Operational Maritime Satellites – An Evolving Concept

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In April 1975, an Inter-Governmental Conference expected to lead to the establishment of an International Maritime Satellite System was convened in London. Preparation for the meeting had involved indepth examination of the operational, technical, economic, and institutional alternatives which might govern the system's implementation and functioning, as developed by the combined expertise of the Panel of Experts on Maritime Satellites. This paper reviews the concept development process within the Panel in these four broad areas, culminating in its recommended approach for the creation of a new Inter-Governmental body, an International Maritime Satellite Organization (INMARSAT), to oversee the management of the space segment.

I. Introduction

ON April 23, 1975, an International Conference on the establishment of an international maritime satellite system was held in London. Although it is viewed by some observers as the formal culmination of ten years' preparation, it is likely that further meetings will be needed to refine the system concept and to reach consensus agreement on the plethora of unresolved issues. The complexity of the task is exacerbated by the lack of prior relevant experience. The proponents of the proposed system seek a profitable multinational management of an expensive satellite system with marginal investment attractiveness, serving a maritime industry inclined to conservatism and historically resistant to technological innovation. The political aspects are underscored by this initial attempt to link the United States and the Soviet Union in a multilateral commercial exploitation of space, while simultaneously fashioning an agreement responsive to the maritime importance of diverse countries and to their hopes for development of aerospace expertise and export sales to counter traditional U.S. dominance. The evolution of the INTELSAT system offers only limited guidance since that system began as a unilateral U.S. initiative mandated by National Law (the Communications Satellite Act of 1962). Nonetheless, progress has been made in defining the outline of a viable operational maritime satellite system. This paper will highlight the factors that have shaped the growth of this evolving concept.

II. Background

As with much of space technology, mobile satellite communications developed initially from defense requirements for high reliability, high capacity, command and control links. By 1966, operational utility had been demonstrated. Aviation was viewed as the first likely candidate for civil satellite use in oceanic air traffic control, and in fact several configurations of VHF and *L*-Band systems were extensively debated. On the maritime side, the Inter-Governmental Maritime Consultative Organization (IMCO) took cognizance of the potential value of a satellite system and began study of the operational requirements. Concurrently, experimental work with the NASA ATS satellite series validated the feasibility of a VHF maritime telecommunications satellite. In 1971, the World Administrative Radio Conference for Space Telecommunications (WARC-ST) allocated UHF frequencies in the *L*-Band region (1535-1660 MHz) for operational systems. This action galvanized the resolve of many IMCO members to seek appropriate means of attaining a maritime satellite capability as quickly as possible, since the leading unknown of spectral occupancy had been resolved. Thus, when the USSR introduced in 1972 the need for an international study of the ranges of issues involved, there was almost universal approval. Their proposal for a study, complete with a timetable for system implementation and a proposed Inter-Governmental Conference to ratify the results, was adopted in toto by IMCO. A Panel of Experts on Maritime Satellites was created to accomplish the study and to document its findings for the Conference. Its final report was issued in Sept. 1974, which formed the basis of discussion at the London meeting. Figure 1 shows the timetable presently contemplated, although there is no agreement yet on the need for a second Conference in 1976.

III. Overall Concepts

Through ten years of thought, experimentation and study, the numerous strategies for satellite implementation have evolved into a reasonably cohesive consensus. There was an early recognition of the multifunctional capabilities of satellite telecommunications, accompanied by a desire to first examine the need for a navigation satellite system. However, the general maturity of terrestrial system development was considered adequate for most maritime requirements, and attention was shifted increasingly to resolving the problems of maritime communications (poor quality, long delay times, manual operations, etc.). Thus, use of the satellites in the initial phase will be predominantly for communications purposes, with navigational and/or surveillance functions permissible only if no spacecraft hardware modifications are involved. The low level of technological risk, coupled with the independent research efforts being conducted by several Administrations, argued against the need for an experimental or pre-operational system of satellites. Acceptance of the desirability of proceeding immediately to operational systems precluded any possibility of a joint aeronautical/maritime service, and in fact the operational incompatibilities of the mobile services requirements reinforced the decision despite any economic benefits that may have been possible. From an institutional viewpoint, there appears to have been a predisposition by many countries to seek implementation of the system through a new Inter-Governmental Organization, since most countries believed that only this form of management could be optimally responsive to international maritime requirements Existing Organizations (INTELSAT, IMCO, etc.) were alleged to be inappropriate for various reasons. This predisposition to independence for institutional/political reasons influenced all aspects of the Panel's work, and thereby rendered unfettered analysis of alternative technical, economic, and operational schemes very

