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Complementary Satellite Sound Broadcasting Systems—A NASA Assessment for the Voice of America

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COMPLEMENTARY SATELLITE SOUND BROADCASTING SYSTEMS -

A NASA ASSESSMENT FOR THE VOICE OF AMERICA

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Abstract

Satellite concepts are examined which can offer potentially significant sound broadcast coverage of audio as a complementary system to the Voice of America's existing and planned terrestrial sound broadcasting system. HF frequency bands are emphasized but additional discussion is included for systems which would use higher frequencies. It is shown that low altitude satellites, shuttle altitude (275 Km) and sun synchronous (about 1600-1800 Km), would not be practical for international broadcasting as many satellites would be needed for reliable and widespread coverage. Two concepts are discussed which would offer significant and practical broadcast coverage at HF. One, an 8 hour posigrade equatorial orbit, would offer about 1 hour of widespread, twice daily, coverage to three areas of the globe. The time of coverage is even greater when confined to densely populated areas only (about 2-3 hours). Another orbit, the Apogee at Constant Time/Equatorial (ACE), provides about the same coverage as the 8 hour orbit, but only once daily to each area. This latter orbit is highly elliptical, which allows the insertion of a greater payload (more broadcast channels) with the existing launch capability. For comparison purposes, it was found beneficial to compare system life cycle costs on the basis of costs per channel of a typical VOA Coverage Area. Making use of this method, the ACE and 8 hour orbit concepts led to systems of about equal costs, with the ACE being slightly better. For a twenty year life cycle, this amounted to about $175M per channel per million square miles of coverage (typical of VOA coverage areas). The use of higher frequencies such as L-band at 1.5 GHz, would reduce costs significantly to about $52M per channel per million square miles.

A hybrid satellite system is recommended which would carry both HF and a higher frequency payload (either L-Band or Ku-Band). The HF payload would be designed to provide acceptable quality broadcasts to rural or residential areas (primarily to developing nations), and the higher frequency payload would be designed to provide coverage to urban and residential areas (primarily in developed nations).

REQUIRED COVERAGE AND BROADCAST SCHEDULE

To initiate the development of complementary sound broadcasting satellite concepts, it was necessary to identify potential coverage areas and broadcast schedules that would meet the criteria of a supplementary system. Two such broadcast scenarios were provided to NASA by VOA.

These scenarios were further processed by NASA to generate an aggregate zoned scenario, more suitable for determining satellite requirements. Broadcast scenario #1 is repeated in Table 1, alphabetically by language. Table 2 is a similar listing of scenario #2. The region codes are used as keys to locate the broadcast areas within the 15 broadcast zones defined in the previous studies done for VOA (References 2,3,4). These zones are illustrated in Figure 1. The result of this aggregation of broadcasts is given in Tables 3 and 4 for scenarios #1 and #2 respectively. For each zone the number of broadcasts are tabulated at 30 minute intervals. The peak of 2 channels occurs for scenario #1 in zones 5, 6, and 7. For scenario #2, a peak of 3 channels occurs for zone 7 between 600-630 UTC. With a slight rescheduling of broadcast times, this latter peak can be reduced to 2 channels.

To evaluate the utility of various orbits in meeting these schedules, it is convenient to display the broadcast schedule by zone as in Figure 2. The schedule shown corresponds to scenario #1. Each broadcast interval is a composite of all broadcasts provided within the zone but not necessarily to be provided to the entire zone. As a result, somewhat pessimistic satellite size and power requirements will result.

The selection and ordering of the zones as in Figure 2 produces a display which nearly corresponds to increasing easterly longitude as one progresses from zone 1 to zone 15.

The broadcast times shown are approximately within local prime time hours of 6-8 AM and 6-12 PM. Progressing from left to right, broadcasts begin at 0 Hrs UTC within the Americas. This corresponds to local late evening hours for these zones. Three hours later, broadcasts are directed to Europe, North Africa, Africa, and the Mideast (zones 5, 6, 7, and 8) during local morning hours. Eight hours later, broadcasts are directed toward Central USSR, India/Pakistan/Bangladesh, Eastern USSR, and East/Southeast/Asia and Japan (zones 10, 11, 12, 13, and 15) during local evening hours.

An ideal satellite system would provide satellite visibility to each region at precisely the times indicated. For geostationary satellites, this is obtained by definition (24 hr visibility is obtained). However, this orbit was shown by MM and TRW (References 2,3) to be practical only for the higher frequency bands (L-band and Ku-band). At HF the satellite mass and power is such that only lower satellite orbits can be supported in the foreseeable future (approx. 13,900 Km and below, corresponding to 8 hour orbit periods and less). For these medium altitude orbits, precise multizone coverage is impossible without making use of multiple satellites and, possibly, multiple orbit planes.

In the complementary satellite systems to follow, their potential for meeting the desired supplementary broadcasting scenarios will be evaluated.

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GLOSSARY OF TERMS AND ACRONYMS

ACE - Particular orbit discovered by Ford Aerospace and Communications Corporation. It is highly elliptical, in the equatorial plane, and has the property that it is triply synchronous (earth, sun, and time-of-day).

AKM Rocket motor used for final orbit insertion at apogee.

AMS A Brand Name Bipropellent manevering rocket or orbit transfer vehicle.

AMSAT American Amateur Satellite Corporation

AOS Aquisition of signal from a spacecraft based on a line-of-sight path.

Ch-MSQM Capacity parameter referring to the product of the number of broadcast channels and the combined area of coverage in millions of square miles.

Ch-Beams Or Channel-Beams. Also a capacity parameter. Except here, we refer only to the number of beams without consideration of the geographical area of coverage.

DBS Direct Broadcast Satellite (Sound).

DBSTV Direct Broadcast Satellite (Television).

DBW Power expressed in decibels above 1 watt.

DBu Field strength expressed in decibels above 1 microvolt/meter

DSB AM Double sideband amplitude modulation.

EIRP Effective radiated power relative to an isotropic source.

GEO Geostationary orbit.

GHz Frequency in gigahertz.

Hrs Time in Hours.

KHz Frequency in kilohertz.

Ku-Band The frequency band near 12 and 14 GHz.

L-Band The frequency band near 1.5 GHz.

LCC Life cycle cost.

LOS Loss of signal referred to a line-of-sight path (satellite below the horizon)

LOTUS 123 Commercial integrated spreadsheet.

MHz Frequency in megahertz.

MSQM Millions of square miles.

OTV Orbital transfer vehicle. An autonomous, but controlled small rocket for manevering satellites already in orbit.

Posigrade An orbit in which the satellite moves in the same direction as the rotation of the earth.

RAAN Right ascension of the ascending node. An orbit parameter which describes the orbit geometry in inertial space.

S-Band The frequency band near 2.5 GHz.

SSB AM Single Sideband amplitude modulation.

STS Space Transportation System.

SVBS Satellite voice broadcasting system.

Sunsynchronous A satellite orbit which moves in inertial space in a way which maintains a fixed geometry with respect to the sun.

UTC Universal Coordinated Time

uv microvolts.

INTRODUCTION

The number of international broadcasters has grown dramatically since World War II. In 1983 there were about 1,600 transmitters worldwide, with about 28 percent of these rated at 200Kw or higher. These transmitters generally operate in the MF to HF frequency range and primarily make use of DSB AM modulation. Recent developments in technology are encouraging transition to SSB modulation (Reference 1).

International broadcasting can span distances of 2,000 Km and greater in some instances. To span such distances, it is necessary to use some means of altering the radio path from line-of-sight propagation, as such service areas would be beyond the horizon. Often, broadcasters will make use of the refracting properties of the ionosphere (at about 300 - 400 Km altitude) to refract radio waves over the horizon. An alternative method, and the subject of this report, is to use satellites to relay broadcasts beyond the horizon.

Previous studies have been performed which evaluated potential satellite scenarios which could replace one entire terrestrial broadcasting network (References 2, 3). Because of the large number of broadcast channels required and the large geographic areas to be covered, these satellite systems were very complex, consisting of 10's of satellites each, with individual satellites having very large power systems and using large antennas. As a consequence, these systems were too expensive to be practical.

Complementary systems which offered supplementary coverage to existing terrestrial systems were given a preliminary evaluation in a previous NASA report to the Voice of America (Reference 4).

The purpose of these systems would be to complement the existing terrestrial system by providing coverage to remote areas and to provide immediate coverage to new areas not covered by the existing terrestrial system. Also, they could be used to introduce broadcasting service in new bands not provided by the terrestrial system. For example, the recent trends in Ku-Band DBS broadcasting would suggest a potential audience eventually at those frequencies. In addition, satellites would be well suited for introducing alternative modulation formats such as FM or advanced digital types. Ultimately, they could be used to introduce TV to international broadcasting.

The purpose of this study is to evaluate and recommend operational scenarios for small complementary satellite systems (preferably one, but no more than a few satellites per system) at HF. In addition, a suitable experimental satellite configuration will be derived from these evaluations and recommended as a suitable precursor system. Finally, higher frequency satellite systems will be briefly evaluated as possible means of introducing very high quality sound broadcasting (as in existing FM systems) to the international arena.

POTENTIAL COMPLEMENTARY SATELLITE SYSTEMS

Low Altitude Systems

The Space Transportation System (STS) has a nominal lift capability of 30,000 Kg into a 275 Km circular orbit which is inclined 28° with respect to the equator. This capability must be derated for other inclinations due to expenditure of fuel for orbit modification. Further reductions must be made if higher altitudes are desired. Consequently, the greatest amount of useful hardware can be placed into the nominal STS orbit and steadily diminishes with increases in altitude. Therefore, it was of interest to examine parameters of conceptual broadcast systems that might make use of altitudes between 300 - 2,000 Km (The region between 2,000 - 10,000 Km is the core of the lower Van Allen Radiation Belt. Severe radiation hardening penalties, in terms of shielding mass, must be paid to operate solar power systems in this altitude range. Consequently, these altitudes are not attractive for sound broadcasting).

Shuttle Altitude -

The shuttle parking orbit is nominally about 275 Km. Considerable areas of the earth can be seen from this altitude and it is the altitude of greatest payload capability for the shuttle. This would therefore be of obvious interest as a possible orbit altitude for a broadcasting satellite system.

The attached Figure 3 is an orthographic view of the contours of visibility for a 275 Km orbit. Each contour corresponds to the position of an observer to whom the satellite would appear to be at an angle of 10° above the horizon. Each contour is drawn at 5 minute intervals. Since the succeeding contours do not overlap, there would be nowhere where one would observe the satellite for 5 minutes (at an elevation angle of 10° or more). It should be noted that these contours are drawn ignoring the effects of the ionosphere on HF propagation. In reality, refraction and reflection may enhance the coverage area significantly. At the time of this writing we had not explored the use of analytic techniques to account for these effects, as this was not included in the original scope of work to be done. However, recognizing that such effects lead to "over the horizon" propagation, an additional simulation was performed to evaluate the feasibility of incorporating such effects. Figure 4 is a similar view of the contours of visibility from the same 275 Km orbit. However, in this case an elevation angle of -10° is represented. This corresponds to the observer looking through the earth in an optical sense. But it could also correspond to an observer looking at the horizon or above with a refracting atmosphere and ionosphere. Significantly larger visibility zones are shown in this case. However, it is not known how accurate this representation may be. This is an intriguing technique but was not pursued further as work in other tasks were more pressing.

In the previous NASA Synthesis Report (Reference 4) it was shown that reliable worldwide coverage from such an orbit would require an unacceptably large number of satellites to achieve (in the hundreds). Even, as in the case here, where only limited coverage would be of interest, the number of satellites would be large and the duration of each over a target area would be small (typically 2-3 minutes). Consequently, this option for a complementary system was dropped from consideration.

Sunsynchronous Altitude -

Figure 5 provides an orthographic view of the visibility contours for a sunsynchronous (1800 Km) orbit. This orbit has the advantage of having a ground track that is synchronous with the sun and therefore always appears at the same time each day (does not experience the 4 minute sidereal shift which was so prevalent in the previously studied concepts). These contours are shown at 10 minute intervals. Note there is a considerable overlap of succeeding contours as they progress from south to north. The overlap area would indicate that observers anywhere within would see the satellite for at least 10 minutes at an elevation angle of 10^{o} or higher. No overlap occurs at 20 minutes. Therefore the maximum visibility time would be somewhat less than 20 minutes and very close to that amount directly underneath the satellite. Contours are also shown for a second satellite pass 2 hours later. Of course the earth has moved to the east 30^{o} but, because we have chosen to use earth as an inertial reference, it appears that the satellite orbit has moved. After 24 hours the satellite will appear to return to the same contours shown here. Actually, the orbit is designed to take advantage of the equatorial bulge of the earth to force the orbit to slightly precess about 1^{o} each day so that it exactly tracks the position of the sun. Consequently, it always will appear at the same local time each day. This synchronization with the sun can be used to advantage. For example, each of the contours shown in Figure 5 could represent a separate satellite view with each satellite spaced at 10 minute intervals (12 satellites to circumscribe the earth). In this instance, continuous coverage could be achieved by switching to adjacent satellites as they pass over. The overlap shown for succeeding orbit passes indicates that about 2 hour coverage of two adjacent time zones could be achieved in this way. Of course, accounting for refraction effects, the coverage could be significantly better.

Because of the large number of satellites required for reliable and regular coverage, this orbit was also dropped from further consideration.

Medium Altitude Systems

Figure 6 illustrates the typical geometry for providing earth coverage by medium altitude satellites. The scale corresponds to that of an 8 hr orbit and an inclined plane is shown to illustrate the concepts to be discussed below. The reader should picture himself in the position of the sun looking outward toward the earth. The earth will be spinning about its axis from left to right while, at the same time, passing from right to left in its orbit. A posigrade satellite orbit is illustrated so that the satellite will progress about its orbit in the same direction as the earth's spin.

Where the satellite orbit plane crosses the equatorial plane (plane of the earth's equator) is designated the ascending node or descending node, depending on whether the satellite is progressing northward or southward respectively. Generally, satellite orbits are controlled so that the ascending node is fixed with respect to the stars (in some special cases this is allowed to vary to meet special requirements or where drift in ascending node is not important). The satellite shown is located over the demarcation zone of the earth's shadow which corresponds to a local time of 6:00 AM.

As the earth progresses in its orbit from right to left, the line from the earth center through the ascending/descending node of the satellite orbit will gradually drift to the left also, beginning to point away from the viewer. After 91 days the descending node will appear to point away from the viewer to the left at an angle of 90 degrees. This is due to the fixed pointing of the node line while the earth has moved 90 degrees in its orbit. Assuming the satellite has an orbit period which is a submultiple of the 24 hr day, it will always return to the same relative position with respect to the sun each 24 hours. However, since the orbit plane remains fixed with respect to the stars, this recurring sun reference of the satellite will place it at the descending node after 91 days. Clearly, the 6:00 PM visibility of the satellite from the northern latitudes will have decreased in this interval.

In previous studies done for VOA (References 2,3), this sunsynchronous condition was not evaluated. Instead, the satellite orbit period was selected to be a submultiple of the sidereal day (23 hours, 56 minutes spin period of the earth) so that the satellite would be synchronous with the earth. This had the advantage of maintaining the same orbit groundtrack on the earth. In our illustration this selection would mean that the satellites would always repeat the same relative positions shown every 23 hours and 56 minutes. Hence, the satellites would always appear at the positions shown but, due to the rotation of the earth about the sun, they would have different orientations with respect to the sun and, therefore, appear at progressively different times. This is the 4 minute sidereal shift which was so prevalent in the orbits examined in earlier studies for VOA.

The sun has an apparent motion of 24 hours about the earth and would appear to move opposite to the motion of a posigrade orbiting satellite. If we require the satellite to repeat its same relative position with respect to the sun each day, it must have an apparent period which is a submultiple of the 24 hour period of the sun. This apparent period of the satellite is not the same as the sidereal period of the satellite and it is the sidereal period which is used to define the satellite orbit. Therefore it is necessary to convert the apparent period to the sidereal period before we can determine the necessary satellite altitude.

