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AERONAUTICAL SATELLITE NAVIGATION: CIVIL AVIATION'S NEEDS AND INSTITUTIONAL ALTERNATIVES

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0. Abstract

Based on an examination of civil aviation's navigation requirements and existing and future system capabilities, this article discusses the institutional consequences of the reluctance of the international community to use the two military satellite navigation systems of the United States and the Russian Federation.
Policy changes in the US Department of Defense may make the international acceptance of the US system easier. As a civil satellite navigation system suiting aviation needs is not realistic in the foreseeable future, a coordination of all emerging rudimentary systems is required.

1. Existing and Future Satellite Navigation Systems

(a) The Global Positioning System (GPS) is operated by the Department of Defense of the United States and consists of a space segment of 24 satellites in intermediate-altitude, inclined orbits. Initial Operational Capability (IOC) was declared in December 1993.

The system provides an encrypted precision signal for the military (P code) and a non-precision signal (coarse aquisition code c/a) whose use was offered to international civil aviation for free. However, the operator reserves the right to degrade the precision of the non-precision code (selective availability s/a) [1].

(b) the Global Navigation Satellite System (GLONASS), developed by the military of the USSR, now operated by the military of the Russian Federation has momentarily about two thirds of its future 24 satellite space segment in intermediate-altitude, inclined orbit. The space segment will be complete not earlier than 1997. The use of signals with similar precision as the GPS coarse signal was offered to civil aviation for free. There is no precision downgrading. Despite the use of other frequencies, time basis and geocentricity data, satellite receivers exist which can use data of both GPS and GLONASS satellites [2].

(c) Until the end of 1995, INMARSAT will establish its new network INMARSAT 3 of four geostationary (communication) satellites around the globe, which will also broadcast GPS compatible signals for overlay [3].

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INMARSAT P/Project 21, another network to follow INMARSAT 3, will use a ten or twelve satellite space segment in intermediate-altitude, inclined orbits and will also carry navigation payloads [4].

(d) The Japanese Civil Aviation Bureau (JCAB) is planning to establish a system of two geostationary satellites until 2004 for aviation purposes only to serve the Asia/Pacific region. Besides communication, it will provide GPS compatible navigation signals for overlay [5].

2. Civil Aviation's Needs

(a) Aviation has stricter requirements than maritime and land mobile users in regard to the number of navigation satellites constantly visible to the user, because aeronautical navigation is three-dimensional.

In terms of geometry four satellites as fix points must be usable to determine the three-dimensional position of an aircraft, whereas the two-dimensional position of a surface vehicle can be determined by three fix points, as long as the altitude does not substanially differ from sea level.

(b) The precision of the altitude determination (150 meters) appears to be one of the weakest points of existing satellite navigation systems, but it is a crucial element for aeronautical users. Precision altitude measurements are of primary importance for satellite guided (precision) approach landings. System augmentations like Differential GPS (D-GPS) will be used to enhance vertical precision. In the future barometric altimetry will be replaced by GNSS altimetry, provided that adequate vertical precision is achieved. Vertical separation at high altitudes could then be reduced.

(c) Another factor why aviation requires an increased number of satellites is integrity monitoring and health warning. Although it is technically possible to detect malfunctions by a ground-based monitoring station and broadcast system integrity messages to all users, the more favorable method is Receiver Autonomous Integrity Monitoring (RAIM) which has become aeronautical practice and requirement for GPS [6]. With RAIM the aircraft-based navigation receiver has to process signals of six satellites simultaniously - two more than for a three-dimensional position determination - and by comparison of the signals it can detect and disregard a false signal and yet determine a precise three-dimensional position by the signals of the remaining satellites.

(d) A fully global satellite navigation system with coverage up to both poles is essential for aviation, because polar routes are everyday practice and will become more important with new aircraft generations with ranges significantly beyond 12,000 km. Due to wave propagation characteristics, geostationary satellites cannot provide coverage of polar areas.

(e) Although the 24 satellites of the GPS space segment fulfil the requirements for three-dimensional positioning worldwide with RAIM capability, propagation shadows in mountainous areas and during various flight maneuvers make a larger number of satellites desirable for aviation.

3. Political Aspects

(a) The reaction of aircraft operators and pilots to the prospects of GNSS and especially GPS was and is overwhelming. In general aviation aircraft owners started to equip their aircraft with GPS receivers even before the receivers were certified and the national authorities had approved their use, so that for instance the German authorities fired a warning shot, by issuing a NOTAM in 1992 stating that GPS use is illegal (7). The airline industry is similarily positive, although the big break-through would require full precision approach capability of the GNSS, e.g. with D-GPS (8). This broad and early acceptance by the users fully underlines the convincing technical concept of satellite navigation.

(b) The political side is different. Member states of the International Civil Aviation Organization (ICAO) have reacted reluctantly to the offer of the US and the (then) USSR to provide the GPS and GLONASS systems to civil aviation free of charge for a period of ten and fifteen years respectively (9).

