must fly the same altitude information that is being reported, 3) the controller must be educated to the fact that instruments do have errors, and finally, 4) the criteria governing vertical separation should be carefully re-examined.

Introduction

IN October 1961, the Project Beacon report[1] was published. Among the many recommendations in this "study of the safe and efficient utilization of airspace" was the recommendation that "all aircraft above 12,500 lb gross weight should be required to carry altitude reporting beacon transponders for use both en route and in terminal areas." The primary purpose of automatic altitude reporting is to give the controller a three-dimensional position fix of the aircraft without the need for oral communication. In other words, without communication the controller would know the altitude of the aircraft. This would greatly relieve the burdens on the pilot, the controller, and the communication system.

It is important to note here that the report did not suggest upgrading altimetry accuracy. For that matter, it specified no accuracy figures at all. Perhaps the reason for not specifying an upgraded system can be understood from one of the recommendations for "future improvements." The sixth recommendation states that "A more precise means of altitude determination in the aircraft will become increasingly urgent as traffic increases. Present means are marginal in accuracy and reliability. There should be a substantial increase in the effort to obtain a significant improvement in this instrumentation by both conventional and new means of measurement. When technological advances make this available, use in the system will improve the position information available on the ground as well as in the air, and increase traffic handling capability."[1]

The task force must have believed that the instruments in general use were state of the art. As most commercial carriers know, there is a tremendous difference between the "minimum standards" and the accuracy of the actual instruments in use. Fortunately, in 1961 the "technological advances" had already been made, as will be apparent later when system tolerances are discussed. Unfortunately, the committee did not know this, and as a result a lot of questions still need resolving. It is the purpose of this paper to point out some of these problems and to suggest ways to resolve them.

Civil Regulations

First, the regulations actually governing altimetry should be known. For general aviation, all that is required is that an altimeter be supplied. There is no requirement that the altimeter be an approved type; its accuracy, therefore, need not conform to any minimum standard. For a transport-type aircraft, the altimeter is required to be a sensitive or precision type and to be approved. This means that it must meet the minimum standards of the technical standard orders (TSO) of the Federal Aviation Agency (FAA). Figure 1 shows the scale error tolerance for TSO-C10, the governing altimeter civil regulation. One curve is for TSO-C10a and the second for TSO-C10b. TSO-C10b superseded TSO-C10a, but aircraft equipped with altimeters conforming to "a" do not have to be upgraded to "b." As a result, aircraft are now flying with altimeters for both standards. These errors are instrument errors only.

Figure 2 shows typical static defect errors for subsonic and supersonic aircraft. The static pressure defect is caused by the aircraft disturbing the air it is moving through, so that the sensed pressure is not the true ambient pressure. Unless a correction is made for the static pressure defect, the system altimetry error could be the sum of the errors in Figs. 1 and 2.

Actually, the only civil regulations for over-all system accuracy (instrument error plus static pressure defect) are for transport aircraft only (at landing and approach configurations only). There are no requirements at cruising and holding. So far, only altimetry accuracies have been discussed. What are the civil regulations governing automatic altitude reporting?

Reference 2 states that the system altitude accuracy should be ±100 ft. It further states, "This accuracy includes the sum of the incremental error and the digitizer error, and

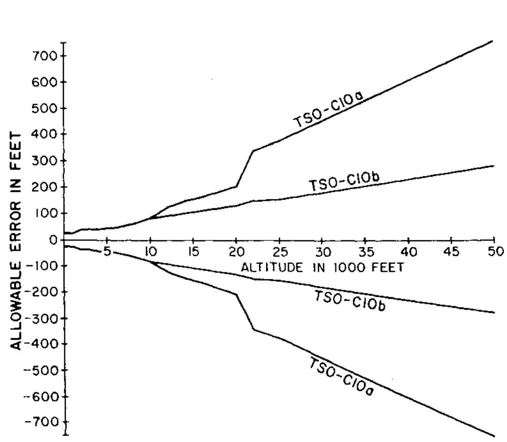

Fig. 1 Altimeter tolerances.

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does not include the pressure-altitude data source errors." It goes on to say "The pressure-altitude information shall be automatically derived from the *best* available pressure-altitude source in the aircraft. . ." And finally, it states that the digitizer error shall not exceed ±50 ft. These then, to date, are the regulations for altimetry and automatic altitude reporting.