Figure 7 is a representation of the two motions as seen by an observer on the earth. S represents the sun which appears to move clockwise at 1 revolution per day. B represents the posigrade satellite which moves in the opposite direction at W_d apparent revolutions per day. This apparent motion is relative to the earth and is given by:

$$W_d = W_s - W_e$$

where both W_e, the sidereal rate of the earth, and W_s, the sidereal rate of the satellite, are with respect to the stars (inertial space). The relative period T_d is given by:

$$T_d = T_e/(T_e/T_s - 1)$$

For a particular apparent period T_d, the inertial period T_s is therefore given by:

$$T_s = T_e/(T_e/T_d + 1)$$

As examples, the following cases are given:

Parameters of Several Posigrade Orbits

T_d, Hrs	T_s, Hrs	H, Km
24	11.9836	20,207.84
12	7.9927	13,916.91
8	5.9959	10,377.61

Note from these that when we refer to an 8 hour orbit we are referring to the approximate sidereal period, not the apparent period. For from the above table, our 8 hr (7.9927) sidereal period posigrade orbit has an apparent period of 12 hours and a 6 hr (5.9959) sidereal period has an apparent period of 8 hours.

Then, in 91 solar days (time required for the earth to move approximately 90 degrees around the sun), the 8 hr satellite will go through:

$$91 \times 24\text{hours}/7.9927 \text{ hours} = 273.25 \text{ orbits}$$

the 0.25 orbit is exactly 90 degrees which enables it to precisely compensate for the motion around the sun and therefore maintain its relative position with respect to the sun. In addition, the target beneath the satellite will undergo:

$$91 \times 24 \text{ hours}/23.9345 \text{ hours} = 91.25 \text{ rotations}$$

and therefore also maintain the same relative position with respect to the sun and with respect to the satellite. Hence, the satellite always repeats the same longitude at the same local time each 24 hours.

Two orbits were considered which could make use of these sun synchronous properties. The use of these and certain modifications are discussed below.

8 Hour Posigrade Equatorial -

Figure 8 shows the 10° elevation contours for an 8 Hr posigrade equatorial orbit. The contours are shown at 2 Hr intervals. The overlap areas indicated where observers would have at least 2 hours of visibility with the satellite at 10° elevation or better. Note that this coverage extends to about 55° north latitude. With proper selection of orbit parameters (through appropriate launch times and minor orbit adjustments with small thrusters), this satellite can be made to appear the same time each day over any three spots of the earth (separated by 120° of longitude). For these spots, coverage would span about 60° of longitude and 110° of latitude. Of course the satellite would also be visible to other areas of the earth, but at a different time of day. Prime time coverage would be available to only 3 areas. With two such satellites nearly complete equatorial prime time coverage could be achieved.

Such an orbit could be also be inclined to the equator without losing the synchronous property with the sun. This would enable higher latitudes of coverage. However, even though the satellite would appear at the same longitude at the same time each day, it would not have the same latitude each day. Consequently, it would appear to gradually swing north and then began to swing south and possibly be below the horizon for the northern latitude observers. The visibility contours for this orbit are shown in Figure 9. The contours are shown at 1 hour intervals. Similar contours were provided by TRW and MM as part of their orbit simulation work (References 2,3). However, their orbits were made to be geosynchronous and consequently would repeat the coverage shown every 24 hours. In this latter case, the satellite being sunsynchronous, an exact repetition of coverage would not occur. The coverage shown would appear to gradually drift about 1° each day, following the apparent motion of the sun.

Figure 10 shows a superposition of the broadcast schedule of Figure 2 and the time of visibility realized for each zone with a satellite in an 8 hr posigrade equatorial orbit. With the satellite orbit plane being within the equatorial plane, and the altitude being only 13,900 Km, the extreme latitude zones (5, 9, 10, 12, and 14) cannot be fully covered. Note also that coverage of zone 3 (South America) is also quite limited due to portions of land area being so far south of the equator. However, for most of these zones, significant coverage is obtained with up to 2.8 hours of visibility being achieved (for East/Southeast Asia).

The period of this orbit has been selected to be an exact submultiple of 24 hours so it always maintains synchronization with the sun. Consequently, it will always pass over selected target areas at the same local time each day. However, times do not necessarily correspond to local prime times (6-8 AM and 6-12 PM). One additional satellite, with suitable starting orbit parameters, would be needed so that the combinations would achieve prime time coverage for all visible zones.

The more extreme latitudes can be made visible only by inclining the orbit plane with respect to the equator. Figure 11 shows the visibility times for an 8 hr posigrade orbit which is inclined 28°. Note that coverage of every zone is achieved at least once per 24 hours, although not necessarily at the desired scheduled times. As with the equatorial orbit, selection of suitable orbit parameters can be made such that the inclined orbit will achieve coverage at other times. Figure 12 shows the visibility achieved with the same 28° inclined orbit, but with the satellite starting position shifted by 90° in longitude. Note the shift in coverage achieved for zones 11, 12, 13, 14, and 15. However, with this starting condition, many of the other zones no longer have coverage at the appropriate times. This suggests two satellites are needed in the same orbit plane, one 90° behind the other, to provide the required coverage.

Having a second satellite in the same orbit plane would not necessarily be an excessive penalty. A backup satellite would ordinarily be present anyway. One would simply make use of the backup to provide portions of the coverage. In the event of a satellite failure, the remaining satellite could easily be positioned to minimize the loss in coverage. This repositioning would require little propulsion resources because both satellites would be in the same orbit plane.

Adding additional orbit planes can also increase coverage significantly. For example, the inclined orbit, Figure 11, provided coverage only once per day for several zones; whereas the equatorial orbit, Figure 10, provided twice per day visibility to all zones that were visible. This is the penalty paid for inclining the orbit plane as the satellite will spend equal amounts of time in the southern hemisphere as in the northern hemisphere. By using two inclined orbit planes 180° apart in right ascension, complementary coverage can be achieved where at least one satellite will be in each hemisphere at any time. Figure 13 illustrates coverage achieved by an inclined 8 hr orbit plane rotated 180° from that of Figure 11. Note that the coverage is exactly the mirror image of Figure 11.

Figure 14 compares the properties of the solar synchronous and sidereally synchronous types of orbits. The earth's orbit around the sun is illustrated as well as that of two satellites about the earth. The earth is shown at approximately 91 day intervals around the sun. The time at each position is selected so that there is an integer number of solar days between them. The sidereally synchronous satellite orbit, indicated by the blank circle, is synchronous with the 23 hour 56 minute spin rate of the earth. This orbit has the advantage of always repeating its ground track on the earth, and thus, passing over the same target each day (in both longitude and latitude). The solar synchronous orbit, indicated by the filled circle, is synchronous with the apparent 24 hour motion of the sun. It therefore has the advantage of passing over the same longitude at the same time each day. However, it will not necessarily pass over the same latitude unless the orbit plane lies in the equatorial plane.

Also indicated is a reference target on the earth. At the bottom of the illustration we show both satellites and the target area as aligned and positioned at local morning hours (6:00 AM). Ninety-one days later the earth will have moved about 90° around its orbit. By definition, the earth will have experienced 91.25 revolutions so that the target will again appear at the same relative sun position of 6:00 AM local time. The solar synchronous satellite will have undergone 273.25 revolutions of its orbit. As planned, it also appears at the same relative sun position at 6:00 AM and over the same target. The sidereally synchronous satellite, on the other hand, will have undergone 273.75 revolutions (having a period of 7.9778 hours) and will appear 180° from the target area and at the 6:00 PM sun reference position.

The plane of the satellite orbit is assumed to be inclined at 28^{o} with respect to the equator. At the beginning position, the ascending node, descending node, and the sun are on the same line in the ecliptic plane. The portion of the orbit plane to the right of the earth is out of the page and covers the northern latitudes. The position of the satellites is therefore over the northern hemisphere. As explained above, after 91 days the target area will appear rotated 90^{o} so that it appears at the same relative sun position. The solar synchronous satellite will do the same. At this position, however, it will be at the orbit descending node and therefore will appear at a lower elevation to viewers in the northern latitudes. After 91 additional days, it will progress to maximum south latitude and will no longer be visible by some areas in the northern hemisphere at 6:00 AM.

The sidereally synchronous satellite, having a period (7.9778 hr) which is a submultiple of the 23 hour, 56 minute spin period of the earth, rotates 270^{o} in the same time the earth rotates 90^{o}. Consequently, at the 91 day position, the sidereally synchronous satellite would have passed over the target at about local midnight. Note that this overflight occurred at the maximum northern latitude as in the starting condition. However, it occurred 6 hours earlier in the day, corresponding to about 4 minutes per day shift.

Consequently, orbit physics constrains us to two choices for an inclined orbit: (1) a sidereally synchronous orbit, providing overflights of the same longitude and latitude each day, but having the disadvantage of a 4 minute shift in time of appearance; and (2) a solar synchronous orbit providing overflights of the same longitude at the same local time each day, but having the disadvantage of varying satellite elevation.

The impact of this satellite elevation change on visibility can be seen by comparing Figure 11 with Figure 15, which shows visibility for the 8 hr, 28^{o} inclined solar synchronous orbit 91 days later. Comparison will reveal there has been major time shifts of visibility times for some zones (especially compare for zones 1, 9, 10, 11, and 12).

One can either accept these time shifts or compensate by adding additional orbit planes and satellites. Figure 16 suggests one geometry for compensation. Two satellites, each in separate orbit planes with ascending nodes 90^{o} apart, are synchronized so that both appear at the same target longitude at 6:00 AM each day. Then as the earth orbits about the sun, the 6:00 AM position of satellite #1, shown at maximum north latitude, proceeds toward its descending node. At the same time, the 6:00 AM position of satellite #2 will proceed toward maximum north latitude. In this way, one satellite will enable additional coverage which will compensate for the loss of coverage for the other. Of course, as one goes beyond 91 days, the 6:00 AM position of satellite #1 will proceed further south, reaching maximum south latitude in 182 - 183 days. Satellite #2 will have progressed past maximum north latitude and returned to the equator. At first sight, it would appear from this that satellite #2 will not be in a position to compensate for the loss of coverage of satellite #1. However, there has actually been very little loss in coverage for satellite #1, as is shown in Figure 17. The reason the loss is small is that the satellite still passes into the northern latitudes at 6:00 PM, and offsets the loss while in the southern latitudes. In fact, Figure 17 is identical to Figure 13, where the starting position of the satellite was deliberately changed to obtain a complementary coverage to Figure 11. After 182-183 days an exact equivalent shift has occurred.

From this, adequate compensation should be obtained by adding another orbit plane 90° from the first, as explained above. Further additions would only increase the system complexity without offering significant gains in coverage.

Without quantifying the coverage efficiency (the current NASA software does not support such analysis), we suggest that four satellites, two in each of two orbit planes, 90° apart in right ascension, would suffice to meet the VOA complimentary broadcast schedules. Two satellites are needed to provide the complimentary coverage discussed with respect to Figure 12, as well as provide for a backup spacecraft in the event of a satellite failure. It is not practical to transfer satellites between orbit planes and, therefore, each plane must have its own spare satellite.

Note that this requirement of four satellites only applies to visibility achieved. The power requirements have not as yet been discussed, and previous studies (References 2,3,4) have indicated multiple satellites were often needed to meet power requirements. In those cases, our individual satellite positions would be replaced with clusters of satellites sufficient to meet these power requirements. This point is addressed separately in "Operational Concepts".

Apogee at Constant Time/Equatorial (ACE) -

This orbit, the Apogee at Constant time of day/Equatorial (ACE), was discovered by researchers at Ford Aerospace and Communications Corporation and reported to NASA as part of a separate activity. The orbit has an approximate 5 hour period, is highly elliptical, and lies in the equatorial plane. The view at apogee (15,100 Km) is slightly better than that of the 8 hour equatorial orbit, but is of shorter duration (about 1 hour). It has the advantage of ease of launch (relative to the 8 hour posigrade equatorial orbit), but has slightly fewer prime time views (5 versus 6 for the 8 hour posigrade equatorial). Also, due to its elliptical nature, the apogee must be set to occur at either the morning or evening prime time hours (whereas the 8 hr equatorial orbit provides views at both morning and evening hours). Some coverage can occur at both, but only one will be optimal coverage (long duration view with little doppler shift).

Figure 18 shows a sequence of views of the ACE orbit from the North pole of the earth. The orbit parameters have been selected such that the satellite begins at apogee approximately over Colombia (75° W). Due to earth rotation, the apogee point will appear to progress westerly at approximately a 72° per orbit rate. Only the apogee passages offer significant visibility times. For most areas of the world, maximum visibility times repeat at 24 hour intervals. However, in some cases, significant coverage is available at other times.

Figure 19 shows consecutive views of the earth at 1 hour intervals for the ACE orbit. The first apogee, starting at 00:00:00 UTC, occurs over Europe/Africa. Successive views appear smaller because satellite altitude diminishes as the satellite progresses toward perigee (at 1030 Km).

The succeeding 1 hour contour shows coverage is still provided to Europe and Africa. Presumably, a similar contour could have been plotted for the view one hour earlier. The combination would indicate a 2 hour view of all of Europe and Africa below 60° N latitude. 4.79 Hours later the second apogee occurs over South America. These orbits can be initialized to any attitude with respect to the sun. Consequently, the views could be interpreted as occurring at, say, 6:00 AM or 6:00 PM (but not both).

Figure 20 shows the times when complete zone visibility is achieved, and compares these with the desired broadcast schedule (Schedule #1-see "Required Coverage and Broadcast Schedule", p.4)

It can be seen that the ACE orbit does not provide as much general coverage as the 8 Hr Posigrade Equatorial orbit (compare Figure 20 with Figure 10). This is mostly due to the ACE satellite being at maximum altitude for only a portion of the time, whereas the 8 Hr is at maximum altitude all the time. However, the channel coverage for the ACE satellite could be comparable or greater because of the greater payload capability for elliptical orbits.

Because of the extent of some zones, the duration of simultaneous zonal visibility can be quite low. Zone 3 is a good example. If simultaneous coverage is restricted to the most densely populated areas, the need for simultaneous coverage can be considerably reduced, and the duration of visibility significantly enhanced. This aspect is addressed in "Operational Concepts".

OPERATIONAL CONCEPTS

Concepts For Providing Simultaneous Zonal Coverage

In previous studies for VOA (References 2,3,4), zonal coverage patterns were constructed with a composite of 17^{o} longitude/latitude diameter contours. These were aggregated to assure efficient zonal coverage, even for zones that were quite irregular in shape. From geostationary orbit, these contours would appear as approximately 3^{o} diameter circles, at the equator. At lower altitudes, of course, the contours would appear larger, being 5.9^{o} for the 8hr orbit (13,916 Km) and the ACE orbit (15,100 Km), 57^{o} for the polar sunsynchronous orbit (1680 Km), and 140^{o} for the shuttle altitude orbit (275 Km).

The lowest orbit has a view just about equal to one contour, if we restrict the satellite elevation to a value greater than 10^{o}. The sunsynchronous orbit can view about 10 such contours simultaneously, with the same elevation angle restriction. The 8hr and ACE orbits could view about 53 such contours.

Table 5 illustrates the approximate size of each zone as the number of 17^{o} longitude/latitude contours required to cover each (Reference 2, p.69). From the polar sunsynchronous, the 8hr, and the ACE orbit, each of these zones can be viewed in their entirety. For the shuttle altitude, several satellites would be required for simultaneous coverage of each zone. Seven satellites would be required for zones 3, 7, and 13.

To achieve a simultaneous view in the latter three cases, it would be necessary to maintain a formation of the seven satellites at about 17^{o} separation. Orbital physics dictate that each satellite would have to continually alter its orbit to maintain such a formation, an impractical requirement with known propulsion techniques.

Consequently, for the 275 Km orbit, it is only practical to provide simultaneous coverage to an area the size of one contour, unless one would be willing to use many orbital planes having several satellites each. This latter case was analyzed and presented in the NASA synthesis report (Reference 4, Fig. 7.3) and was shown to require between 200-400 satellites.