The concerns are:

(i) that the services are offered unilaterally, each by a single state, and thus user states would become dependent on the provider states;

(ii) that the systems are owned, controlled and managed by the military of the provider states;

(iii) that the services can be interrupted or, in the case of GPS, precision be downgraded, at the discretion of the provider state;

(iv) that the shutdown of domestic (terrestrial) radio navigation systems as a consequence of GPS/GLONASS as sole-means radio navigation system would give the US and the Russian Federation enormous bargaining power upon expiry of the ten and fifteen year operation periods.

(c) ICAO's FANS II Committee (10), assisted by the ICAO Legal Committee, has established guiding principles relating to satellite navigation (11) and has proposed to establish an institutional path leading from GPS/GLONASS to a civil GNSS.

Impacted by the concerns relating to the unilateral provision of the GPS and GLONASS systems, discussions in the FANS II Committee about the institutional aspects evolved around the elements of ownership, control and management of the satellite navigation systems and their *components. Control was identified as the crucial element to define the influence of the user (state) on the system [12] and it was concluded that contractual relationships in one form or another could establish an adequate level of control by the user state's air traffic services (ATS) authority [13]. The Legal Committee was tasked, inter alia, to propose arrangements that include provisions on ownership, control and management [14].*

The FANS Committee seems to view positively an international navigation system owned, controlled and managed by an international organisation like INMARSAT [15].

4. Institutional Alternatives

(a) Starting point for the discussion of the institutional alternatives should be the possible system scenarios [16]:

(i) GPS and/or GLONASS

(ii) GPS and/or GLONASS with an overlay of rudimentary satellite navigation systems (eg. INMARSAT 3, MTSAT)

(iii) a fully operational civil GNSS with or without overlay by GPS, GLONASS and/or rudimentary satellite navigation systems.

For the sake of completeness it must be mentioned that overlay is possible with non-satellie navigation systems, including existing terrestrial radio navigation aids and inertial navigation systems (INS). Precision upgrading with methods like D-GPS are possible. A purely civil GNSS could provide precision navigation signals to its civil users, similar to the encripted military signal of GPS.

(b) Due to the general concerns raised against GPS and GLONASS and due to the financial constraints which will make it unlikely that a fully operational civil GNSS will emerge in the closer future, aviation users could be confronted with the situation that their home states do neither authorize the use of GPS and GLONASS, nor certify the corresponding avionics. It is not a satisfactory solution to wait for civil satellite navigation systems, when all prospective civil alternatives offer only rudimentary space segments [17].

(c) Instruments to overcome the doubts about GPS and GLONASS would be bilateral [18] or multilateral agreements between provider and user states. Arrangements similar to the DEN/ICE Agreements could be another alternative [19]. It is doubtful, if the rights of the users under such arrangements should be considered as "control" over the systems as defined by the FANS II Committee. But this may only be a question of terminology.

One reason why the provider states could be willing to enter into such agreements is the chance to agree on user charges, despite earlier offers to provide the systems for free: More civil user-friendly terms and conditions have their price. Additionally, under these prospective agreements the provider state could be willing to make the system available for a longer period than ten or fifteen years.

Another reason of US to agree to such commitments, could be a change in the perception of the military role of GPS. The Defense Department will not be able to reserve the precision navigation only for military uses, but D-GPS and other methods offer similar capabilities to civil users, perhaps even on a worldwide basis [20]. Consequently, the reservation of the encrypted precision signal for the US military has become meaningless. The fact that the Defense Department has discussed control and management matters of the GPS system with the Department of Transportation [21] supports the impression that the military may not any longer attach highest security interest to GPS and its precision capabilities and tries to recover some cost.

(d) At the present point it does not appear to be wise to discuss at the international level ownership, control and management of two nationally owned systems. Contractual obligations are the legal instruments to bind provider states to comply with users requirements (for payment of user fees).

However, if the US Defense and Transportation Departments discuss about GPS, it is consequent and of use for the international aviation community that management and control issues are discussed. Should the US Department of Transportation be in control and manage GPS to some degree, it could be a convincing representative of the US Government to offer contractual relations to user states.

(e) An additional obstacle for a worldwide acceptance of GLONASS (as a sole means navigation system) is the politically uncertain course of its provider state.

(f) At the moment no candidate for a civil GNSS exists. Even Inmarsat P/Project 21 with ten or twelve satellites, would not provide a sufficient space segment for aeronautical navigation.

Politically, an organisation like Inmarsat must be considered to be ideal to provide civil GNSS, because ownership of the organization's system is held internationally. The fact that the everyday-management is in the hands of the signatories, nationally assigned private or public telecommunication operator organisations, does not create problems. There is no need to implement institutional elements for the control of national ATS authorities in an organisation like Inmarsat [22]. Instead, each member state to Inmarsat must take care that the signatory it assigns is sufficiently bound to comply with the needs of the national aviation authorities. This compliance obligation should be a purely domestic law matter between each member state and its signatory.

