Seeking a New Precision Approach and Landing System—A Test of Maturity

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The Radio Technical Commission for Aeronautics Special Committee 117, on A New Precision Approach and Landing Guidance System, was formed in late 1967 to develop a new precision guidance concept for approach and landing. The existing ILS, although in use since World War II, requires increased implementation now, and is only now being implemented in many parts of the world. There is a risk of delaying implementation of needed ILS service by public consideration of a successor system. Nonetheless, the present Instrument Landing System falls short of meeting the future requirements of fixed wing and VTOL/STOL aircraft, and literally dozens of new landing system ideas have been developed. The paper describes the efforts of RTCA SC-117 to select a new approach and landing guidance system. The Committee has concluded that an optimized scanning fan beam system can meet most of the operational requirements, and that such a system can be recommended with high confidence of practical success. The paper reviews some of the conclusions reached, and notes several of the most important problems facing the designers—such as frequency, data rate, and antenna requirements as they affect aircraft systems, as well as the tradeoff between demands of aircraft systems and limitations of radio systems.

Why Search for a New Landing Guidance System?

THE task of Special Committee 117 of the Radio Technical Commission for Aeronautics was to develop a precision guidance system concept for approach and landing and an associated signal structure. The concept and signal structure was to satisfy, to the maximum extent possible, the various operational needs of the several classes of users—here in the United States, and hopefully throughout the world. But why look for a new instrument landing system? The present ILS works well in many circumstances and will continue to do a first-rate job for years. In fact, there is a widely held view that with adequate precautions, ILS is fully capable of providing guidance signals for Category III all weather landing. There are problems, however, and it is time, in the view of many, to look toward the future and a possible successor to ILS. Such a successor should have the potential of satisfying difficult future requirements for all kinds of aircraft services and should provide simple facilities that can be implemented at very low cost.

A question of major importance is whether the existing ILS has been fully exploited. There is one view that the upheaval caused by transition from ILS to a new system would be so great that such a step should be taken only as a last resort. Another view is that the basic ILS technique can be extended, either in a fully compatible or an evolutionary manner, to provide all needed present and future functions of an instrument landing system.

However, a more widely held view is as follows:

1) The present ILS falls short of future requirements for fixed-wing aircraft primarily because a) it has proved susceptible to interference effects from nearby terrain, structures, and aircraft in the air and on the ground. b) It is heavily dependent for the creation of its beams on the terrain in the immediate vicinity of the antennas. c) It can provide proportional deviation information on only one approach path. d) The size and characteristics of the required antennas are not appropriate for installations at the small landing areas likely to be used by fixed-wing STOL aircraft.

2) The present ILS has additional difficulties in meeting the needs of a broader spectrum of aircraft, including military tactical fixed-wing aircrafts as well as military and civil VTOL and STOL aircraft: a) Because of the frequencies used, the antennas must be large and are relatively difficult to calibrate. b) A given installation cannot provide optimum service for the particular needs of both fixed-wing and V/STOL aircraft, in terms of complex lateral-approach paths and several different glide path angles. c) ILS has not shown itself capable of the "man-pack" type of construction or of the installation ease required for certain military uses. d) ILS, because of its dependence on the terrain and the several interference effects with which it is plagued, imposes severe limitations on rapid installation and free use in difficult terrain.

3) The ILS has not proved to be economically feasible over implementation levels ranging from the general-aviation grass field to the most complete Category III service, although flexibility within a single, compatible building block system and signal structure is highly desirable.

Putting all this into operational and economic terms: 1) Increasing difficulties are already being experienced in keeping the critical areas around ILS ground antennas clear. At a number of airports operations are restricted when airlines make Category II and autoland approaches. Large hangars being constructed by some airlines are increasingly affecting existing ILS's. The large aircraft coming into use are seriously aggravating this situation and are likely to cause further spreading out of arrivals and compromises on airport operations on departures, simply to protect the delicate nature of ILS antennas. 2) It is probable, in order to achieve maximum use of existing airports that flexible precision approach paths, both vertically and laterally, may have to come into being, and ILS cannot provide such paths. 3) There is a growing number of locations, particularly in mountainous areas, but also at some major airports, where ILS cannot be implemented because of local terrain features. In some cases highly expensive ILS antenna installations are required, just at places where there is