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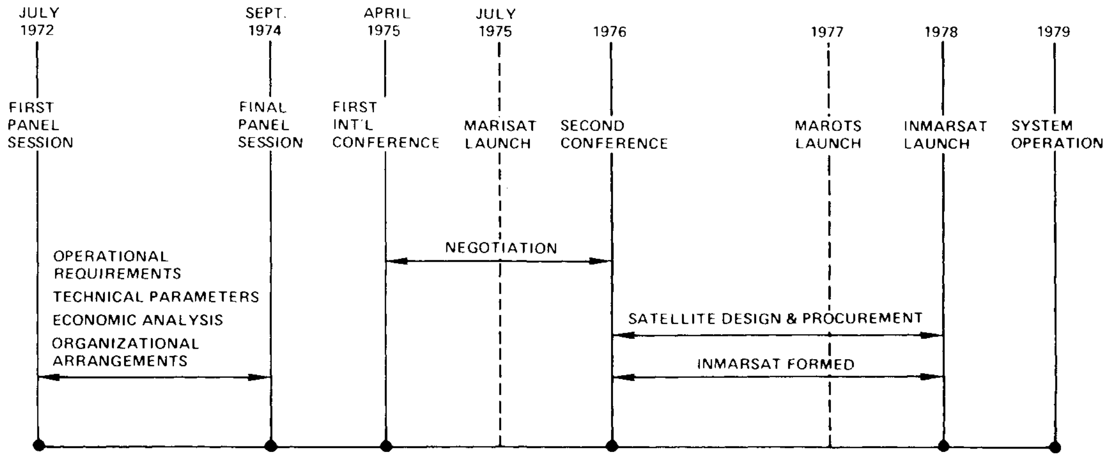

Fig. 1 IMCO timetable for maritime satellite development.

difficult. In the final report, however, treatment is given to competing concepts of dedicated and multi-purpose satellite systems as viable methods of satisfying the service requirements.

Overall, then, the framework of the panel's deliberations visualized a rapid development of an international funded and managed communications satellite system, using readily available technology, with a high probability of cost recovery and eventual profit. In the long term, less urgent requirements (i.e., navigation, surveillance, etc.) could be met by later generations of spacecraft and/or more innovative use of software by the maritime user community.

Having established the broad guidelines of the system, detailed consideration was given to the operational, technical, economic, and institutional questions. Although in fact all work proceeded in a parallel and iterative stream, the presentation following assumes serial accomplishment of each study.

A. Operational Requirements

With the perspective of the primary of communications, the development of operational requirements centered on the identification of quantitative user needs. These related both to the expected volume and quality of communications traffic, each implicity dependent on its tradeoff with cost. Forecasting the likely traffic was undoubtedly the most difficult task because of the uncertainty of owner acceptance (the rate of fitting ship terminals) and of average traffic intensity (system usage per day per ship). For example, a 25% increase in traffic is expected if national regulations prohibiting in-port transmissions from ships were rescinded. The approach taken appears relatively conservative in view of the quantum improvement in quality expected from satellite communications. Essentially, it was assumed that half of the new, larger ships would be fitted after 14 yr of system operation, and that their average utilization would be 2.5 times greater than today's HF unit traffic count. Both of these assumptions impact greatly on the subsequent economic analysis, which is highly sensitive to uncertainties in the assumed traffic levels. Criteria for service reliability, availability, and quality were arrayed against expected ship population and geographic density, message loading and its temporal and geographic distribution, and types of messages to define the traffic and channel requirements. It was found that global coverage was needed (70°N to 70°S) to serve the clientele of 7000 larger ships (10,000 grt and above) expected to eventually participate in the system. The requirement for improved distress and safety communications, which had been the original motivation for the IMCO studies, is to be satisfied through the use of a priority-interrupt mechanism on the normal working channels. The expected use of the computer-to-computer interconnects and the primary voice requirements for information exchange between unskilled operators using the land telephone network forced the selection of high-quality standards. (See Table 2.)