Neither of these options, for the 275 Km orbit, appear attractive as these spacecraft are not small nor inexpensive, except possibly for the rural coverage case. For these reasons, the 275 Km orbit is not recommended as a viable operational concept.

The coverage for the polar sunsynchronous orbit was found to be significant. However, the number of satellites required was more than that required for the 8hr inclined orbit, and the satellite appeared to have the same power requirements and, therefore, about the same mass and cost. Consequently, the polar sunsynchronous orbit was not recommended as a viable operational concept.

The power budgets for satellites in each of these orbits is given in Table 6. Because of the wide simultaneous coverage area involved in each case, it was judged beneficial to account for coverage at beam center and beam edge separately. The largest variation in power occurs for the sunsynchronous polar orbit (2hr), the difference between the center beam and edge beams being about 6 dB.

The power budget shown is designed to provide 328 uv/meter or 50.3 DBu in each case. The spacecraft power requirements will be dominated by the edge beams where all beams are in use. The average edge beam power required is about 40 DBW or 10Kw RF per channel. There is very little variation of power with altitude. This is due to having equal coverage areas and equal field strength for each case. Most of the variation shown is due to difference in ionospheric losses and antenna losses.

Certain key parameters for the zonal coverage systems are listed in Table 7 for three coverage communities, Urban, Residential, and Rural. The EIRP per channel was taken from Table 6 and adjusted by the required field strength. Antenna size and final RF power was based on obtaining maximum possible number of beams and channels within the launch capabilities of the STS. The increase in cost at reduced field strength is due to the increasing complexity of the satellite as more beams and channels are added. More details are given in the section "Life Cycle Cost Estimation".

The costs shown for the 8hr and ACE orbit cases include one satellite and its launch. No detailed costs were determined for the STS and sunsynchronous satellites as these were not regarded as viable operational options. In the costs shown, no operations are included, although the non-recurring and recurring costs are accounted for. More detailed cost information can be found in the section "Life Cycle Cost Estimation".

Concepts Providing Simultaneous Local Coverage

Because of the extent of some zones, total visibility times can be quite low for either the 8 Hr or the ACE orbits. Zone 3 is a good example. Because of this effect, further orbit simulations were performed to evaluate the effect of confining broadcasts to just the more densely populated areas. One advantage to defining coverage in this way is elimination of the need to simultaneously cover entire continents with broadcasts. Such wide coverage leads to high power requirements and also penalizes visibility statistics by requiring simultaneous visibility over the same large areas. The modifications to coverage areas were provided by VOA.

Population density maps, provided to NASA by VOA, were examined with a view toward generation of a new traffic model based on simultaneous service to the most densely populated areas only. New coverage areas were defined and subjected to analysis for determination of visibility statistics.

Figure 21 illustrates some of these new coverage areas. These are only a fraction of the sizes originally considered for simultaneous coverage. Consequently, it can be expected that visibility times will improve.

Figure 22 illustrates the impact of this reduced simultaneous coverage requirement for the ACE orbit. Eastern Brazil (New Zone 1) now would receive two coverage times, one exceeding 3 hours (2300-0200). Similarly, each of the newly defined areas have visibility times exceeding 3 hours except for the most northerly new zones 8, 9, 10, and 11.

The disadvantage to this approach to coverage is the increase in antenna and transmitter complexity. For now each population center must be treated as distinct, and isolated coverage provided to each. This implies the need for multiple, independently steerable beams, and possibly multiple transmitters. Otherwise, with the use of simpler zonal coverage antennas, the transmitted power would "spillover" into adjacent areas, providing broadcasts at irregular times.

Satellite Configurations

The resulting satellite configurations are based on the TRW 8 hour concept (Reference 3) shown in Figure 23. The ACE orbit apogee altitude is only about 10% greater than the 8 hour altitude (15,100 km versus 13,890 km). As a consequence, the antenna size for the ACE orbit would be about 10% larger than that for the same coverage with an 8 hour orbit.

Therefore, for the same coverage, the configuration shown would be nearly the same for both orbits, though the ACE antenna would be about 20% heavier than the 8 hour antenna (mass varies nearly as the square of antenna diameter).

The antenna size is related to beam size by the approximate relation:

$$D=50\ L/BW$$

where D is the antenna dimension in meters, L the wavelength in meters, and BW the desired antenna beamwidth in degrees.

The antenna is constructed of a lightweight truss, upon which is mounted numerous transmitters, individual cross-dipole antenna elements, a mesh ground plane, and the required solar panels to provide electrical power.

The particular configuration shown is for a beamwidth of about 6.2° actual, or 3° equivalent GEO beam width. The stated power capability would correspond to three broadcast channels providing an urban quality signal (328 uv/meter).

Figure 24 provides greater detail on construction of the truss and antenna feed elements as well as illustrating how the antenna could be folded to be launched with STS.

Currently, NASA has no official plans to build the STS compatible upper stage shown in this illustration. The development of this stage was cancelled after the STS accident. However, it is believed this, or some similar stage, will eventually be developed and made available for use.

The satellite main body (bus) is attached to the backside of the antenna array. It contains the transmitters, the attitude control system, and the power processing equipment. Thermal control is by means of deployed heat rejection panels.

From this basic configuration, variations were developed to provide various field strengths, coverage areas, channel capacities, and necessary adjustments to account for orbit differences (i.e. antenna sizes would be slightly larger for the ACE orbit).

These configurations were compared on the basis of several performance parameters and the most effective configurations selected for recommendation to VOA for future consideration. The results of these comparisons are given in "Life Cycle Cost Estimation".

LIFE CYCLE COST ESTIMATION

Method of Computing

A very simple method was used to determine these costs. Costs of all hardware including non-recurring costs, ground stations, and launch were added to an estimated annual expenditure for operations and maintenance. For the operational system, the scenario life was assumed to be 20 years. The satellite life was assumed to be 10 years so that two launch cycles would be necessary through the life of the system. The cost of the master control station(s) was a constant fixed cost of $10M. Operations and maintenance were $3M annually per master control station. Satellite and launch costs depended on the particular satellite configuration, and were estimated using cost estimating software developed by NASA. The basic data for these estimating procedures were obtained from previous contractor studies done for VOA, and some variations were developed (for the smaller satellites) making use of cost estimating models developed by the Air Force Space Division.

The procedure was to estimate the non-recurring and recurring costs for the satellite(s) and the launch costs (including cost of upper stages); adding these to the fixed costs of the master control station; and making a total of these with the annual operations and maintenance costs for the 20 year life cycle.

Life Cycle Costing Results

Numerous satellite configurations were evaluated, each of which performed some degree of the VOA mission. Most were artificial variations which were evaluated only for establishing trends in various performance measures. In this process, it was intended that "optimal" performing configurations would be obvious. These results are reported below.

8 Hour Posigrade Equatorial Orbit -

The basic parameters for configurations considered for the operational 8 hour posigrade equatorial systems are shown in Table 8. Variations are marked by field strength (1-3 all at 76 uv/meter, 4-7 all at 187 uv/meter, and 8-9 all at 328 uv/meter), and by coverage (1, 4, 7 at 6^{o} spot size, 2, 5, 8 at 4^{o} spot size, and 3, 6, 9 at 3^{o} spot size). A cryogenic upper stage was assumed, although none are currently available for STS, because the performance of such stages are essential if significant communications capacity is to be achieved at HF. Cryogenic upper stages will be available on expendable launchers, but launch costs would be greater than that used in this analysis.

A summary of the subsystem mass properties is given in Table 9. For configurations 1-6, parameters were selected to maximize satellite capacity (within the STS launch constraints). Our analysis indicated it was not feasible to obtain multiple channels at 328 uv/meter. Hence for configurations 7-9 the satellites were optimized to provide one channel at the minimum possible launch weight.

The 20 year LCC are given for these 9 configurations in Table 10. Note that the total costs for configurations 1-6 are nearly the same. This is probably due to forcing all satellites to make maximum use of STS launch capability. Then all satellites would weigh nearly the same (which can be verified from Table 9) and, consequently, tend to cost the same (there is a strong correlation between a satellite's mass and it's cost). However, each of these configurations has a different number of broadcast channels. Taking this into consideration the cost per channel differs by a factor of ten ($54M to $560M). Hence the total cost is not a good indicator of system value. Value needs to be evaluated on the basis of channels provided, at least. Another method is to include a measure of the area covered, for 6^o (about 2400 mile diameter) of coverage is of more value than 3^o (about 1200 mile diameter) of coverage. Combining these, we use a parameter, (number of channels)x(area of beam in millions of square miles, MSQM), indicative of the total coverage provided in channels as well as area coverage. On this basis, the LCC/Ch-MSQM varies over a range of 19:1, with configuration #1 being least expensive and configuration #4 being the most expensive. Methods of extrapolating between these configurations will be illustrated later, and it will be shown that a 4^o spot size (about 1600 miles) is nearly optimum (which slightly differs from that assumed by TRW, 3^o).

ACE Orbit -

The results for similar analyses of the ACE orbit configurations are given in Tables 11-13. Note that the ACE configurations have more mass and, consequently, more cost. The ACE orbit, as explained earlier, requires less energy to achieve, and the STS can launch significantly more payload into this orbit. We propose to take advantage of this to launch more channel capacity. This implies the need for more hardware and power. In addition, the slightly higher altitude of the ACE apogee (versus the altitude of the 8 hour orbit) leads to a slightly larger antenna (about 10% larger diameter and 20% greater mass) for the same coverage and channel capability. Hence, we obtain the higher mass and cost.

However, on the basis of our performance parameter, the ACE and 8 hour orbits are about the same. Though the absolute mass and cost is greater for the ACE orbit, the increased capacity for this orbit essentially compensates so that the two compare about the same. Therefore, NASA favors the ACE as an operational configuration as the costs per area of coverage are about the same, while the capacity of the ACE orbit configurations are significantly greater.

Extrapolations -

Additional configurations were evaluated to establish trends among those listed in Tables 8-10 and 11-13.

The achievable capacity is compared for the ACE and 8 hour orbits in Figure 25. The maximum capacity is clearly achieved at a 4^o (about 1600 miles) spot size.

The achievable coverage, in terms of our coverage parameter, is compared in Figure 26. This parameter continually increases over the range shown, even though the number of channels diminishes beyond a 4^o spot size. This is probably due to the rapid growth in beam area (increasing as the square of spot diameter) compensating for the diminishing channel capacity.

Clearly, the ACE orbit has the advantage with respect to coverage and capacity.

Coverage achievable for the ACE orbit is compared for rural signal quality (76 uv/meter) and residential signal quality (187 uv/meter) in Figure 27. These data indicate that achievable coverage varies inversely with the square of desired field strength. This can be further verified by examining Tables 8-13.

The 20 year LCC for the ACE orbit is compared for rural signal quality and residential signal quality in Figure 28. Cost performance improves as the beamwidth is expanded. However, the major improvement occurs in the transition from 3° to 4° spot size. It was evident from Figure 25 that maximum capacity was achieved at 4°. Therefore NASA recommends 4°, and the implied antenna size, as the best performing satellite configuration.

The subsystem mass and power requirements for the ACE orbit satellite are compared in Figure 29 for rural signal quality and residential signal quality. The decrease in antenna subsystem mass, as spot size is increased, is offset by the growth in power subsystem mass. In principle, the power ought to increase as the square of spot size for a given field strength. However, due to a fixed launch constraint, the number of broadcast channels is not constant, but diminishes as spot size increases. Consequently, the power and power subsystem mass does not increase as rapidly as one might expect.

Normally, the antenna diameter would vary inversely with the spot size. All other things being equal, this would suggest that antenna mass would vary inversely as the square of spot size. However, this trend is not apparent because the channel capacity is not constant, nor are the transmitters of constant size.

Nevertheless, the trends shown are nominally what one would expect. Note that for small spot size, the antenna mass dominates while at $5\text{-}8^{\circ}$ spot size the power subsystem and the antenna subsystem have about the same contribution to satellite mass. Therefore, making use of very large antennas does reduce power requirements, but this gain can be offset by the mass of the antenna if the antenna is too large. Conversely, too small an antenna can lead to an excessively heavy power system. The proper balance between the two depends on the technology and launch capability. For HF technology the balance occurs at about a 4° spot size.

SUITABLE FLIGHT EXPERIMENTS

ACE and 8 Hour HF Experiments

In defining a HF flight experiment, it was assumed that a prototypical satellite configuration was desirable, having at least rural or residential signal quality capability. In addition, the technology used, though not full size, would be suitable for demonstration of the readiness of the technologies needed for the operational system. On the other hand, since this would only be experimental, some further guidelines were adopted to reduce costs and enhance the likelihood of a near-term launch.

Specifically: (1) the satellite would be capable of only one broadcast channel; (2) existing upper stages would be used for launch from STS or expendables; (3) a conventional solid apogee kick motor would be used for final apogee burn, if any; and (4) the satellite would have sufficient power to provide rural coverage (at 26 MHz, 76 uv/meter from a satellite system is sufficient to provide an equivalent 73 db S/No to 90% of rural locations, 90% of the time)

Of the available upper stages, only the AMS orbital transfer vehicle (OTV) offered by Orbital Sciences Corporation provides the complete capability needed to meet most of the requirements of either an 8 hour or an ACE orbit. Assistance from a solid rocket motor will be needed for final orbit maneuvers, however.

Table 14 lists parameters of satellite configurations considered for the 8 hour experimental concepts. Note that field strength is constant for all configurations, and that coverage varies from 3^{o} to near earth coverage (earth coverage is about 17^{o} from GEO).

Summary mass properties for these configurations are given in Table 15. Minimum total dry mass occurs in the range of 7-9^{o} spot size.

In computation of LCCs, it was assumed that the experimental/prototype phase would be ten years, or about half of an operational phase. Though only a prototype system, it was assumed that VOA would need the reliability offered by an orbiting spare satellite, and a spare was included in these costs. These 10 year LCCs are given for the 9 configurations in Table 16. Note that costs are nearly the same over a wide range of coverage (6% variation over 6-11^{o} coverage). Hence, great flexibility exists for trading off antenna and power system complexity without a great concern for cost impact.

Results of similar analyses for the ACE orbit are given in Tables 17-19.

In the operational configurations, we adopted the strategy of maximizing channel capacity for each configuration. Because of that strategy, the ACE configuration tended to be heavier than the 8 hour operational configurations. For the experimental configuration, since we allow only one channel, we use only the necessary mass to provide a single channel.

Consequently, the mass for the ACE satellites will tend to be less (since a smaller AKM motor will suffice for the ACE orbit). This can be seen by comparing Table 18 and Table 15. However, these weight trends are offset somewhat by the larger antenna for the ACE orbit.

The net 10 year LCCs are given in Table 19, and these are nominally the same, or slightly lower, than the corresponding 8 hour configuration of Table 16 (average difference is 1.3% with a bias toward the ACE configurations).

Figure 30 shows the variation of antenna and power subsystem mass with coverage. For the experimental configuration, the contributions of each to total satellite mass are nearly the same for spot sizes greater than 8° (antenna mass includes the mass of the transmitters).

Figure 31 shows the variations of the 10 year LCCs with spot size. Since only one channel is used, it would appear there is no particular advantage to any configuration having coverage greater than $6\text{-}7^{\circ}$, but LCCs remain essentially constant out to nearly earth coverage. As mentioned before, this trend indicates great flexibility in selection of configurations for experiment. The tradeoffs between interacting technologies, such as antenna and power system, can be based on technical difficulty alone without great concern for cost impact.

HF Experiment/Prototype Recommendation -

Should VOA choose to implement an HF complementary system, NASA would recommend experimental configuration #5 as a suitable prototype. The sixteen feeds imply a phased array antenna having a 4x4 element configuration, each generating about 300 watts of RF power. This is judged to be of sufficient size to demonstrate the deployable antenna structure, but not so large as to require technology breakthroughs. Also, the power system should be easily obtained as it is smaller than systems now being designed for space station.