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a need for low cost. 4) While ILS electronics costs have been significantly reduced in the last several years, it is expected that a new microwave system can in the long run be implemented less expensively and at more kinds of runways than ILS. 5) Airports with uneven terrain ahead of threshold may continue to suffer relatively high Cat. II minimums because of the inconsistencies in radio altimeter performance. The ILS cannot help this problem, but a new landing guidance system can. 6) The prospective needs of V/STOL aircraft cannot be met by ILS; yet it may be undesirable and in the long run uneconomical to establish a new system purely for V/STOL's. 7) There have been many development efforts on new landing guidance systems. The United States alone has supported more than forty landing guidance system developments over past years. The real prospect of a single, universal landing guidance system acceptable nationally and internationally, and by civil and military users alike, offers the long-term prospect of significant economies in the implementation of a new landing guidance system. 8) Lack of coordinated industry activity now toward the development of a new landing guidance system would continue to stimulate wasteful development by a number of government agencies of a variety of systems with little prospect of agreement or international standardization. The length of time needed to develop and coordinate a workable system makes this work necessary in order to be ready when the users themselves conclude that a successor system to ILS should be considered for implementation.

DOT Air Traffic Control Advisory Committee Views

A searching look at the need for a new landing system was taken by the Department of Transportation Air Traffic Control Advisory Committee. There is not space to go into detail on all their views, but the Committee agreed on the need for a new and highly flexible microwave landing guidance system. One of the purposes would be for aircraft to be able to navigate on curved flight paths connecting the enroute course to the runways. Such precision curved paths, said the ATC Advisory Committee, would provide better sequencing flexibility from the enroute course to the runway, more asymptotic intercepts of the approach and landing course, and routings to avoid noise sensitive areas.

The ATC Advisory Committee indicated that a new landing aid is needed both to provide high capacity service to and from high density runways, and to overcome many of the shortcomings of the current ILS. The ATC Advisory Committee concluded that technology is now available to replace ILS as operational and economic conditions indicate.

Reservation

In beginning the long and hard task of developing a new precision approach and landing guidance system, the airlines were and are concerned that interest in a new system might be misunderstood and used by some as a signal to slow down implementation of existing ILS. To the contrary, the primary airline requirement today is for large scale implementation of the existing system. All implementation efforts and cost reduction efforts on the existing international standard ILS were and are strongly encouraged by the airlines. ILS can provide fine, high-quality service for Category I, Category II, and, with care, for Category IIIa all weather operations. High quality, modern-design ILS, properly installed and carefully controlled, can provide the signal integrity necessary for all weather operations.

However, it is the view of the carriers and a large part of the rest of the aviation community that a new system, capable of overcoming the difficulties outlined previously, should be sought. We know that a number of improvements to the ILS are feasible and many have not yet been fully explored. Nonetheless, even if these improvements were fully exploited, the new demands for electronic guidance for landing will not be met with the existing ILS.

Many people believe that transition to a new system of precision approach and landing guidance must be based on clearly demonstrable major superiority of the new system from the standpoint of technical performance and economy. It is my view that only a single transition from ILS to a new system can be practically considered. Interim systems, or systems tailored to meet one or another specific need, are operationally and economically undesirable and unlikely actually to be implemented.

How Do We Go about Agreeing on a New System?

Considering the very large investment of study and money which had been made by 1967 by government agencies in more than forty landing systems of various sorts, the problem of how to go about obtaining national and international agreement on a single new system was a perplexing question in the light of so many individual interests. Because such a job could only go forward with the full cooperation of many people and organizations both in and out of government, both in the United States and abroad, consideration of a forum focused quickly on the Radio Technical Commission of Aeronautics, whose Executive Committee established Special Committee 117.

The response of the world's best experts, and cooperation by many diverse interests was remarkable. It was a test of maturity for all of us to see if we could, as free and independent people and organizations working together, agree on a single way to go forward to develop a new precision approach and landing guidance system.

Literally hundreds of people, organizations, agencies, and governments participated wholeheartedly in the RTCA effort and made available both technical and operational experts. RTCA may have done what individual organizations of government or any individual companies, or even individual countries might find very difficult to do alone—develop a consensus of operational requirements and a system concept and signal structure which, while not beloved by all, may be acceptable to all.