Before continuing, an explanation of incremental error is perhaps necessary. Incremental error is sometimes called coarseness or quantizing error. When a digital signal is received, the value of the analog signal that it is derived from is indeterminate by $\pm\frac{1}{2}$ a bit. In the case of automatic altitude reporting, the reporting increments are 100 ft. The controller reading an altitude does not know the value of the analog signal generating the information to better than ±50 ft. In other words, assuming no other error when the controller reads 10,000 ft, the analog shaft positioning a digitizer could be between 10,050 and 9950 ft.

System Analysis

Although altimeter requirements are fairly well defined, the meaning of the requirements of the national standard are not. Its requirements have been interpreted as follows: the unit that measures the static pressure and computes the altitude should be equal in accuracy to the best altitude information on board. In other words, this unit should meet the requirements of TSO-C10a or TSO-C10b. Also, an additional tolerance of ±50 ft is allowed for the digitizer. Since the pilot's pressure source is the best in the aircraft, the transducer should be connected to that source.

With the equipment meeting all the current instrument and altitude reporting regulations, the maximum difference between what the pilot sees and what the controller could see for TSO-C10b equipments is shown in Fig. 3. This is equal to two times the TSO plus 50 ft for the digitizer and the incremental error of 50 ft. It can immediately be seen that this is an impossible situation. At 15,000 ft, for example, the difference would be 300 ft! At 15,000 ft the separation standard is 1000 ft for instrument flight rules (IFR) traffic, but only 500 ft for mixed IFR visual flight rules (VFR) traffic. It is apparent that the controller would be quite upset to see an aircraft so far off its assigned altitudes. There is a very good possibility that two aircraft assigned to adjacent flight levels will be reporting overlapping altitudes.

This has come about because of the way in which the requirements have been specified. In a sense, the altimetry system has been degraded by a factor of 2. Today, the pilot reports his altitude to the controller orally. He reports what he reads, and both he and the controller have the same reading. In effect, the system has zero transmission error. Assuming that the automatic altitude reporting equipment has an accuracy equal to that of the pilot's instrument, it can be seen that the controller can receive information with twice the error plus the 50 ft encoding error.

It is very important to remember that the pilot will be flying by the same instrument he has always flown by, so that the same separation standards will be maintained. Unfortunately, the controller will be receiving severly degraded information. In order to prevent this degradation, two approaches are possible. First, the permissible errors in the individual instruments can be halved. This, of course, is technically feasible. Second, the pilot can be required to fly by the equipment that is doing the reporting. A number of reasons dictate the second approach. Considerable apprehension on the part of pilots has been expressed concerning the fact that automatic altitude reporting can be used as a "spy in the sky." A sealed black box that reports to the ground alone is felt to be a monitor of the pilots' alertness, and many pilots have already expressed their disapproval of such a unit. On the other hand, pilots are willing to accept a system in which the information being transmitted is the same as that being read and flown by.

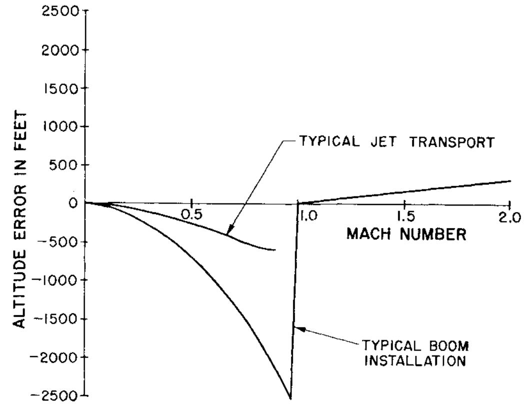

Fig. 2 Static pressure defect curves.

In case of a malfunction in a sealed black box system, the pilot will not be aware of it without the use of auxiliary equipment. This is not the case with the second system where a malfunction will quickly show up. And finally, the reported information will always be best for the system in which the pilot flies by the altitude being transmitted. No matter how accurate the individual units are, the reported information can be improved by a factor of 2 by using only one unit. Therefore, the first recommendation is that "The altitude information used by the pilot to maintain vertical separation should be the same information that is automatically reported." The logical question to ask, once it is established that the pilot will fly by the reported altitude, is what should be the maximum allowable difference between the pilot's indication and the controller's reading? In order to keep the automatic reporting system as close as possible to today's oral reporting system, the difference should be kept as small as possible. It should be remembered that today's system has zero error.