B. Technical Parameters

As a necessary prelude to assessing the economic viability of a maritime satellite system, engineering tradeoffs were made to define the "optimal" system configuration to meet the operational requirements. Not surprisingly, the flexibility available in satisfying the link equations allowed for a large number of alternative system solutions. For example, although both dedicated satellites and multi-purpose satellites were separately evaluated, it was found that selection of either alternative could only be made on an economic or operational basis. A Thor-Delta rocket was assumed as the dedicated launch vehicle. The leading parametric variable remains the shipboard terminal "figure of merit" (G/T), which may technically and economically range from -1 db/K to -10 db/K with a corresponding impact on system capacity. The antenna, the receiver preamplifier, and the output power amplifier are the components which vary significantly with cost. Within the twin constraints of severe power shortages in the satellite-to-ship link and of terminal size limitations on the vessel, the design must aim for maximum antenna gain, receiver sensitivity, and output EIRP consistent with economy. In the final analysis, it was found that terminal costs increased only 21% in this G/T range while offering an eight-fold capacity increment. (See Table 1.)

To conserve satellite prime power, cross strapping from L to C or X band was assumed for the satellite-shore links. Propagation effects on system margin are believed to be relatively inconsequential at L-Band frequencies, but a generous net loss of 4 db was assumed in the absence of quantitative measurements.

In general, the description of technical parameters aimed for a conservative design, using today's state-of-the-art in aerospace and electronic components. Where significant advances in technology could be confidently forecasted as available in a 1977 time frame, these were factored into the analysis. For example, the issue of body vs spin stabilization has been left open as has the choice of optimum modulation techniques, since intensive developmental work can be expected during the intervening period. Most importantly, from a conceptual viewpoint, it was recognized that this preliminary technical specification would remain highly speculative and could only be fixed when the confluence of technological factors, coupled with economics and traffic requirements, had become clearer. (Table 3 lists tentative technical parameters.)

Table 1 Ship terminal costs

Ship terminal G/T, db/K	Antenna diameter, meters	Transmit power, watts	Receiver noise, db	Cost 1974$[a]	Cost variation %	Cost 1979$[b]	Satellite capacity variation
−10	0.9	25	6.0	$28,500	base	$40,000	base
− 7	0.9	25	3.5	29,000	1.75	40,700	×2
− 4	0.9	25	1.5	31,500	10.5	44,200	×4
− 1	1.2	12	1.5	34,500	21.0	48,400	×8

[a] Delivery and installation costs not included.
[b] Delivery and installation costs and inflation included.

Table 2 Marsat operational requirements

Size of participation	200 ships initially. Annual increment of 400 ships to a final population of 7000 ships in year 14.(50% of all ships above 10,000 grt.)
Numbers of channels (Atlantic Ocean. Pacific and Indian Oceans are half each)	1) telephone and wide-band: year 7-19, year 14-70. 2) telegraphy and narrow-band: year 7-17; year 14-65. Assumes 6% yearly growth in base telephone/telegraph daily usage of 6 min. and 5 min./day respectively.
Quality of service	1) telephone—0.8 articulation index for 99% of time. 2) data—10^{-5} uncoded bit error rate for 99% of the time.
Coverage	70°N to 70°S—continuous; 72° to 82°, N&S—as possible.
Connectivity	Interconnection to direct dial public network to CCITT standards.

Table 3 Tentative technical parameters

Orbit	geosynchronous with low inclination (±5°)
Launcher	Thor Delta 2914 or 3914
Satellite characteristics	
1) number of satellites (7 y life)	4-7 (dependent upon failure rate, spares philosophy) single beam, earth coverage
2) antenna	
3) eclipse capability	1 voice channel
4) channel capacity	14-160 (dependent on stabilization, ship G/T)
Shore terminal characteristics	
1) G/T	30-35 db-K (11-1420-25 db-K (4-6 GHz)
Ship terminal characteristics	
1) G/T	-10 to -4 db-K
2) EIRP	31 to 37 dbW
Accessing	FDMA probable in both directions

Table 4 Dedicated system costs as a function of ship G/T

G/T (db-K)	Earth and space system costs ($M)	Ship terminal costs ($M)	Total costs (1979) ($M)
-10	402	184	586
- 7	364	187-192	551-556
- 4	322	202-212	524-534

C. Economic Analysis

Beginning with the assumed traffic levels and the tentative technical parameters, an extensive analytic effort was undertaken to evaluate the economic viability of a maritime satellite system. A cost/benefit analysis was particularly desired, but was not practicable in view of the lack of agreed measures of benefit. However, in earlier studies by the Maritime Administration, expected annual savings of $117,000 to $468,000 per ship had been forecast.

Several computer models were developed to explore the full range of alternative system solutions. Three basic approaches were considered: a) A satellite system exclusively for maritime use; b) A multi-purpose system based upon shared use of INTELSAT-V capacity by both maritime mobile and fixed satellite services; c) A "hybrid" system shifting from initial multi-purpose to dedicated satellites as traffic load increases.