The greatest risk, even if agreement were to be reached, was that the agreement would be on a multihumped committee camel. The people closely involved understood that risk, and a significant amount of blood and sweat were shed to provide at least a hope that the result is a racehorse rather than a multihumped camel.

It is important to recognize that the task was not the development by a clever organization of a fine new landing system. Silly as it sounds, that is not the toughest problem. The real job is to achieve a new landing system which is acceptable to, and will be pressed toward standardization by, the widest possible concert of interests.

Process of Achieving Agreement

It was noted previously that the response to the effort to achieve agreement on a new landing system concept and structure was remarkable, and that experts from many countries and in many disciplines actively participated. It is worth re-emphasizing that the process SC-117 attempted to carry forward was unique. There are few other instances in which the attempt has been made to gather consensus of a large group of experts in the development of a technically sophisticated system in a completely publis forum.

The first task undertaken by the Committee was the development of a Statement of Operational Requirements. An Operational Working Group of approximately 100 experts labored for almost a year to develop these requirements.

This work was conducted under the able leadership of W. Fuchs of the Department of the Navy.

Particular hardware ideas and even economic questions were consciously avoided in order to achieve a relative by pure statement of requirements. It was recognized, of course, that any final statement of requirements must be tempered by both technical feasibility and cost consederations, as well as problems of implementation.

During this same period, a Technical Working Group under D. Sheftel of FAA was conducting a review of the technical state-of-the-art to identify existing concepts and techniques which might be used to satisfy the forthcoming requirements.

The full Committee agreed that the best way of assessing techniques for their capability of meeting a variety of needs within a single signal structure, was to describe typical system configurations which are likely to find application in the real world. Therefore, the Committee selected from the Tentative Operational Requirements a small number of typical configurations, which most likely would account for the large majority of installations, on which judgments of technical and economic feasibility could be made. Technical descriptions of this small number of configurations were then completed by the Technical Working Group and circulated to potential sponsors of techniques and proposers of ideas for meeting these requirements. Over 600 copies were circulated throughout the world. Twenty-three specific proposals were received for study. The techniques suggested ranged from satellite systems to multilateration systems to penetrating gamma rays and to scanning beams.

The proposals were examined by a group of experts chosen from the SC-117 membership, called the Techniques Assessment Team (TAT). This team was headed by T. Ellison of United Airlines and D. Babcock of the Stanford Research Institute. The team was composed of some 28 users and implementers of systems. They served as advisors to the full Committee on techniques available and offered conclusions and judgments on which the Committee could base its actions.

The team completed its work and made its recommendations in October 1969 after an eight-months study. The team concluded, and the Committee concurred, that a system based on the scanning fan beam concept—a melding of the best features of several proposed techniques—could meet most of the operational requirements, and that such a system could be recommended with a high confidence of practical success. Here then was the second major milestone in the task of SC-117.

After deciding to concentrate its further efforts on scanning beam systems, the Committee agreed that the next step in the definition of a detailed signal structure could best be accomplished by the seven proposers of scanning fan beam systems (five U. S. companies, one British, and one French) working together to develop a single signal format.

Each of the proposers agreed to work within this framework. This group was headed by W. Fuchs of the Department of the Navy. This team worked with a small group of other SC-117 members from DOD and FAA, as well as a small group of industry representatives from general aviation, the airlines and informal representatives of foreign governments interested in approach and landing systems. Their work was adopted, essentially unchanged, by the full Committee in Oct. 1970.

A Thumbnail Sketch of the Provisional System Characteristics

1) The RTCA SC-117 Microwave Scanning Landing Guidance System (LGS) will be comprised of the following elements: a *C*-Band elevation and a *C*-Band azimuth guidance element; a DME at *C*-Band; a *Ku*-Band elevation element for flare guidance to touchdown. The *C*- and *Ku*-Band elevation elements will make use of compatible signal formats allowing the simplest possible signal processing in the airborne receiver.

The decision to utilize a frequency for the flare guidance element separate from that for the major elements of the system, finally reached after a mail survey of the full Committee's views, was one of the most difficult decisions to reach, since it means that two frequencies are required in an aircraft to use all features of the new system. The basic reasons were the questionable capability of penetrating heavy rain to significant ranges at *Ku* Band, and the unknowns of providing guidance very close to the ground and very close to antenna elements at *C* Band.