Before the question can be answered, it is necessary to discuss the various systems possible that enable the pilot to fly by the information being transmitted. These systems can be divided into the following three general categories: 1) self-contained altimeter and digitizer, 2) altimeter and remote digitizer unit positioned by the altimeter output, and 3) altitude computer and remote servoed indicator.

Typical examples of these systems are shown in Figs. 4–6. In each of these types of systems, it is fairly easy to obtain a correspondence between the shaft of the digitizer and the reading of the altimeter/altitude indicator that is within ±25 ft.

Although the national standard allows 50 ft for the digitizer error, this does not reflect current technology. A more reasonable figure is ±25 ft for an encoder. With such an encoder, the max-max error between the indicated altitude and the information being transmitted would be 25 +25 or 50 ft. Since the altitude is reported in 100-ft increments and the transitions occur at the 50-ft levels, i.e., 10,050, 10,150,

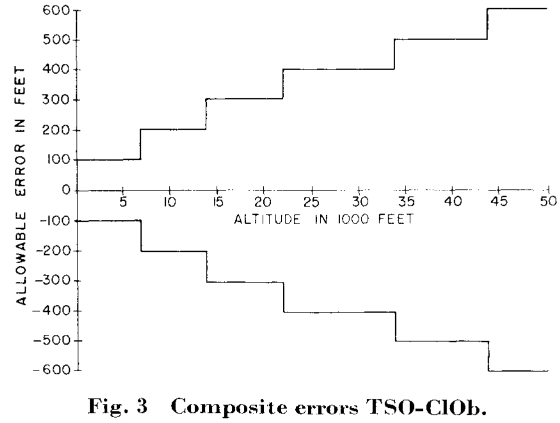

Fig. 3 Composite errors TSO-C10b.

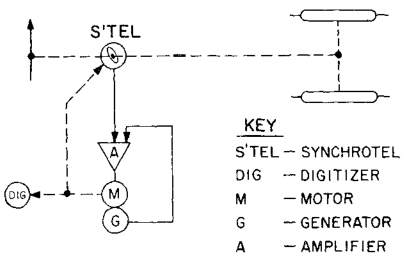

Fig. 4 System A, SLATE type.

etc., a 50-ft difference could be reported as a 100-ft difference. The controller, therefore, could receive information that is 100 ft different than the pilot's indication. This is a reasonable figure.

The second recommendation is that "the controller should receive an altitude signal which is within ± 100 feet of what is being read on the pilot's indicator." It must be emphasized that this is the only type of tolerance that can be specified correctly for an automatic altitude reporting system and that will still keep to the spirit of the Project Beacon requirements.

The automatic altitude reporting program is to let the controller know what the pilot is reading automatically. It is not a program to improve altimetry. Actual pressure altitude accuracy is a different question, which will now be examined. Forgetting for the moment automatic altitude reporting, one may still question whether today's standards for altimetry are satisfactory for maintaining the 1000- and 2000-ft separations. Although there have been no collisions attributed to altimetry, there have been enough incidents to warrant a closer look at the "minimum requirements." It must be remembered that there is much pressure being applied to lower the separation to 500 and 1000 ft. TSO-C10a allows 375 ft error at 25,000 ft. This cannot be considered a reasonable figure for the 1000-ft separation. Even the 120-ft figure for TSO-C10b at 18,000 ft is not reasonable when the 500-ft mixed IFR and VFR traffic is considered. An automatic altitude-reporting system using units built to the TSO-C10b tolerances could not properly function. For example, a controller reading an altitude of 18,000 ft would know only that the aircraft was within 195 ft of 18,000 ft, i.e., 120 ft for the altimeter tolerance plus 25 ft for the digitizer tolerance and 50 ft for the incremental error. In other words, with today's tolerances, two aircraft could be reporting altitudes of 18,000 and 17,500 ft to the controller and be only 110 ft apart, 500 ft minus 2 times 195 ft. And this condition does not take into account static pressure defect error that, under present regulations, does not have to be corrected.