The primary input variables were needed capacity (±25% from the nominal traffic levels noted earlier), revenues as a function of user charges ($4/min for both telephone and telegraph services as base case) and ship terminal "figure of merit" (−10 db-K to −4 db-K). Additionally, since all comparisons would be made on a present value basis discounted at 10% or 15%, numerous deployment philosophies were tested by assuming phased introduction of service, variable failure rates, in-orbit vs ground spares, and different satellite constellations. Earth stations, which will be the property of the countries belonging to the organization, were not considered, nor were the costs of the ships' terminals, in computing the break-even points.

From a business viewpoint, the results were not particularly encouraging. At the base charges for services, the dedicated system would remain unprofitable through its first 14 yr of operations. Increasing the charges to $8 and $4/min for telephone and telegraph, respectively, yields a break-even point at 10 yr. Further, assuming inelasticity of demand, the variable factors of discount rate, phasing of service or adoption of the hybrid or multi-purpose approach do not materially shift the break-even point. The best improvement in system economics is achieved by the use of high quality ship terminals. Table 4 shows that the cost of increase in G/T for 7,000 terminals is more than offset by the corresponding decrease in required space segment cost.

Although the studies seem to indicate that economic success is heavily dependent on good levels of message traffic at fairly high charges, certain factors tend to add some optimism to the figures. Firstly, the use of satellite communications may well augur a revolution in fleet management methods and procedures. Today's communications are at best inefficient and haphazard, with the dramatic quality improvement expected to substantially increase the desire and necessity to communicate. Secondly, many countries view satellite communications as an essential adjunct to the vital business of shipping, and are prepared to underwrite the losses which may be incurred in the early years of system operation in the overall national interest. Table 5 recapitulates the anticipated costs and technical parameters of the dedicated and multipurpose systems studied.

Table 5 Comparison of dedicated and multi-purpose satellite system costs

	1	2	3	4	5	6	7	8
				Ship Terminal				
	Channel requirements	Class of satellites	Cost[a] space segment (1979) ($M)	G/T (db-K)	Total investment cost over 10 yr (1979) ($M)[b]	Total operating cost over 10 yr (1979) ($M)[b]	Overall ship terminal cost; present value over 10 yr (1979) ($M)	Cols. 3 + 7 (1979) ($M)
1	52 db-Hz 40 channels per satellite	TD 2914 spin stab.	314	- 7	87-89	51-53	138-142	452-456
2	52 db-Hz 40 channels per satellite	TD 2914 body stab.	289	-10	86	50	136	425
3	52 db-Hz 40 channels per satellite	TD 3914 body stab.	338	-11	86	50	136	474
4	52 db-Hz 40 channels per satellite	Atlas-Centaur INTELSAT V, TDMA Model	117/314	- 2[c]	97-103	57-61	154-164	271/468-281/478
5	52 db-Hz 40 channels per satellite	Atlas-Centaur INTELSAT V, FM Model	206/314	- 2[c]	97-103	57-61	154-164	360/468-370/478

[a] Includes land earth stations.
[b] Assumed to be approximately 15% per annum of initial investment.
[c] The related operational antenna gain is approximately 25 db, which is not easy to realize on board ships.

D. Institutional and Organizational Matters

Whereas the operational, technical, and economic facets of maritime satellites lend themselves to ease of analytic manipulation, the issues of system ownership and operation are not readily amenable to compromise agreement. As noted previously, basic philosophical differences remain between nations as to the need for and functions of a maritime satellite organization. Many countries apparently favor the creation of a new Inter-Governmental Organization, whose primary function would be that of policy and financial control of the use of the space system. During Panel discussions, the United States remained unconvinced that any new organization was needed, believing that lengthy negotiations and serious delays would be thereby incurred. As alternatives to it, several candidates were offered for further study. A non-Governmental Consortium, open for membership to all designated telecommunications entities, was rejected by the Panel because it was felt that policy control of a global satellite system should be exercised by an Inter-Governmental Organization. INTELSAT was considered acceptable as a provider and/or manager of maritime satellite system under the control of the Inter-Governmental body. However, its lack of membership by some major maritime countries, especially the USSR, coupled with its assumed lack of responsiveness to maritime requirements, were alleged to be insuperable difficulties if relegation of financial and policy control were contemplated. A final proposal to establish a suborganization within IMCO met with little enthusiasm; most Panel members felt that inclusion of a telecommunications body would tend to either derogate the effectiveness of IMCO in promoting maritime safety, or else would result in insufficient attention being paid to the important needs of international maritime satellite communications.