(g) It is not unlikely that various (civil) satellite *operators decide to equip their (e.g. communication) satellites with navigation payloads. In many cases the orbital geometry will not suffice civil aviatons needs, like in the cases of Inmarsat 3 and MTSAT. Consequently, future (civil) navigation satellies should be technically compatible and be operated to complement each other's orbital geometry. Thus there should be international coordination in order to achieve a civil GNSS constellation suitable for all users including aviation. When the FANS II Committee speaks of an institutional path from GPS/GLONASS to a civil GNSS, it must be expressly emphasized that a coordination effort is needed in order to bridge rudimentary (civil) systems to achieve a fully operational GNSS.*

The same coordination is required for the navigation earth segment (master control station and monitoring stations). Duplication of (civil) satellite navigation earth segments should be avoided. Should several (rudimentary) civil systems emerge, all efforts should be undertaken to cooperate in one unified satellite navigation earth segment.

5. Conclusions

(a) Civil aviation requires a more complex satellite navigation space segment than maritime and land mobile users. To secure polar coverage, the space segment must include not only geostationary satellites.

(b) Despite the reluctance of the international community to accept GPS and GLONASS as vital elements of future aeronautical navigation systems, the cooperation between the US Departments of Transportation and Defense could open a door to make GPS internationally more acceptable.

(c) A purely civil GNSS to meet the requirements of aviation is not in sight, but rudimentary civil systems will emerge (e.g. INMARSAT 3 and P, MTSAT). Thus there is the need for coordination

(i) that those systems operate with the same signal standard (likely GPS compatible),

(ii) that their space segments complement each other to achieve a global system and

(iii) that duplication of the earth segment is avoided.

(d) The prospects for a civil GNSS consisting of a number of rudimentary systems may not look so dim, when considering the increasing number of non-geostationary (communication) satellites in low or intermediate-altitude orbits. These satellites will be ideal platforms for navigation payloads, provided there are financial incentives.

Notes:

(1) ICAO Doc. 9623 FANS(II)/4 4H 2.

(2) ICAO Doc. 9623 FANS(II)/4 4H 3., Wilson, Andrew (Ed.) Jane's Space Directory 1993-94 p.415 (Croulsdon 1993)

(3) Wilson, Andrew (Ed.) Jane's Space Directory 1993-94 p.335 (Croulsdon 1993)

(4) AW&ST 83 (June 27,1994)

(5) Okada, Kazuo ICAO J 24 (Oct.1993)

(6) US Department of Transportation, Notice 8110.47 of 4/23/93, 5.c

(7) Bundesministerium für Verkehr, Nachrichten für Luftfahrer [NfL] II 27/92. In the meantime another NOTAM, NfL II 20/93, has changed this position

(8) The US Air Transport Association (ATA) has urged the Federal Aviation Administration (FAA) to implement GPS to provide precision landing capability, AW&ST 34 (Feb.7, 1994)

(9) The offers were renewed in the 29th ICAO Assembly in 1992, ICAO Doc. 9623 FANS(II)/4, 6.4.3.1

(10) Special Committee for the Monitoring and Co-ordination of Development and Transition Planning for the Future Air Navigation Systems

(11) ICAO Doc. 9623 FANS (II)/4 8A, 2.6.7.2, see also general guidelines 8A, 2.6.4.1, also reprinted in Guldimann, Werner / Kaiser, Stefan, Future Air Navigation Systems, Legal and Institutional Aspects, Martinus Nijhoff Publishers 128 (1993)

(12) The continuity, availability and quality of the system, standard-setting, definition of procedures, financing arrangements etc.

(13) ICAO Doc. 9623 FANS(II)/4 6.3.3.4, 6.3.3.5, 6.3.3.6

(14) See North, R.F. ICAO J 13 (Dec.1993)

(15) See ICAO Doc. 9623 FANS(II)/4 6.2.4.4.2

(16) The following alternatives differ slightly from the list submitted by the FANS 2 Committee, ICAO Doc. 9623 FANS(II)/4 6A

(17) For the legal relationship between provider and user of GPS and GLONASS see Kaiser in Guldimann/Kaiser (supra note 11) p.237

(18) E.g. the US - Fidji cooperative program, see ICAO Doc. 9623 FANS(II)/4 6.2.4.4.1

(19) Under these two-tier agreements drafted along the provisions of Chapter XV of the Chicago Convention [Convention on International Civil Aviation, signed in Chicago 7 Dec. 1944], Denmark and Iceland respectively provide ATS services and user states contribute financially

(20) Klass AW&ST 23 (July 26,1993)

(21) AW&ST 32 (Jan.3,1994)

(22) As proposed by Altink-Pauw, Mieke ICAOJ 20 (Dec.1993)

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