It is obvious that better altimetry is needed. It also appears unhealthy that VFR and IFR traffic be mixed using todays standards. Earlier it was stated that better altimetry is available. Today, state-of-the-art altimetry accuracy is 25 ft or 0.25% of indication, whichever is greater. State of the art means economically feasible, producible, and available. Figure 7 shows this accuracy as plotted against altitude. Also, the proposed tolerances of TSO-C10c are plotted for comparison. The accuracies are about the same, and it is hoped that the TSO will be changed so as to better reflect the way instruments behave, i.e., percentage of indication rather than arbitrary values. At an operating altitude of 40,000 ft the accuracy of a 0.25% instrument is 100 ft. The controller receiving information from this system would know the altitude of the aircraft to within 175 ft (100-ft instrument +25 digitizer +50 incremental) at 40,000 ft and to within about 140 ft at 25,000 ft. The aircraft itself would be within 125 ft of its assigned altitude (100-ft instrument +25-ft indicator) at 40,000 ft and within about 90 ft at 25,000 ft. These values are more realistic for the air traffic control system of today.

As yet, static pressure defect correction has been neglected because it is a difficult subject to pin down. Everyone is in fairly general agreement as to what it is, what causes it, and how to correct it. No one, however, seems to agree on how to measure it, what the accuracies of the measurements are, and what tolerances should be applied. Static defect is determined by flight tests, and a number of different methods are used: flyby, trailing bomb, pacer, and photo theodolite. There has been very little done about cross-checking methods or standardizing procedures.

It is important always to bear in mind the fact that altimetry is based upon comparative rather than absolute values. Pressure altitude is not a physical property, and absolute values are not necessary for vertical separation. This pertains to static pressure defect too. If one method is used throughout the industry for determining the defect correction, and if this method is repeatable, then the systematic errors are unimportant, and the absolute values of the defects are unimportant.

The third recommendation is that "a standard method for determining the static pressure defect should be established. The repeatability of this method should be determined. The nonrepeatable error should be added to the over-all system altimetry tolerances. Corrections for the static pressure defect for cruise and holding flight should be required by regulations."

It is generally assumed today that the data are fairly good, and that no value is allotted to the flight-test error. In this analysis, the same assumption is made. As will be seen later, automatic altitude reporting will help prove or disprove the validity of this assumption.

One additional altimetry tolerance should be discussed. Once the static defect is known (and assume it is known exactly), the computer can correct it only to a certain accuracy. This accuracy is based upon the slope of the defect curve and the accuracy of the Mach computation. For subsonic aircraft, this is generally fairly small and can be neglected. For supersonic aircraft in the transonic range, this error can be considerable. Fortunately, aircraft do not fly for any

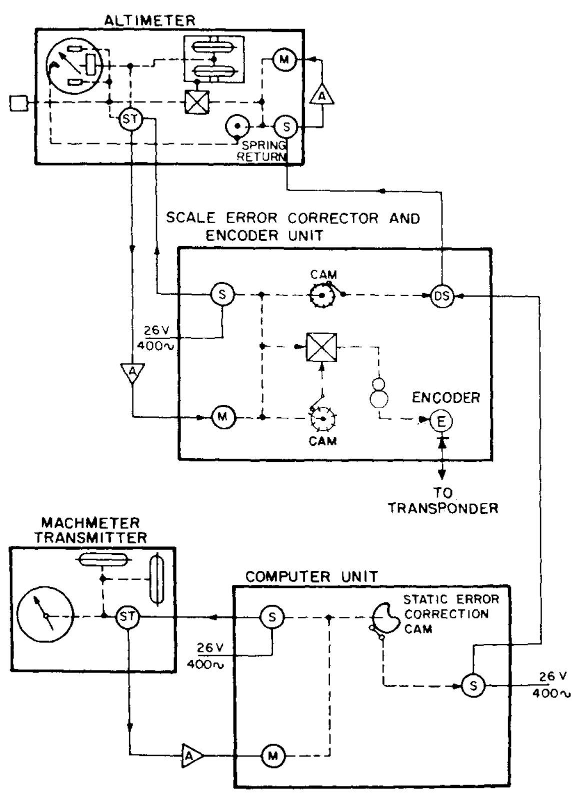

Fig. 5 KIFIS alticoder.