After considerable review, the Panel proceeded on the assumption that a new organization offered the only viable approach to satisfying all requirements. With this basic concept established, attention then was given to the organizational details which would govern the new International Maritime Satellite (INMARSAT) Organization. Although there is some disagreement on the scope of such an organization, there is a general consensus that it should limit itself to an overview role, assigning day-to-day responsibility to a system manager as its agent for space segment control and operation. It would be empowered to own or lease satellite capacity, dependent upon the economic attractiveness of either alternative. Membership in the organization would only be open to States, but each could designate an entity (PTT, Common Carrier, etc.) to act in its behalf. Financial liability would be an ultimate responsibility of the member States. The structure would be quite similar to that of existing UN specialized agencies, composing a Council (executive body), Assembly of all Parties (legislative and broad policy decisions), and Directorate (organizational routine, responsible to Council). Ships of all nationalities would be able to use the system, but only members of the organization could own the earth stations.

The United States participated fully in the Panel of Experts, but consistently reserved its position as to the presumed need for a new organization. Nonetheless, certain basic principles examined in the organizational details were deemed of such intrinsic importance to the U.S. that their exclusion from a Convention might make it unacceptable, assuming a new organization was found necessary. Among these were the rights of a government to designate an entity as its representative, the allocation of investment shares based on actual space segment utilization by land stations as opposed to other criteria, the award of procurement contracts based on open international bidding, and the right of nondiscriminatory access to the system by all Flag States' ships. Some of these points have been incorporated into the draft Convention, but contention remains as to the most appropriate measurements of space segment utilization and as to the need for production sharing or other form of restricted competition in procurement. Further, while the concept of entity representation has been agreed, the division of responsibilities between a Government and its entity is open to diverse interpretation.

IV. Future Activities

Assuming INMARSAT becomes a reality, the future growth of satellite communications will be entrusted to it. New services can be expected in second-generation systems, with software integrations to the existing ship terminals to provide enhanced utility. Emphasis will be given to the development of low-cost equipment for smaller ships, since these represent the only source of additional marketing opportunities (100,000 ship total by the year 2000). Telecommunications automation will be stressed; if through-dialing is not available initially, a short-term goal of the organization will be to provide this capability. Navigation and surveillance functions will become increasingly important for their potential effectiveness in improving ship safety and productivity. As usage of the system spreads, it will be necessary to give study to the role of satellites under the provisions of the Safety of Life at Sea (SOLAS) Convention. Possibly, removal of all presently required MF/HF equipment would be permitted if equivalent safety facilities were available in the satellite system. This might be accomplished through a provision for the use of portable, low power emergency position-indicating radio beacons (EPIRB) operating through a satellite relay.

In the long term, coverage of polar areas will be needed, particularly for the Arctic. Further, assuming that the technical and operational difficulties can be resolved, deployment of a joint aeronautical/maritime satellite system may be desirable for efficient utilization of earth stations and spacecraft.

V. Conclusions

As this paper shows, the evolution of maritime satellite communications is very much in a state of flux. Although the technical and operational factors are fairly well understood, there are lingering concerns over the economic viability of the system and over the management arrangements which should be adopted. Further, the conceptual development to date has taken place in an environment relatively free from political considerations. In the Conference, it is possible that technical criteria may diminish in importance, particularly in view of the growing political importance and solidarity of the Third World Countries in Inter-Governmental forums. At any rate, it is likely that the final form of operational maritime satellite systems may remain cloudy for some time, with the experience gained in the MARISAT/MAROTS programs offering substantial new insights into the most appropriate future direction of evolution.

Editor's Note: Forty-three countries were represented at the Maritime Satellite Conference in London, from April 23 to May 9, 1975. While there was substantive discussion there of all the points described in the paper, the Conference was only able to reach agreement on the need for a worldwide maritime satellite system and on the desirability of an international organization to administer and manage the system. Some of the thornier issues that remain to be resolved are the rights and obligations of a telecommunications entity designated by its Government to participate in the system, the distribution of powers between the Assembly and the Council of INMARSAT, the policy on restricted or open procurement, the question of initial investment shares and the manner of determining final investment shares. Further, one major country (USSR) is still not prepared to accept completely the concept of a designated entity. An encouraging note was the recommendation from the Conference that ships be permitted to use their communications terminals in port and in territorial seas, which should provide a powerful incentive for the fitting of the equipment by merchant vessels. In recognition of the need to progress toward agreement, an Intersessional Working Group has been formed to study these questions and to make recommendations concerning them to the next Conference session. That next session will meet in London again, from Feb. 9-27, 1976.

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