2) The DME function, required to be an element of the landing guidance system, is to be in a separate part of *C* Band, spaced at 3 MHz intervals, channel correlated but not integral with the angle channels.

3) The beams, both azimuth and elevation, must be capable of yielding planar information.

4) The Format will use narrow band channels for angle data, spaced approximately 0.6 MHz apart. Fixed tones will be used for coding, and a tone range for angle data frequency-proportional to angle. The system will provide for 100 channels initially and will be expandable to 200 channels.

5) Scan rates of up to 5/sec will be available within the signal structure for elevation element No. 1 and azimuth front and back course guidance, and 10/sec for elevation No. 2.

While we had hoped that the signal format would be able to accommodate both conventional scanning beams and a unique type of Doppler scanning technique, specific decisions on dwell time and manner of beam passage require a branching of the Format into one branch suitable for conventional scanning beams and another for Doppler scanning systems. Alternatively, a decision could be made to reject one or the other.

So far, neither method of scanning can in good conscience be rejected, and verification efforts will have to encompass both Doppler scan and the conventional scan versions of the same general format.

6) For the conventional scanning beam system branch a 0.8 msec minimum dwell time is provided, and a $\frac{1}{2}°$ elevation element No. 2 beam width is possible if needed.

7) For the conventional scanning beam branch, a continuous scan sum pattern beam will be used. Step-scan antennas can be accommodated in the system.

8) For the conventional scanning beam branch the modulation is narrow deviation angle modulation; for the Doppler scan branch, the modulation will be a modified Double Sideband-AM.

9) The Format will accommodate a *Ku*-Band azimuth scanner in the event special military needs require it as a complementary feature of the basic SC-117 system.

10) The system will be capable of providing discrete identification plus certain limited data messages, such as indication of the status of the particular aid, the runway served, the identification of the facility and possible certain other very simple data messages.

11) It will be possible to utilize the system on a single site, co-located basis such as might be required for simple man-packable military systems, as well as possibly for V/STOL and general aviation applications, and in a multisite arrangement in which the basic elevation and azimuth scanners would be located at the conventional ILS localizer and glide slope sites with the *Ku*-Band flare guidance located several thousand feet behind the basic *C*-Band elevation to provide flare and touchdown guidance.

Saying it in operational terms, the system will permit implementation of a new class of landing aids with major new capabilities, according to the chosen system configuration: a) guidance service for fully automatic touchdown without dependence on other sensor systems; b) broad coverage, in both azimuth and elevation for automatic turn-on to final approach and controlled departures and missed approach; c) proportional coverage over wide angles for curved approach paths and glide paths; d) relative freedom from sitting effects; e) small size for equipment to meet military tactical needs, including aircraft carriers and certain needs for general aviation; f) potential for low-cost ground and airborne equipment for small airports and general aviation use.

The provisional signal format will allow the simplest and lowest-cost airborne equipment to obtain service from either simple or high-capability ground equipment. The most sophisticated airborne equipment will be able to obtain service from simple ground equipment, but with reduced capability. This concept provides modularity of airborne and ground equipments for cost-benefit choices by implementers.

Items of Concern to Aircraft Designers

There are two aspects of the system which, in my view, are of particular significance to aircraft designers.

Aircraft Antennas

First of all, the problem of the aircraft antenna. Unlike the VHF ILS, new problems arise in providing antennas for highly directive systems at *C* Band or *Ku*. It is necessary to provide relatively wide angle data acquisition capability in the aircraft to permit turn-ons, and for use of the system on a wide angle basis, especially since in the more sophisticated versions of the new landing system, azimuth sector coverage of $\pm 60°$ will be provided. Thus, good antenna coverage is required at *C* Band in the front sectors of the aircraft.

To complicate things further, there is an increasing demand for accurate departure and missed approach guidance from this system as well. This means that good coverage must be provided in the rear sectors of the aircraft as well. SC-117 attempted to help the problem a little by specifying the major units of the system at *C* Band, which should make relatively omni-directional antennas a little easier than at *Ku* Band.

Of course, a *Ku*- Band antenna must be provided, but it can do its flare job with relatively narrow front sector coverage since it would be used for the final approach portion only. It will be necessary to provide for such an antenna however, and this may mean two transmission line systems as well. It is not too early to start considering the new problems which are likely to be encountered in aircraft from an improved landing guidance system, since the bright and shiny new system is likely to cause a number of headaches to airplane designers.