The field strength should be sufficient to reach 90% of listeners in rural areas with an acceptable signal. For listeners having high quality receiving equipment, acceptable signals will be received in residential areas, and perhaps in some urban areas.

L-Band/S-Band Experimental Concepts

Full coverage and single-channel coverage L-band (1.5 GHz) satellite scenarios were generated by TRW in previous NASA/VOA contractor studies (Reference 3). In those studies conventional FM modulation techniques were assumed and propagation conditions were adopted which corresponded to fixed site receivers.

A satellite configuration which was suitable for fixed receivers is shown in Figure 32. The configuration shown would support about 27 high quality sound channels to a 3° diameter (about 1200 miles) area. TRW estimated such a satellite would weigh about 2700 pounds (including 20% reserve), have a non-recurring cost of about $100M, a recurring cost of about $70M, and a launch cost of about $80M.

This particular configuration was designed for geostationary orbit. As such, only one portion of the earth could be covered unless multiple satellites were used. Three active satellites and one spare would suffice for worldwide coverage. 10 year LCCs for such a system would be about $812M, or $28M/Ch-MSQM.

The choice of geostationary orbit for the L-band system may not be the best choice for the VOA application. Since coverage during prime time hours is of primary interest, it might be more economical to use either the 8 hour or ACE orbit so that a single satellite might be used in several broadcast areas.

In such a case the antenna would decrease in size by about a factor of 2, and weight by a factor of four. The power requirements would remain about the same. Assuming satellite costs are nominally the same; the satellite mass is nominally the same; and the launch cost to ACE orbit of $38M, the 10 year LCCs would be about $356M, or $12M/Ch-MSQM.

This assumes a system designed only for fixed receivers with modest gain antennas. There are indications that portable and mobile receivers could be serviced with about the same size spacecraft provided suitable advanced modulation and coding schemes are used (Reference 5). These techniques are being evaluated as part of a separate activity by Toledo University under NASA sponsorship.

Recommendation -

Should VOA choose to implement an L-Band system for complementary coverage, NASA would recommend the use of a medium altitude orbit (either the 8 hour or the ACE orbit) because of the obvious economics afforded to the VOA mission where only prime-time coverage is of interest. One potential difficulty with this mode of operation is the need for an essentially 360° orbit assignment (because the satellite is continually moving as it broadcasts). Nevertheless, such a mode should be considered because of the economies involved. Multiple satellites might be discriminated on a scheduled frequency basis as the terrestrial systems now are. Other methods might be possible.

Other Experiments

It may be feasible to arrange for sound broadcast experiments from existing satellites. Domestic experiments could easily be achieved through use of domestic Ku-Band satellites. Alternatively, L-Band or S-Band experiments might be possible by cooperative international agreements.

The INSAT 1B satellite has a capability of 42 DBW EIRP. With the aforementioned advanced modulation and coding techniques, this could support a single channel broadcast through light foliage (Reference 5).

One caution regarding such experiments is in order. Power flux density limitations may negate obtaining permission for such an experiment.

Regulations indicate a ceiling of -137 DBW/m^2/4KHz (RR 7-26/470NH) for a satellite viewed in the vertical direction and -151 DBW/m^2/4KHz in the direction of the horizon. With typical low gain portable and mobile receiver antennas, the flux density could exceed these limitations, even if the advanced modulation and coding schemes are used. Of course, with a suitably sized receiver antenna, experiments could be performed. However, with the higher gain antenna, the advanced modulation and coding scheme would not be needed.

CONCLUSIONS AND RECOMMENDATIONS

The utility of satellites for complementing terrestrial international sound broadcast networks has been examined. Cases were considered where HF (26 MHz) sound broadcasting satellites provided effective coverage to latitudes of plus and minus 50° while requiring only two satellites (In principle, only one would be needed but we include two to enhance reliability. Additional coverage afforded by the backup spacecraft will offset the higher costs somewhat).

Two orbits were found especially attractive, the 8 hour posigrade equatorial and the apogee at constant time/equatorial (ACE). Both orbits provide same time-of-day coverage. Since the satellites are in constant motion, the duration of visibility is limited to an hour or so, depending on the size of the area receiving the broadcast. Broadcasts of over two hours duration are possible to areas the size of Mexico or the eastern 1/3 of Brazil. One-half hour coverage is possible for larger areas like the South American continent.

Either the 8 hour or ACE orbit is acceptable for the complementary mission. Both offer nearly the same cost performance (life cycle cost of about $174M/Ch-MSQM for residential coverage at 26MHz), but slightly more capacity can be supported in the ACE orbit. These two orbits are equally useful at higher frequency bands (such as L-Band at 1.5 GHz) as well as HF (26 MHz). The higher frequency band satellites have significantly better cost performance, L-Band satellites having a LCC of about $52M/Ch-MSQM.

The higher cost performance of the higher frequency bands would suggest the utilization of those technologies over HF technologies. However, the current dominant receiver population would suggest the use of HF technology.

On the other hand, it is expected that a significant Ku-Band receiver population will exist by the year 2000 and beyond. Also, there is growing international interest in allocation of a satellite sound broadcasting band in the range of 0.5 to 2.0 GHz. Such an assignment could stimulate the development of a significant receiver population there as well. Consequently, any new sound broadcasting satellite system ought to carry an appropriate payload to reach these receiver populations.

In the implementation of a complementary DBS sound broadcast system, NASA views these separate bands as being useful to supplement one another. Therefore NASA would recommend the consideration of a hybrid HF/(L-Band or Ku-Band) satellite system. The HF subsystem would be designed for broadcasts to rural or residential areas, primarily to the lesser developed nations. HF receiver technology should readily be available in these areas, whereas the higher frequency receiver technology would not.

The higher frequency subsystem would be utilized for coverage to developed nations and to urban/residential areas of other nations. The listener population in these areas should have the available resources to acquire the necessary receiver technologies. It is expected that much of this technology would be obtained anyway for participation in DBSTV or domestic sound broadcasting.

To implement such a system, it would be necessary to develop some critical technologies and, perhaps, verify the readiness of these technologies with a flight experiment. In particular, the deployable HF antenna, the HF transmitters, deployable heat pipes, and power system would be critical items in need of further development. It is estimated that development of all these items could be completed in 3-4 years at a cost of approximately $50M (1987). A prototype system could be launched in mid '90s, and the operational system by 2000.

Under USIA/VOA sponsorship, NASA could provide the necessary technical management of the technology development program and assist VOA in the establishment and execution of the prototype program as well as the operational phase.

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TABLE 1
VOA TRAFFIC MODEL #1 ALPHABETICALLY BY LANGUAGE

Language	Country	Region Code	Morn Hours	Even Hours	Morn-UTC	Morn UTC	Even-UTC	Even UTC	Local Clock
Arabic	NE SAsia	3,4	2		400	600			AM
Chinese	EAsia	46,47	2		2200	2400			AM
English	Africa	19	2		400	600			AM
English	Africa	19		2			1600	1800	PM
English	Am.'s	15,16, 17.		4			0	400	PM
English	EAsia	23		4			1100	1500	PM
English	Europe	18	2		400	600			AM
English	MEast	21	2		400	600			AM
English	MEast	21		2			1130	1400	PM
English	SAsia	22		2			1130	1400	PM
English	SAsia	22	3		100	400			AM
Farsi	NE SAsia	25		2			1700	1900	PM
French	Am. Rep	New		4			1830	2230	PM
Polish	Europe	50	2		500	700			AM
Russian	C. USSR	60		2			1200	1400	PM
Russian	E. USSR	61		3			800	1100	PM
Russian	W. USSR	59		3	200	500			AM
Ukraine	USSR	72	2		200	400			AM
Ukraine	USSR	72		2			1600	1800	PM

TABLE 2
VOA TRAFFIC MODEL #2, ALPHABETICALLY

Language	Country	Region Code	Morn Hours	Even Hours	Morn-UTC	Morn UTC	Even-UTC	Even UTC	Local Clock
Bengali	Bangdsh	7		1			1600	1700	PM
Czech	Czech	11	1		2000	2100			PM
English	Africa	19	2		600	800			AM
English	EAsia	23	1		0	100			AM
English	Europe	18		2			600	800	AM
English	Europe	18		1			1800	1900	PM
English	MEast	21		1			1700	1800	PM
English	MEast	21	2		600	800			AM
English	SAsia	22		1			1700	1800	PM
English	W. USSR	59	1		400	500			AM
French	Africa	28,30		1.5		500	630		AM
Hindi	India	35		1			1600	1700	PM
Hungrn	Hungry	36		1.5			1730	1900	PM
Pashto	Afghan	49	2.5		0	230			AM
Portgse	Africa	51,52, 53,54,55		1			2300	2400	PM
Portgse	Am.'s	56	1		1000	1100			AM
Russian	W. USSR	59	1		400	500			AM
Urdu	Pak/Ind	74		1			1330	1430	PM

TABLE 3
SIMULTANEOUS CHANNEL REQUIREMENTS FOR EACH ZONE, SCENARIO #1

Time UTC	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15
0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
30	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
100	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0
130	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0
200	1	1	1	0	1	0	0	0	1	0	1	0	0	0	0
230	1	1	1	0	1	0	0	0	1	0	1	0	0	0	0
300	1	1	1	0	1	0	0	0	1	0	1	0	0	0	0
330	1	1	1	0	1	0	0	0	1	0	1	0	0	0	0
400	0	0	0	0	1	2	2	1	0	0	0	0	0	0	0
430	0	0	0	0	1	2	2	1	0	0	0	0	0	0	0
500	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0
530	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0
600	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
630	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
730	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
830	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
900	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
930	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1030	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1100	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
1130	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1
1200	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1
1230	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1
1300	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1
1330	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1
1400	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
1430	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1530	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1600	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0
1630	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0
1700	0	0	0	0	1	1	1	0	1	0	1	0	0	0	0
1730	0	0	0	0	1	1	1	0	1	0	1	0	0	0	0
1800	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1830	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0
1900	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2030	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2100	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2130	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2200	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0
2230	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
2300	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
2330	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0

TABLE 4
SIMULTANEOUS CHANNEL REQUIREMENTS FOR EACH ZONE, SCENARIO #2

Time UTC	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15
0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1
30	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1
100	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
130	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
430	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0
530	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0
600	0	0	0	1	1	1	3	0	0	0	0	0	0	0	0
630	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
700	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
730	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
830	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
930	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1030	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1330	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1400	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1430	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1530	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1600	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0
1630	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0
1700	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1730	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
1800	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
1830	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
1900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
2030	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
2100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2300	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0
2330	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0

TABLE 5
ZONE COVERAGE REQUIREMENTS

ZONE	Approx. Size in Contours(1)	No. of Satellites For Instantaneous Coverage 275 Km	1680 Km	13916 Km
1	2	2	1	1
2	2	2	1	1
3	7	7	1	1
4	3	3	1	1
5	2	2	1	1
6	3	3	1	1
7	7	7	1	1
8	2	2	1	1
9	1	1	1	1
10	3	3	1	1
11	4	4	1	1
12	2	2	1	1
13	7	7	1	1
14	2	2	1	1
15	2	2	1	1

(1)Circular Contours of About 17° Longitude/Latitude

TABLE 6
HF LINK BUDGETS FOR LOW ALTITUDE SATELLITES

	8-HOUR Center	Edge	2-HOUR Center	Edge	1.5-HOUR Center	Edge
Power, dBW	38.3	40.6	34.9	40.9	36.4	37.1
Line Loss, dB	-0.5	-0.5	-1.0	-1.0	-1.0	-1.0
Antenna Gain, dB	28.7	28.7	15.6	15.6	6.2(7)	6.2(7)
EIRP, dBW	66.5	68.8	49.5	55.5	41.6	42.3
*Spreading, dB	-153.9(1)	-156.2(2)	-137.0(3)	-142.9(4)	-131.0(5)	-131.2(6)
Polarization, dB	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
Ionospheric, dB	-2.0	-2.0	-2.0	-2.0	-0.0	-0.0
EOC, dB	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
Free Space Z, dB	25.8	25.8	25.8	25.8	25.8	25.8
Ref. uV/M, dBuV	120.0	120.0	120.0	120.0	120.0	120.0
Field dBu	50.3	50.3	50.3	50.3	50.3	50.3

*Slant Range

(1)14,018 Km (2)18,204 Km
(3) 1,988 Km (4) 3,942 Km
(5) 1,004 Km (6) 1,084 Km

(7) Antenna is not well defined for this altitude. Antenna pattern might be very complex and needs more careful examination.

TABLE 7
SATELLITE CONCEPT PARAMETERS FOR COMPLEMENTARY COVERAGE
39 dB S/N TO STATED COMMUNITY(1)

Location	Alt Km	Orbit Type	Field Strn uV/M	EIRP dBW	Ant Gain dB	RF Pwr/ch KW	Ant Size M	Vis. Dur. Min.	Sat. Cost(5) $M	Orbit Period Hours
URBAN	275	STS	328	42.3(2)	6.2	5.1	(6)	2.5	(6)	1.5
	1,680	Polar	328	55.5(3)	15.6	12.3	(6)	12	(6)	2.0
	13,916	Equ/Pos.	328	68.8(4)	28.7	11.5	80	60	567	8.0
	15,100	ACE	328	69.4(4)	28.7	13.2	80	120	586	4.8
RESID.	275	STS	187	37.4(2)	6.2	1.5	(6)	1.3	(6)	1.5
	1,680	Polar	187	50.6(3)	15.6	3.2	(6)	12	(6)	2.0
	13,916	Equ/Pos.	187	63.9(4)	28.7	3.3	80	60	698	8.0
	15,100	ACE	187	64.5(4)	28.7	3.8	80	120	747	4.8
RURAL	275	STS	76	29.6(2)	6.2	0.2	(6)	2.5	(6)	1.5
	1,680	Polar	76	42.8(3)	15.6	0.5	(6)	12	(6)	2.0
	13,916	Equ/Pos.	76	56.1(4)	28.7	0.5	80	60	706	8.0
	15,100	ACE	76	56.7(4)	28.7	0.6	80	120	749	4.8

(1) Actual S/N 9dB less to account for processing gain
(2) 3 dB Polarization Loss; 1 dB Feed Loss; 3 dB EOC Loss
(3) 3 dB Polarization Loss; 1 dB Feed Loss; 2 dB Ionospheric Loss; 3 dB EOC Loss
(4) 3 dB Polarization Loss; 0.5 dB Feed Loss; 2 dB Ionospheric Loss; 3 dB EOC Loss
(5) Cost for First Spacecraft Including Non-Recurring, Recurring, and Launch. Multiple Spacecraft Not Proportionately More.
(6) Antenna is not well defined for this altitude. Antenna pattern might be very complex and needs careful examination

TABLE 8
8 HOUR POSIGRADE EQUATORIAL OPERATIONAL CONCEPTS

Item	1	2	3	4	5	6	7	8	9
SYSTEM:									
Orbit	8Hr	8Hr	8Hr	8Hr	8Hr	8Hr	8Hr	8Hr	8Hr
Ant Code	2	2	2	2	2	2	2	2	2
OTV	Cryo	Cryo	Cryo	Cryo	Cryo	Cryo	Cryo	Cryo	Cryo
Band, MHz	26	26	26	26	26	26	26	26	26
uv/meter	76	76	76	187	187	187	328	328	328
Feeds	36	100	196	36	100	196	36	100	196
Channels	19	32	28	3	5	4	1	1	1
RF Kw/Beam	4.9	2.2	1.2	29.6	13.2	7.4	12.5	8.3	6.2
DC Kw/Beam	8.4	3.7	2.1	50.8	22.6	12.7	92	40.9	23
Bm, Deg	6	4	3	6	4	3	6	4	3