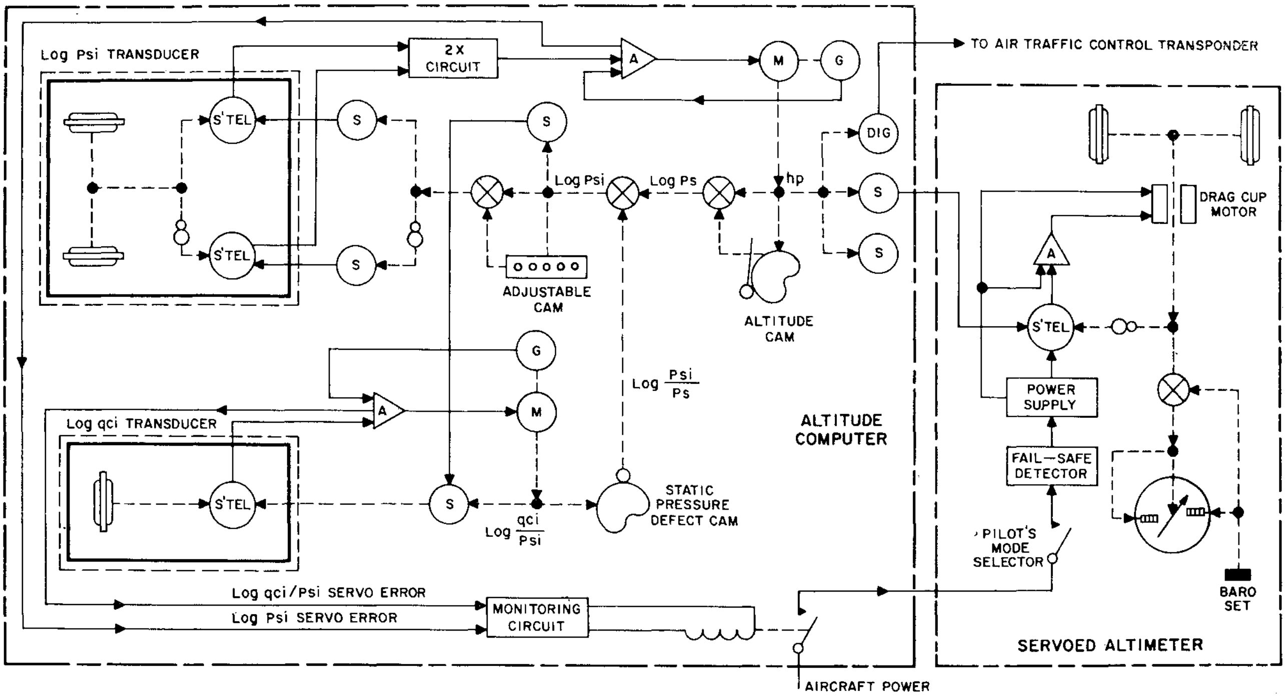

Fig. 6 Typical air data computer and servoed pneumatic altimeter.

length of time in that range. Generally, in the other ranges the error is again small.

In summary, for altimeter systems incorporating automatic correction for static pressure defect, the altimetry errors are instrument error of 25 ft or 0.25%, whichever is greater; indicator error of 25 ft; static defect calibration error (i.e., flight-test error); and static defect correction $\delta\Delta h(0.01)/\delta M$, where $\delta\Delta h/\delta M$ equals the slope of the defect curve, and 0.01 is a typical Mach tolerance.

The fourth recommendation is that "accuracy of the pilots altitude system should be $\pm$(25 feet +25 feet or 0.25%)." Now the question of how far off the assigned altitude should an aircraft be allowed before the controller contacts it can be considered.

Since the tolerance is 100 ft between what the pilot reads and what the controller sees, as a minimum the controller must accept a $\pm$100-ft deviation. With a $\pm$100-ft deviation, the system would have a minimum of 50 ft for flight technical error and turbulence. It is recommended that $\pm$100 ft be the allowed deviation. Once the system is put in operation this might have to be increased if it is found that it causes too many oral communications.