Information Renewal

Perhaps an even more critical problem has to do with information renewal or scan rate considerations. One of the critical decisions in the development of a new approach and landing guidance system is the rate at which guidance information is made available to the aircraft. Unlike the conventional ILS which provides its information continuously, a microwave scanning beam landing system, especially any conventional scanning system in which information beams sweep past the aircraft periodically in order to provide volumetric sectors of coverage, requires decisions on the optimum rate at which information a) is needed by the aircraft and b) can be made available by the ground element. The choice of information renewal rate is affected by a number of basic system design considerations.

Viewed from the standpoint of efficient low-cost ground elements, a low scan rate is desirable to permit use of mechanical scanning, especially if it is necessary to scan relatively large sectors. Certain system mechanizations become impractical if high data rates are required, and systems generally become more costly as the data rate requirements rise. If unreasonably high information renewal rates are called for, mechanically scanned systems become impractical, and the currently more expensive electronic scanning systems must be used—to the over-all economic disadvantage of the system.

Viewed from the aircraft side, it is advantageous to have a very high information renewal rate in order to permit the aircraft flight control system designer to choose the rate at which he wishes to extract and use information, and to permit the shortest possible lag between the actual instantaneous position of the aircraft and the guidance information received. Starting with the recognition that present day ILS provides continuous guidance data (even though only on one course and one glide path) aircraft designers may not be enthusiastic about accepting low data rates.

The airborne system problem is complicated by a tradeoff problem resulting from the desire to use a single landing guidance system design to serve a multiplicity of uses. For example, an aircraft of very large mass and limited maneuverability which is equipped with inertial attitude and rate information may be served well by approach and landing guidance information with a rather low information renewal rate, as long as the information received, when received, is very accurate. The same aircraft without inertial quality information will require higher information renewal rate. A very light aircraft with high maneuverability, and without inertial information available from a separate source, may require a renewal rate which may be significantly higher than that needed by heavier, but less maneuverable aircraft.

The nature of the terminal maneuver also affects the information rate requirement. For some applications the most critical maneuver is the automatic flare and touchdown function. The assumption made by RTCA SC-117 was that the new system must provide sufficient guidance information for approach, flare, and automatic landing; it may not be assumed that a radio altimeter or other external aid will be available to assist in making an automatic landing. This means that the precision elevation guidance required of the proposed system includes the area of high rate of change of sink rate in the vicinity of touchdown.

The information renewal rate is influenced by other factors as well, including, importantly, the character of the airborne signal processing system. As noted, the ground system designer is best served by permitting relatively slow scanning of the beams, particularly when large sectors of coverage must be provided. At the same time it is desirable to provide relatively broad blunt-nose beams which help make the guidance information available in the aircraft for a relatively long dwell time on each sweep. In direct contradiction to this desirable feature, blunt-nosed beams are inefficient of radiated energy and use of time, and may cause reflection problems. In the vertical case, they can be highly undesirable if accurate coverage at very low angles near the ground is required in the vertical axis. In the aircraft, while reflections are undesirable, a reasonable dwell time is needed to permit the airborne system to extract the best quality information from the beam with a minimum of airborne processing cost.

In the aircraft, the problem of beam noise (from whatever source) is important since it will determine the instantaneous accuracy and the requirements for integration time. Higher confidence can be obtained by integrating the information over several sweeps (scans), but obviously only at the price of the integration time constant.

Thus, a host of inter-related problems affects the choice of information renewal rate. The two boundary constraints appear to be the ground antenna system capability and the assumptions which can be made about aircraft maneuverability and available airborne data needs from the guidance system and from sources other than the landing guidance system. It is the wish of the system designers to permit the use of mechanically scanning antennas on the ground, while not requiring inertial-quality attitude and rate data sources in the aircraft. It is also desired to serve the heavy, high mass aircraft, light aircraft, and helicopters which have their own peculiar data rate requirements.

SC-117 attempted to learn from the designers of aircraft and flight control systems what their specific needs are and to have aircraft system designers help reach the best compromise on what the LGS system should provide. The judgment arrived at is based on the range of inputs received. While a number of responses were received, the range of needs remains broad, and no absolutely convincing data have become available on which fully justified information renewal rates could be set. Because of the many variables in airborne systems, it may remain difficult even after further study and experimentation to achieve consensus on optimum data rates, although work should continue to refine this parameter.