TABLE 9
WEIGHT PROPERTIES OF 8 HOUR CONCEPTS, POUNDS

Item	1	2	3	4	5	6	7	8	9
Payload	4586.6	3702.4	2018.8	4385.1	3501.0	1746.0	4386.7	2054.7	1232.9
Buss, dry	2672.7	2334.9	1793.1	2632.2	2297.2	1747.9	2385.3	1580.4	1460.2
Antenna	1332.1	3770.4	7430.4	1332.1	3770.4	7430.4	1332.1	3770.4	7430.4
Power	4211.0	3332.1	1863.8	4034.2	3162.9	1652.9	2524.9	1313.8	910.7
Tot, Dry	12802.4	13139.8	13106.1	12383.6	12731.5	12577.2	10629.0	8719.3	11034.2

TABLE 10
LIFE CYCLE COSTS FOR 8 HOUR CONCEPTS, $MILLIONS

Item	1	2	3	4	5	6	7	8	9
Pgm Yrs	20	20	20	20	20	20	20	20	20
Sat Life	10	10	10	10	10	10	10	10	10
#Sats	2	2	2	2	2	2	2	2	2
NR	351	334	311	346	331	306	319	286	288
REC	217	224	231	212	220	225	176	169	205
STS	99	100	100	99	99	99	86	76	89
OTV	48	48	48	48	48	48	41	36	42
MCC	10	10	10	10	10	10	10	10	10
O&M/YR	3	3	3	3	3	3	3	3	3
20YR LCC	1879	1892	1896	1851	1869	1863	1603	- 1478	1701

TABLE 11
ACE OPERATIONAL CONCEPT

Item	1	2	3	4	5	6	7	8	9
SYSTEM:									
Orbit	ACE	ACE	ACE	ACE	ACE	ACE	ACE	ACE	ACE
Ant Code	2	2	2	2	2	2	2	2	2
OTV	Cryo	Cryo	Cryo	Cryo	Cryo	Cryo	Cryo	Cryo	Cryo
Band, MHz	26	26	26	26	26	26	26	26	26
uv/meter	76	76	76	187	187	187	328	328	328
Feeds	49	121	225	49	121	225	49	121	225
Channels	22	37	35	3	6	5	1	1	1
RF Kw/Beam	5	2.2	1.3	30.4	13.5	7.6	55	24.4	13.7
DC Kw/Beam	8.6	3.8	2.2	52.2	23.2	13	94.4	42	23.6
Bm, Deg	6	4	3	6	4	3	6	4	3

TABLE 12
WEIGHT PROPERTIES OF ACE CONCEPTS, POUNDS

Item	1	2	3	4	5	6	7	8	9
Payload	5396.6	4391.9	2471.0	4456.8	4311.6	2136.5	4460.5	2088.0	1216.3
Buss, dry	3117.4	2712.1	2113.0	2927.9	2699.0	2056.0	2480.3	1674.8	1559.1
Antenna	1773.8	4540.7	8582.6	1773.8	4540.7	8582.6	1773.8	4540.7	8582.6
Power	4937.9	3899.3	2329.4	4117.6	3841.0	2063.2	2582.0	1357.6	952.7
Tot, Dry	15225.7	15544.0	15496.0	13276.1	15392.3	14838.3	11296.6	9661.1	12310.7

TABLE 13
LIFE CYCLE COSTS FOR ACE CONCEPTS, $MILLIONS

Item	1	2	3	4	5	6	7	8	9
Pgm Yrs	20	20	20	20	20	20	20	20	20
Sat Life Yrs	10	10	10	10	10	10	10	10	10
#Sats	2	2	2	2	2	2	2	2	2
NR	370	353	329	351	352	322	321	291	294
REC	246	252	261	222	251	252	185	181	222
STS	99	100	100	96	100	99	88	78	91
OTV	44	44	44	44	44	44	41	36	42
MCC	10	10	10	10	10	10	10	10	10
O&M/YR	3	3	3	3	3	3	3	3	3
20YR LCC	1995	2006	2016	1869	1999	1970	1643	1539	1783

TABLE 14
8 HOUR EXPERIMENTAL CONCEPTS

Item	1	2	3	4	5	6	7	8	9
SYSTEM:									
Orbit	8Hr	8Hr	8Hr	8Hr	8Hr	8Hr	8Hr	8Hr	8Hr
Ant Code	2	2	2	2	2	2	2	2	2
OTV	AMS	AMS	AMS	AMS	AMS	AMS	AMS	AMS	AMS
Band, MHz	26	26	26	26	26	26	26	26	26
uv/meter	76	76	76	76	76	76	76	76	76
Feeds	9	9	16	16	25	36	36	81	225
Channels	1	1	1	1	1	1	1	1	1
RF Kw/Beam	11.5	9.7	8	6.5	5.1	3.9	2.9	2	0.7
DC Kw/Beam	19.7	16.6	13.7	11.1	8.8	6.7	4.9	3.4	1.2
Beam, Deg	12	11	10	9	8	7	6	5	3

TABLE 15
WEIGHT PROPERTIES OF 8 HOUR EXPERIMENTAL CONCEPTS, POUNDS

Item	1	2	3	4	5	6	7	8	9
Payload	925.3	777.5	642.5	525.8	417.9	320.0	235.5	168.0	66.2
Buss, dry	881.9	823.1	781.5	755.9	723.1	722.8	697.5	739.2	1014.0
Antenna	271.8	284.8	300.4	534.0	834.3	902.4	1332.1	2339.1	7430.4
Power	957.9	839.9	732.8	637.5	554.1	482.5	423.9	379.8	348.2
AKM	4388.4	3925.7	3653.5	3517.4	3653.5	3462.9	3898.4	5232.2	12799.0
Tot, Dry	7425.3	6651.0	6110.7	5970.6	6182.9	5890.6	6587.4	8858.3	21657.8

TABLE 16
LIFE CYCLE COSTS OF 8 HOUR EXPERIMENTAL CONCEPTS, $MILLIONS

Item	1	2	3	4	5	6	7	8	9
Pgm Yrs	10	10	10	10	10	10	10	10	10
Sat Life	10	10	10	10	10	10	10	10	10
#Sats	2	2	2	2	2	2	2	2	2
NR	242	174	166	168	168	167	171	179	213
REC	100	73	71	73	75	75	79	91	152
STS	36	34	33	32	32	33	35	44	90
OTV	14	10	10	9	10	10	11	14	28
MCC	10	10	10	10	10	10	10	10	10
O&M/YR	3	3	3	3	3	3	3	3	3
10YR LCC	581	448	435	435	441	442	462	515	794

TABLE 17
ACE EXPERIMENTAL CONCEPTS

Item	1	2	3	4	5	6	7	8	9
SYSTEM:									
Orbit	ACE	ACE	ACE	ACE	ACE	ACE	ACE	ACE	ACE
Ant Code	2	2	2	2	2	2	2	2	2
OTV	AMS	AMS	AMS	AMS	AMS	AMS	AMS	AMS	AMS
Band, MHz	26	26	26	26	26	26	26	26	26
uv/meter	76	76	76	76	76	76	76	76	76
Feeds	9	9	16	16	25	36	49	81	225
Channels	1	1	1	1	1	1	1	1	1
RF Kw/Beam	11.8	9.9	8.2	6.6	5.2	4	3	2.1	0.7
DC Kw/Beam	20.3	17	14.1	11.4	9	6.9	5.1	3.5	1.3
Beam, Deg	12	11	10	9	8	7	6	5	3

TABLE 18
WEIGHT PROPERTIES OF ACE EXPERIMENTAL CONCEPTS, POUNDS

Item	1	2	3	4	5	6	7	8	9
Payload	925.3	777.5	649.4	526.0	418.1	320.7	239.4	170.2	65.3
Buss, dry	902.0	843.7	810.7	765.1	741.4	733.0	738.2	791.1	1111.3
Antenna	282.0	296.0	523.2	555.9	868.5	1265.7	1773.8	2924.3	8582.6
Power	977.0	858.1	750.8	655.1	571.2	500.0	442.4	399.4	373.9
AKM	2190.2	1975.3	1975.3	1806.5	1852.5	2006.0	2267.0	3042.2	7256.0
Tot, Dry	5276.5	4750.6	4709.4	4308.6	4451.7	4825.4	5460.8	7327.2	17389.1

TABLE 19
LIFE CYCLE COSTS FOR ACE EXPERIMENTAL CONCEPTS, $MILLIONS

Item	1	2	3	4	5	6	7	8	9
Pgm Yrs	10	10	10	10	10	10	10	10	10
Sat Life	10	10	10	10	10	10	10	10	10
#Sats	2	2	2	2	2	2	2	2	2
NR	239	173	168	167	167	169	172	180	209
REC	98	72	73	71	74	77	82	95	159
STS	33	31	31	29	30	31	34	42	84
OTV	14	10	10	9	10	10	11	14	28
MCC	10	10	10	10	10	10	10	10	10
O&M/YR	3	3	3	3	3	3	3	3	3
10YR LCC	568	438	435	427	433	446	466	520	791

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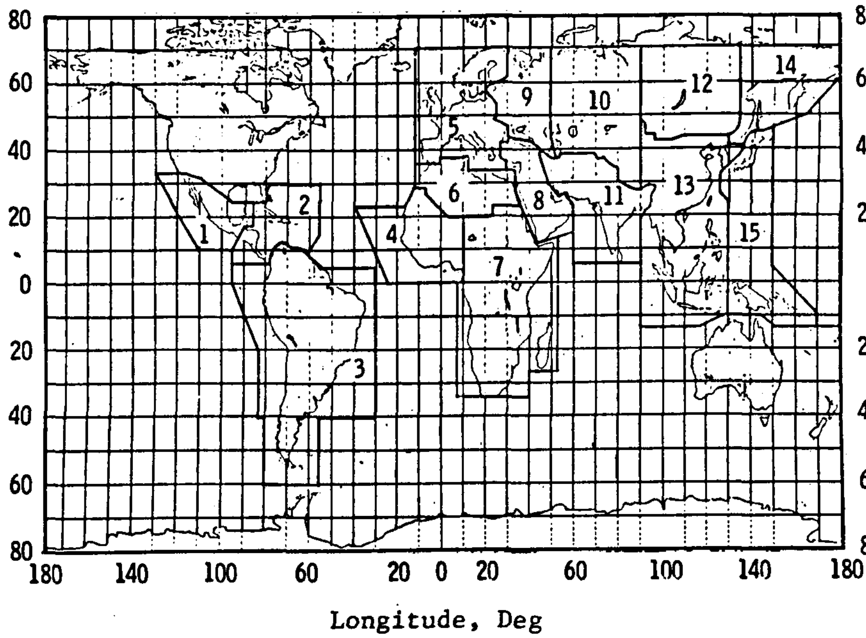

Figure 1 - Aggregated Sound Broadcast Zones 1-15

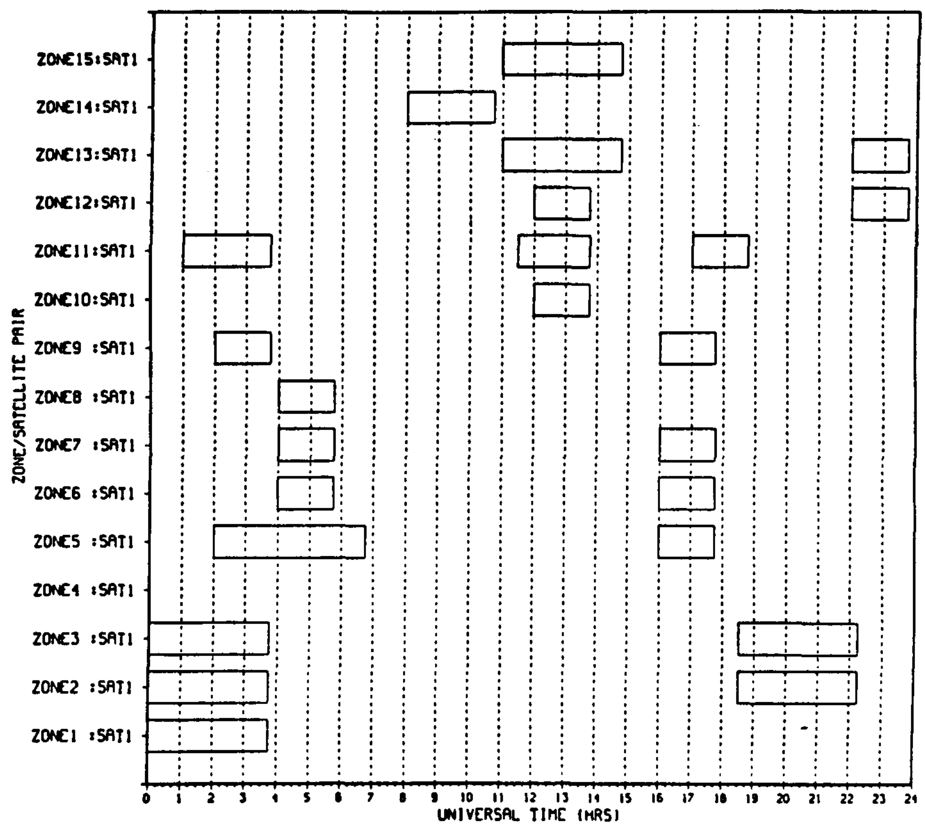

Figure 2 - Required Times For Sound Broadcasts

Figure 3 - Visibility Contours For Shuttle Altitude Orbits (275 Km)

Figure 4 - Shuttle Altitude Contours With Correction For Refraction

Figure 5 - Visibility Contours For Sunsynchronous Altitude (1800 Km)

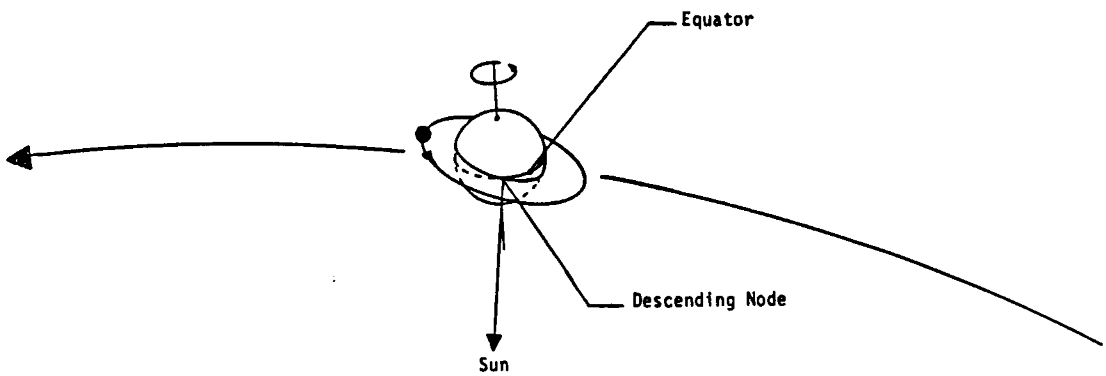

Figure 6 - Inclined Orbit With Satellite in Northern Latitude at 6:00 A.M. Position

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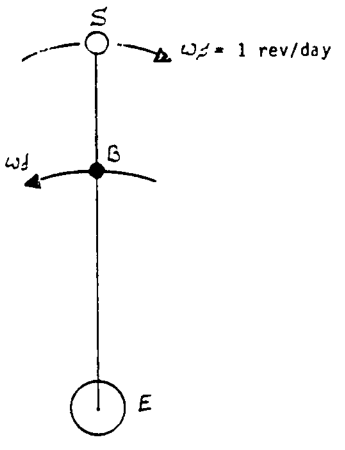

Figure 7 - Determining Relative Angular Velocity Between Satellite And Apparent Sun.