Typical Systems

Earlier, three general systems in which the pilot flies by the information being reported were listed. They are shown schematically in Figs. 4–6. System A, Fig. 4, consists of an altimeter in which an encoder has been built in. The altimeter mechanism positions the pointer, and an electrical servo follows the position of the mechanism and drives an encoder. This system does not have the capability of correcting static pressure defect. It is recommended for low-performance aircraft. The first version developed by Kollsman was for the FAA Small Lightweight Altitude Transmission Equipment (SLATE) program.

The second system, Fig. 5, is the very familiar KIFIS with the Alticoder. In this system, the basic altitude information is transmitted from an altimeter to a computer. In the computer the static pressure defect is computed and the correction is sent back to the altimeter. The corrected altitude then positions the encoder in the computer.

And finally, the third system, Fig. 6, consists of an air data computer where altitude corrected for static pressure defect is computed. In the air data computer, the altitude shaft positions a synchro and an encoder.

The synchro is used to position a pilot's indicator. In Fig. 6, the indicator shown is a servopneumatic altimeter, and the air data computer is the minimum air data computer possible for computing altitude. Both air speed and Mach are available in the computer but their outputs are not used externally. This system (altimeter and computer) was developed for the military as an optimum system for altimetry and automatic altitude reporting for supersonic aircraft.

The A system can be used on all aircraft that have no static pressure defect. The KIFIS Alticoder is for commercial jets. The air data computer indicator system is for aircraft with vertical scale indicators and high-performance supersonic aircraft. All of these systems can meet the forementioned recommended accuracy tolerances, and different versions of them have been in production for a number of years.

Uses of Automatic Altitude Reporting

Although automatic altitude reporting is used primarily to reduce the amount of oral communications, it can serve a number of other functions.

1) It can be used for filtering. The controller can have all targets not in his altitude band automatically eliminated

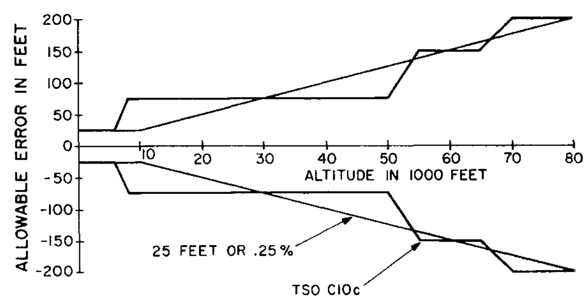

Fig. 7 Current altimetry accuracy.

from his screen. Thus he will only see the aircraft that he is immediately concerned with.

2) It can be used to give better advisory service. The controller will be able to advise pilots of traffic that really are threats.

3) It can be used for conflict prediction. In an advanced air-traffic-control system, the information can be fed directly into a computer that would in turn warn the controller of possible conflicts.

4) It will give information that can be used for setting the standard for altitude separation. As experience is gained with this system, more realistic data will become available for determining vertical separation standards.

5) This last is a surprising benefit; it will give information on turbulence. The FAA has reported that, on their experimental systems, they are able to determine when planes are flying through turbulence and, to some extent, how bad the turbulence is.

Conclusion

The state of the art is such that automatic altitude reporting is feasible. If the system is instituted with the current accuracy tolerances, it will not work. It will cause a greater amount of communication between the controller and pilot than now exists. In order to have a workable system, the following is recommended: 1) the pilot should fly by the same information being transmitted, 2) the maximum difference between controller and pilot readings should be 100 ft, 3) a standard procedure should be established for determining static pressure defect, and corrections for the static pressure defect for cruise and holding flight should be required by the regulations, and 4) 0.25% altitude computers should be required. If these recommendations are followed, automatic altitude reporting will be a successful adjunct to the air-traffic-control system.

References

[1] Hough, R. R., "Report of task force on air traffic control; A study of the safe and efficient utilization of air space: Project Beacon," Federal Aviation Agency (October 1961).

[2] "U. S. national standard for common system component characteristics for the IFF Mark X (SIF)/air traffic control radar beacon systems SIF/ATCRBS," Federal Aviation Agency (December 27, 1963).