In order to permit greatest flexibility in the system to permit simple ground and air configurations the proposed signal format can accommodate different data rates in different configurations. RTCA has made certain assumptions about the requirements for the several functions of the SC-117 landing guidance system: for azimuth guidance (for both front and back course information)—up to 5 updates/sec; for elevation No. 1—up to 5 updates/sec; for elevation No. 2 (flare)—up to 10 updates/sec; for DME—5 samples/sec ($\frac{1}{5}$ sec smoothing time).

In order to permit the most cost-effective system scan mechanization both ground and airborne systems must be capable of accommodating various scan rates or information renewal rates for various functional applications. It is permissible, for example, to use the highest data rates near the touchdown point and lower rates in the coverage sectors away from the touchdown area.

As already stated, decisions on information renewal rate involved assumptions which were difficult to validate, and on which more evidence is required.

What Happens After Acceptance of a Provisional Signal Format?

Now that RTCA has developed a system concept and a provisional signal format, ready for verification in actual hardware and flight tests, what should happen next?

It would be unrealistic to hope that an absolutely final system standard and signal format would emerge from RTCA. However, RTCA has created a provisional signal format which represents the best judgment of the qualified experts.

Now that RTCA agreement exists on a system concept and a provisional signal structure, what should happen next? The Department of Transportation, Department of Defense, and NASA have chosen to establish a planning group to develop a program which will use the work of SC-117 as a guidepost to establish a nationwide development plan.

RTCA considered the best ways to marshal the large amount of good will and government and industry know-how toward achievement of a landing system which may be likely, in good time, to find national and international acceptance.

These recommendations suggest a procedure which may protect what has been done and may possibly help avoid the pitfalls of intergovernmental and interindustry rivalries. The recommendations are as follows: 1) RTCA believes the proper course now is the establishment of an analytical and experimental effort to last perhaps a year in which the proposed system concept and signal format would be examined in detail by dispassionate experts to determine that the chosen best-judgment decisions are indeed correct. The effort should be carefully directed and coordinated to validate what has already been done and to offer changes where needed, rather than start over again. RTCA stands ready to assist, within its capabilities. 2) The next step is the construction and testing of verification systems. It is critical that this step not be delayed so long as to see the momentum lost. It is in this process of developing and testing several versions of the RTCA system scientifically and operationally, that the real verification effort will take place. Close coordination in this phase is essential to assure that different versions continue to work together. 3) RTCA recommends that timely development and construction of verification hardware during this step be undertaken by the implementing and using agencies of the United States and elsewhere, using different designers both in the United States and abroad to provide for the broadest possible spreading of expertise over the world, both in government organizations and manufacturing concerns. This most important recommendation is made for these reasons: a) It is essential that the different user and implementer agencies become involved, financially and technically, with the specific system versions which they will expect to use most heavily. The history of landing system development makes it obvious that the several implementing agencies each must have a compelling stake in the work. b) It is essential that a level of competition be established in the best American tradition, both within the Government and outside it, in order to achieve the best result for all. c) It is essential that the broad range of industrial interests, which has served as the major cohesive force in creating this provisional signal format, be kept as tightly coupled to the work as the available resources will permit.

Conclusion

It was noted at the outset that work has been done over the past few years on more than forty different landing systems. It has been done by many organizations and by literally hundreds of people—each of whom has strong opinions and a firm conviction that his approach is best. Obviously, not all of them could win. The process which RTCA chose to proceed to achieve agreement may be attractive to prevent victory by default to the system which happens to gain moneyed backers. The process which RTCA undertook to achieve agreement on a new landing guidance system represents a fine way for free people to move forward in a complex field of technology where cooperation of many is critical.

The support of government agencies to RTCA SC-117 was generous, unstinting, and open. We were offered facilities and the services of good people, even though what RTCA did often was at least implicitly critical of the pet ideas of the various organizations. It is to be hoped that the follow-on process, the really hard part of creating a new system, will be conducted in the same spirit. The development effort on which the government is now about to embark deserves the strong support, as well as continuing constructively-critical appraisal from the aviation community—the eventual beneficiaries and users.