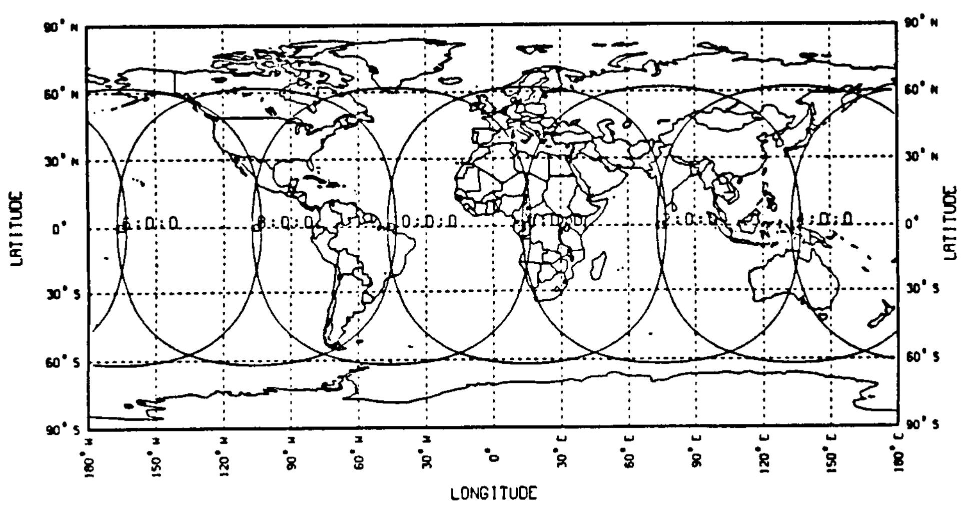

Figure 8 - Visibility Contours of 8 Hour Posigrade Equatorial Orbit at 2 Hour Intervals. Corresponds to 10° Elevation

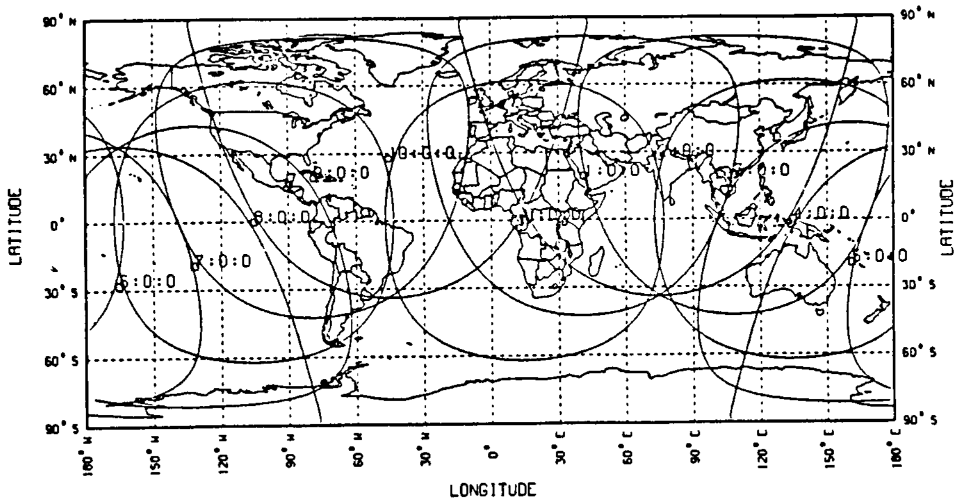

Figure 9 - Visibility Contours for Inclined 8 Hour Orbit at 1 Hour Intervals. Corresponds to 10° Elevation, 28° Inclination

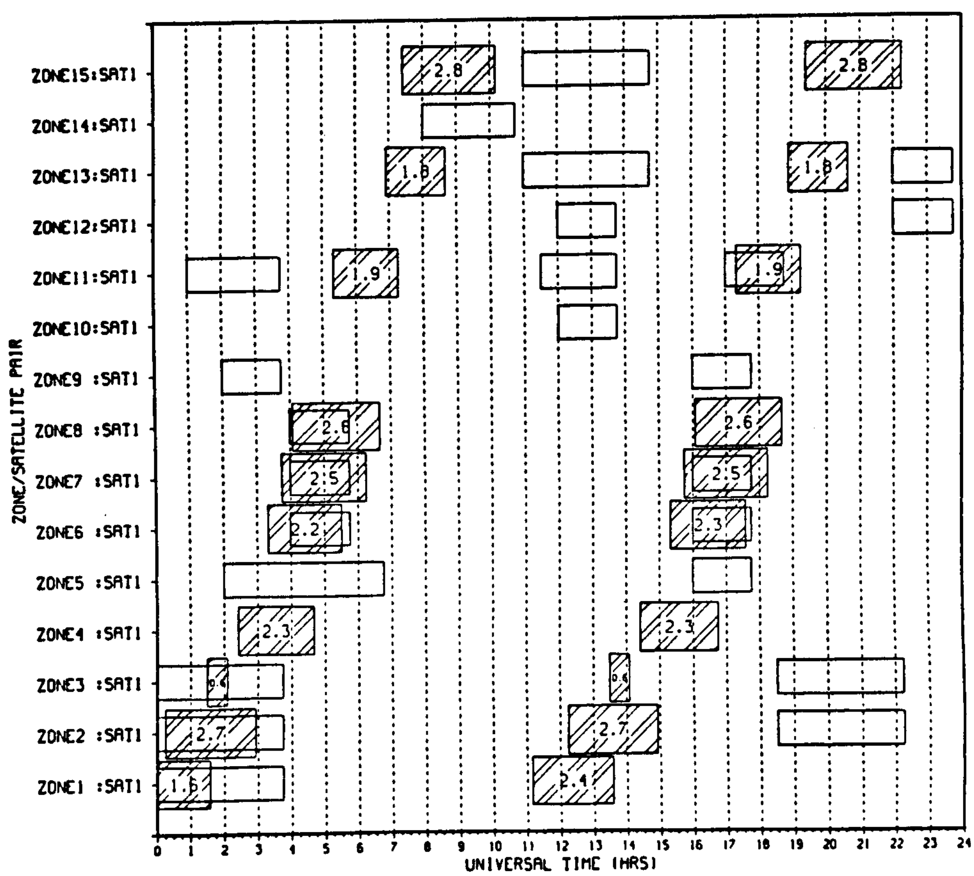

Figure 10 - Comparison of Required Broadcast Times and Achieved Visibility Times (Cross-hatched) For 8 Hour Equatorial Orbit

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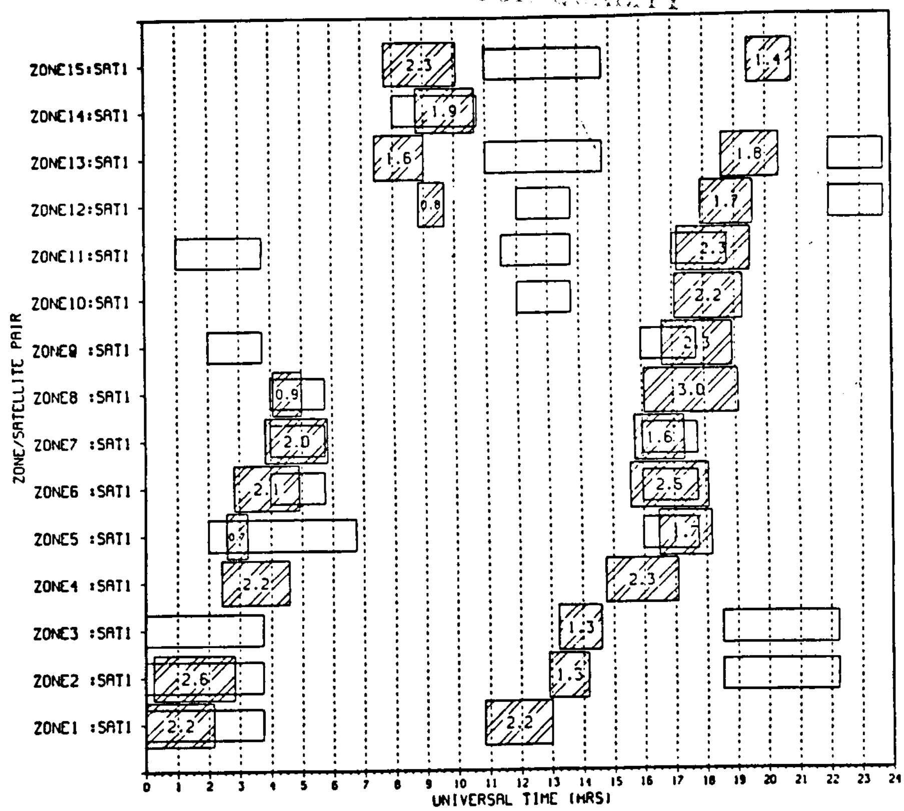

Figure 11 - Comparison of Required Broadcast Times With Achieved Visibility Times For Inclined 8 Hour Orbit

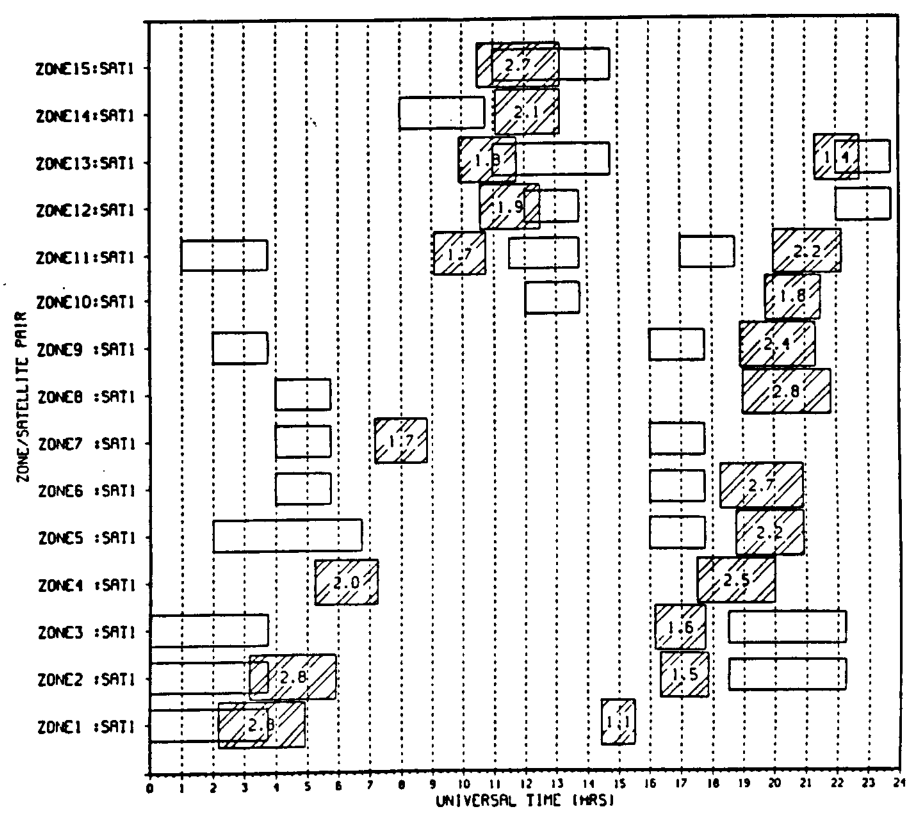

Figure 12 - Comparison of Required Broadcast Times With Achieved Visibility Times For 8 Hour Orbit Shifted 90°

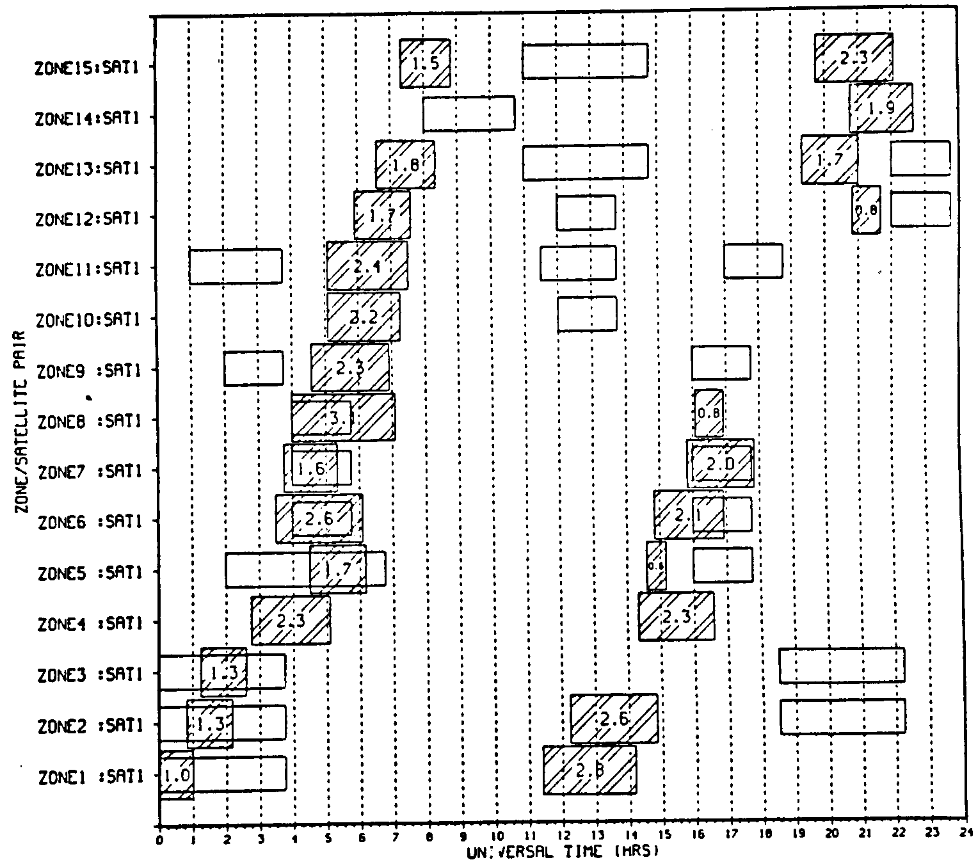

Figure 13 - Comparison of Required Broadcast Times With Visibility Times Achieved With An 8 Hour Orbit Rotated 180°

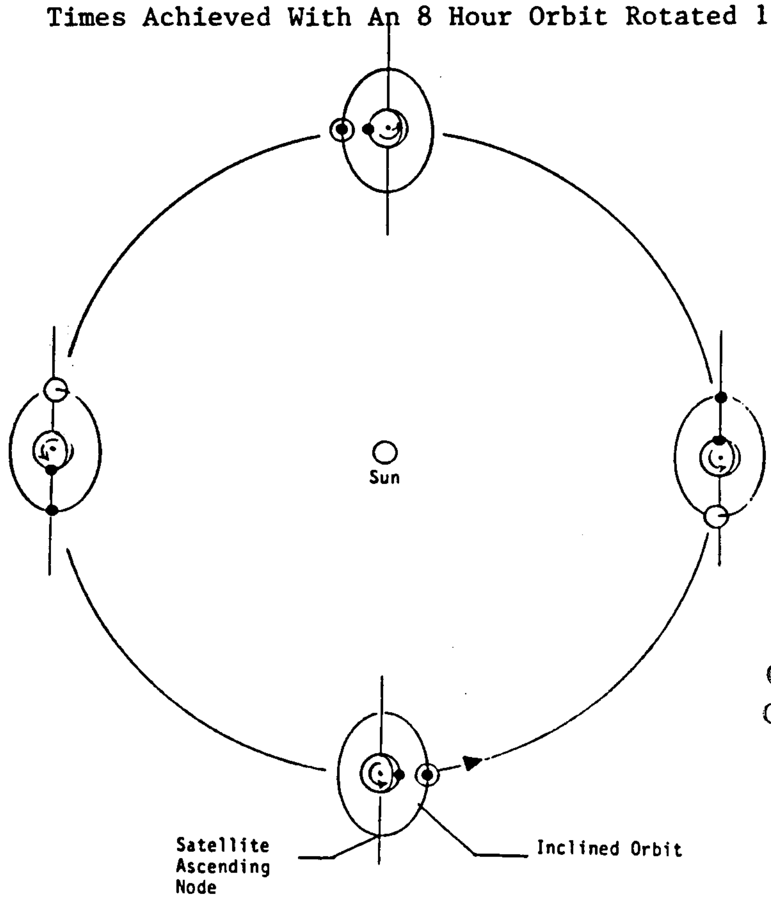

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Figure 14 - Geometry of Satellite Orbits and Relation to Earth's Orbit About the Sun

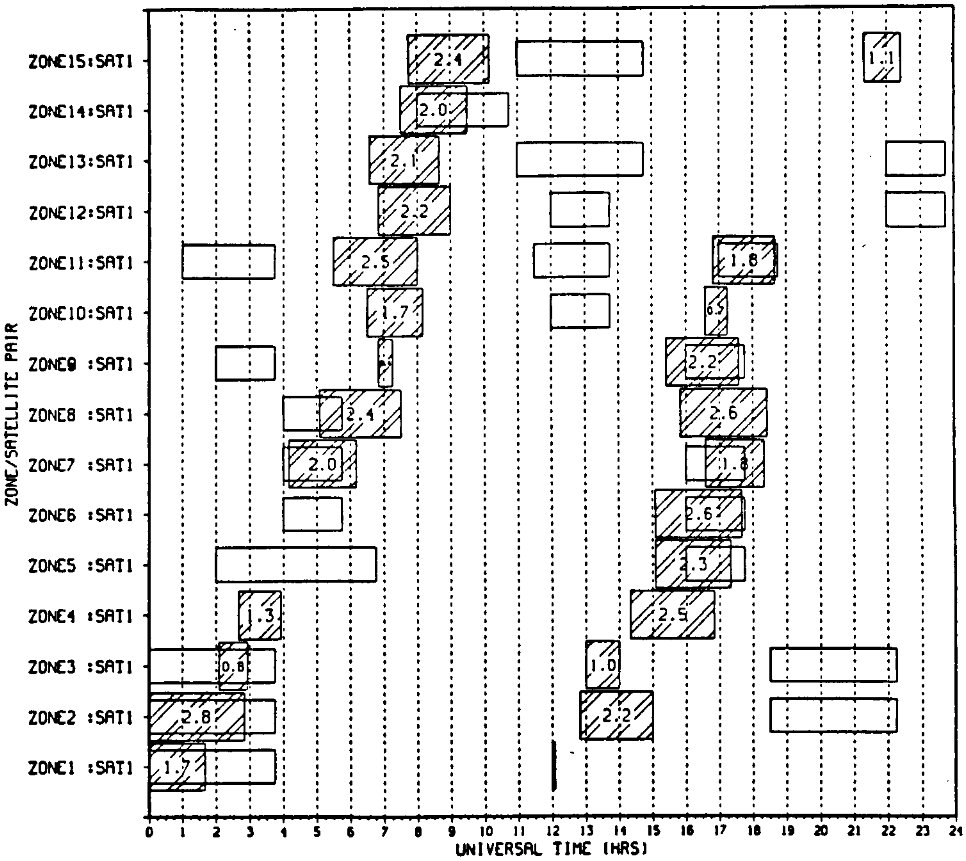

Figure 15 - Comparison of Required Broadcast Times With Visibility Times of 8 Hour Inclined Orbit 91 Days After Epoch

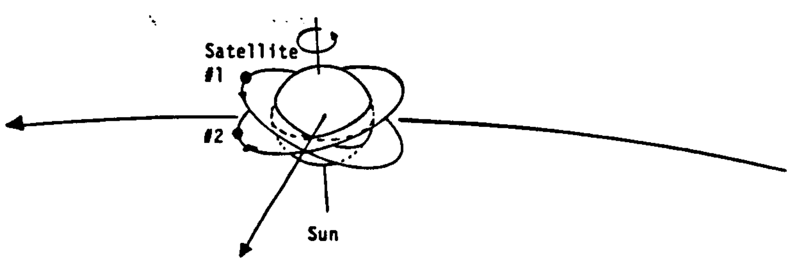

Figure 16 - Using Two Satellite Orbits to Gain Complementary Coverage

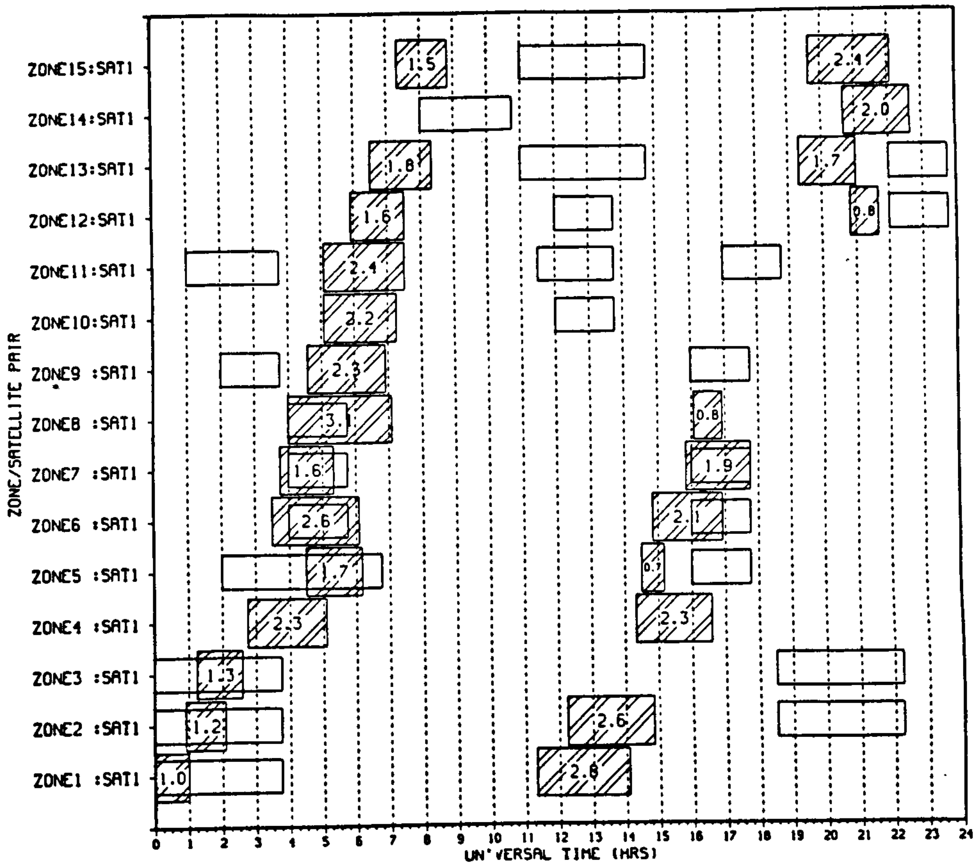

Figure 17 - Visibility Times for 8 Hour Inclined Orbit 183 Days After Epoch

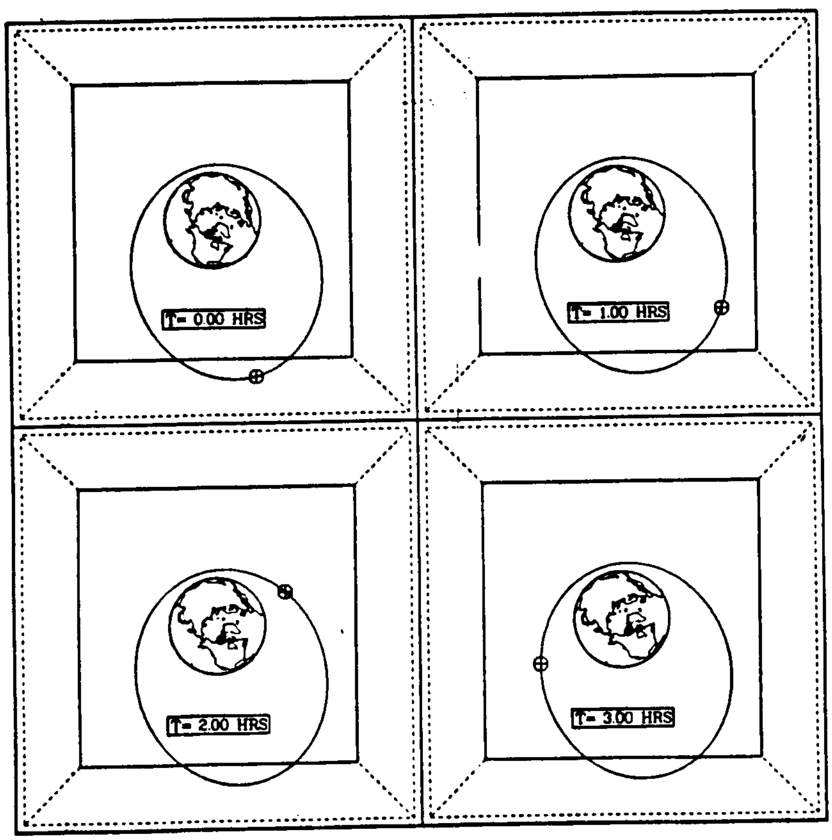

Figure 18 - Apogee at Constant Time/Equatorial (ACE) Orbit at 1 Hour Intervals

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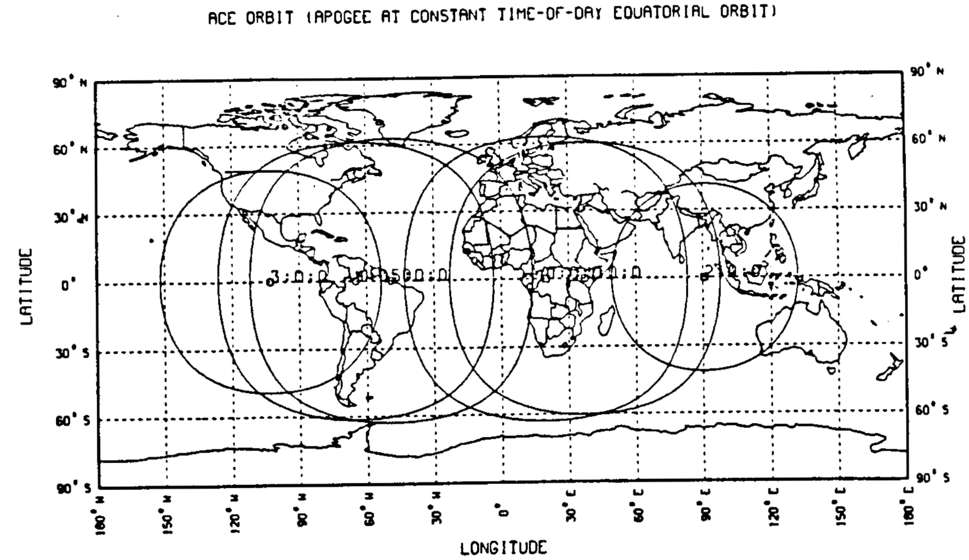

Figure 19 - ACE Orbit Visibility Contours at 1 Hour Intervals

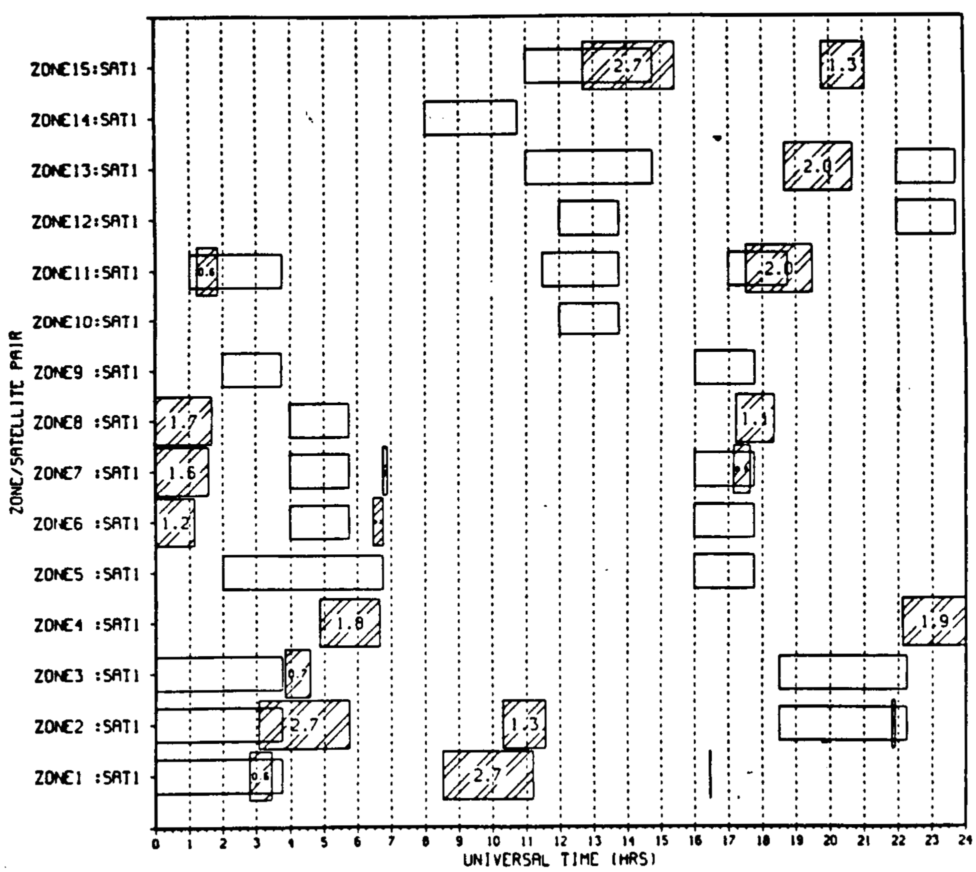

Figure 20 - Visibility Times for ACE Orbit. Times Correspond to Total Zone Visibility.

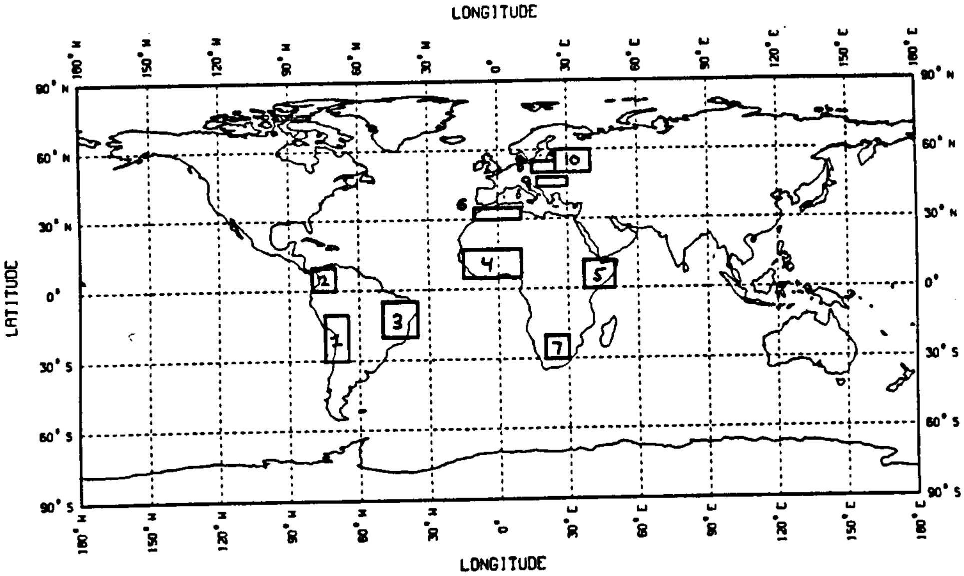

Figure 21 - Selected Zones For Evaluating Selective Visibility For Orbits

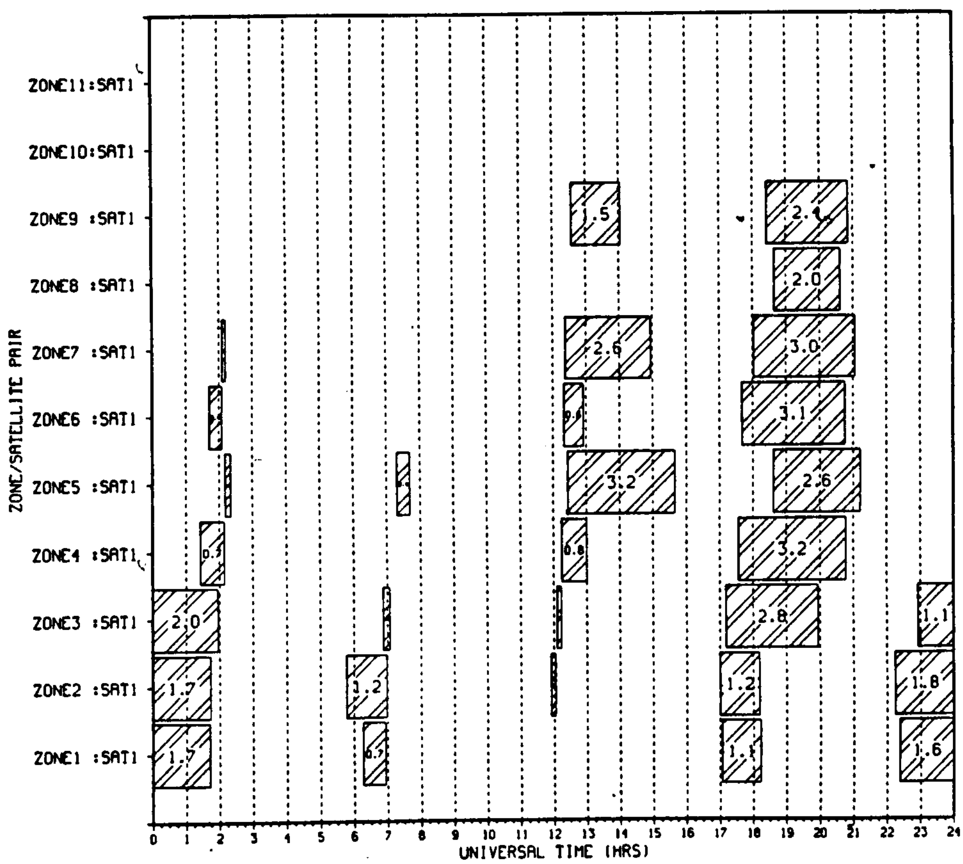

Figure 22 - ACE Orbit Visibility Times For Selected Zones

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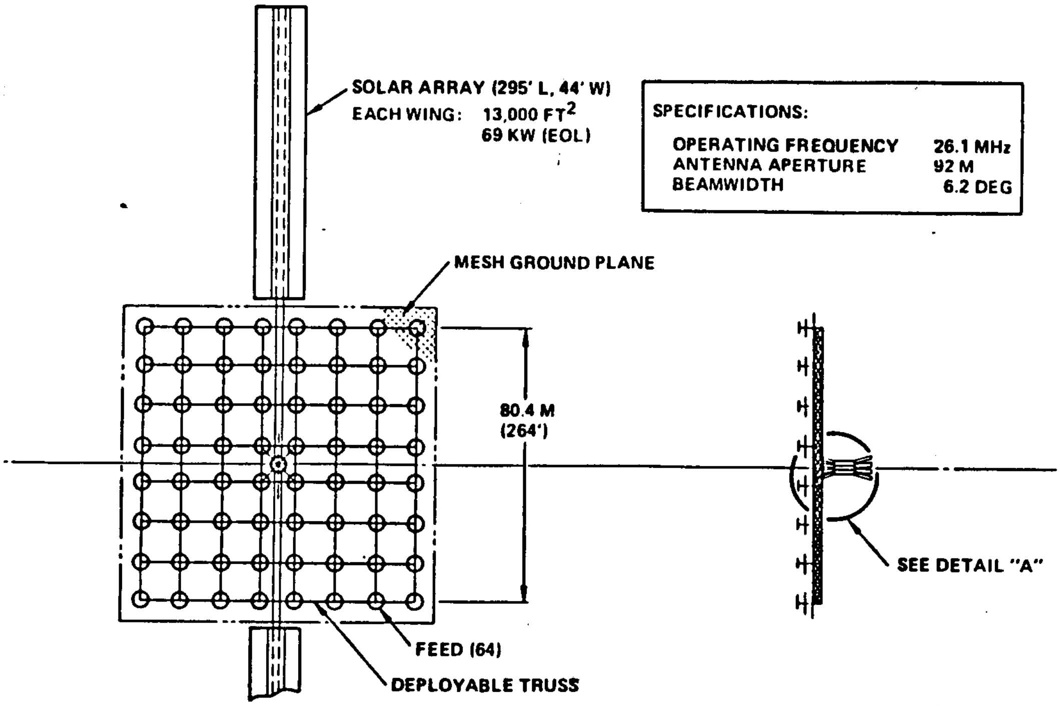


Figure 23 - TRW Concept for Medium Altitude HF Satellite

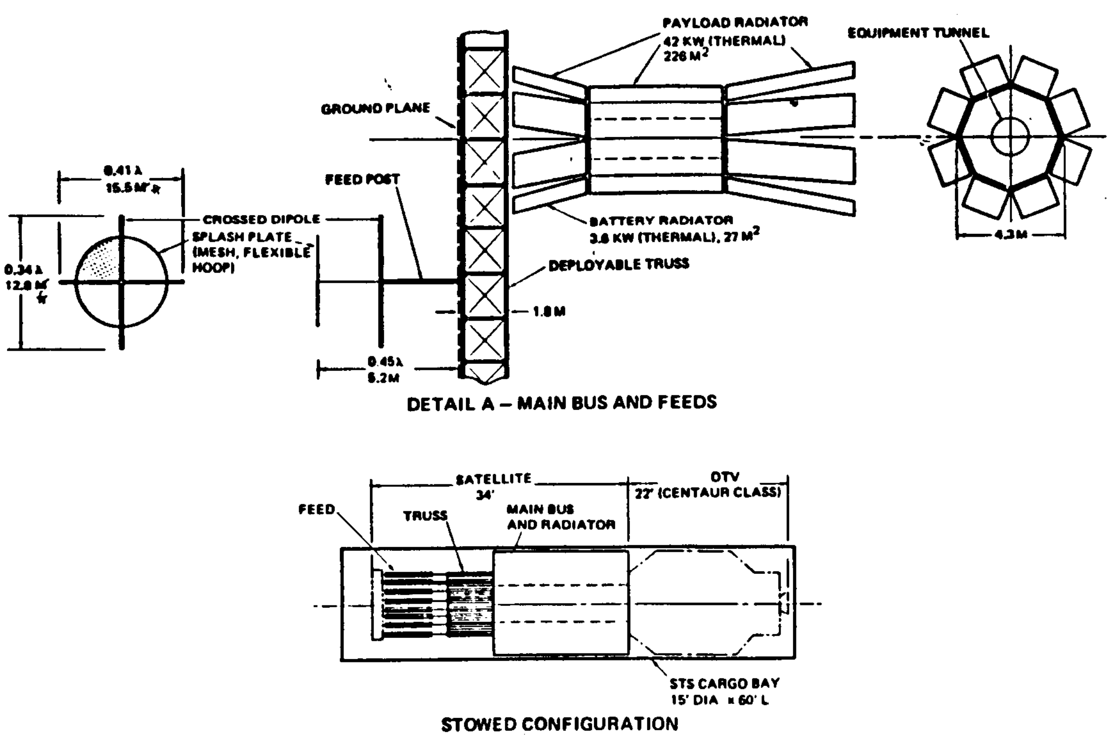


Figure 24 - Details of TRW Concept

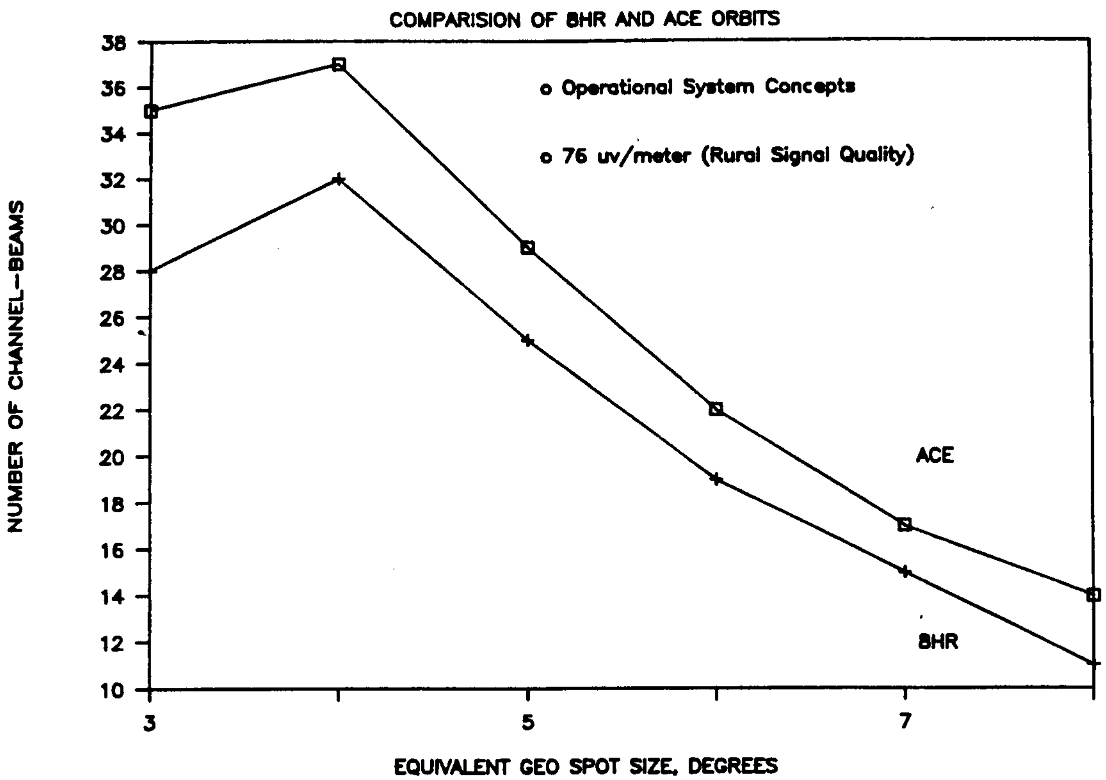


Figure 25 - Comparison of Achievable Capacity for the ACE and 8 Hour Orbits (STS/Cryogenic OTV Launch)

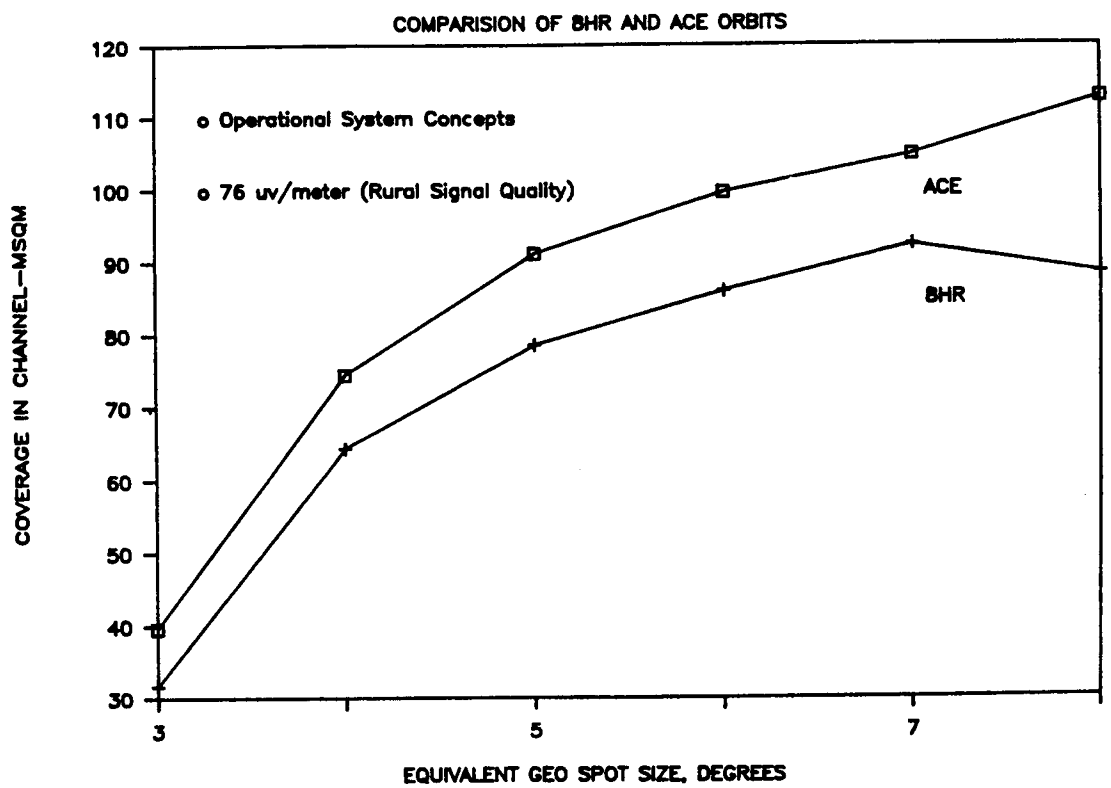


Figure 26 - Comparison of Achievable Coverage for the ACE and 8 Hour Orbits (STS/Cryogenic OTV Launch)

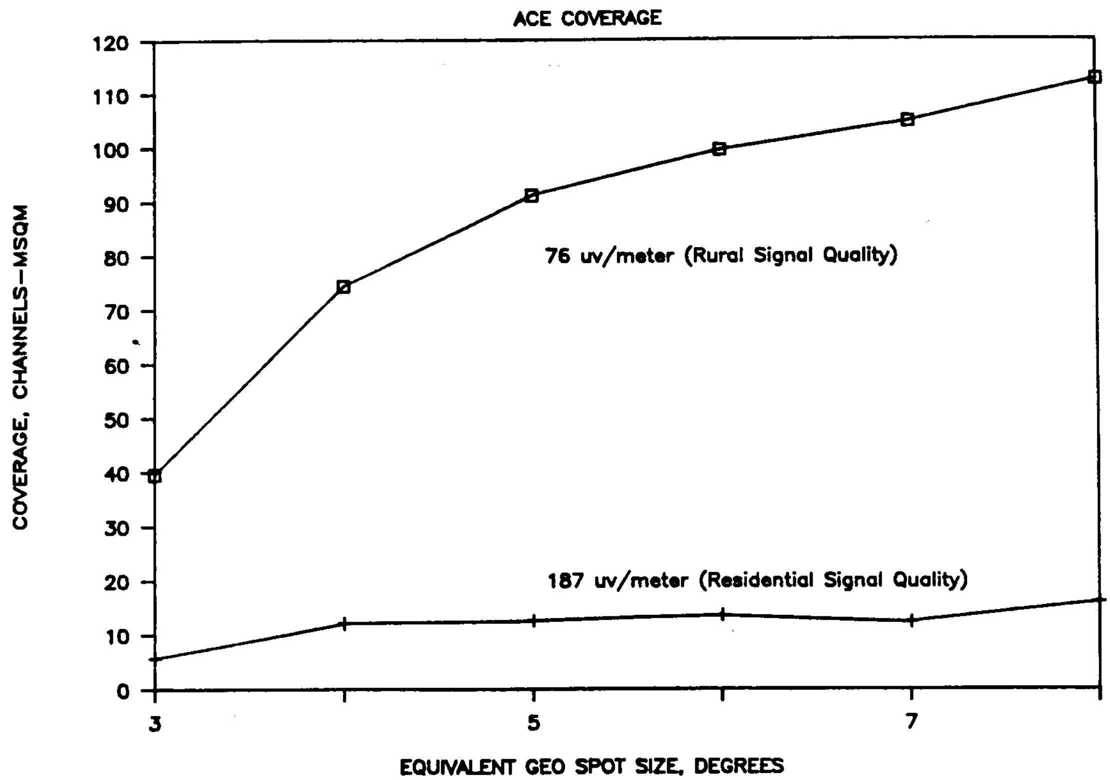


Figure 27 - Comparison of Achievable Coverage for Rural Signal Quality and Residential Signal Quality With an ACE Orbit

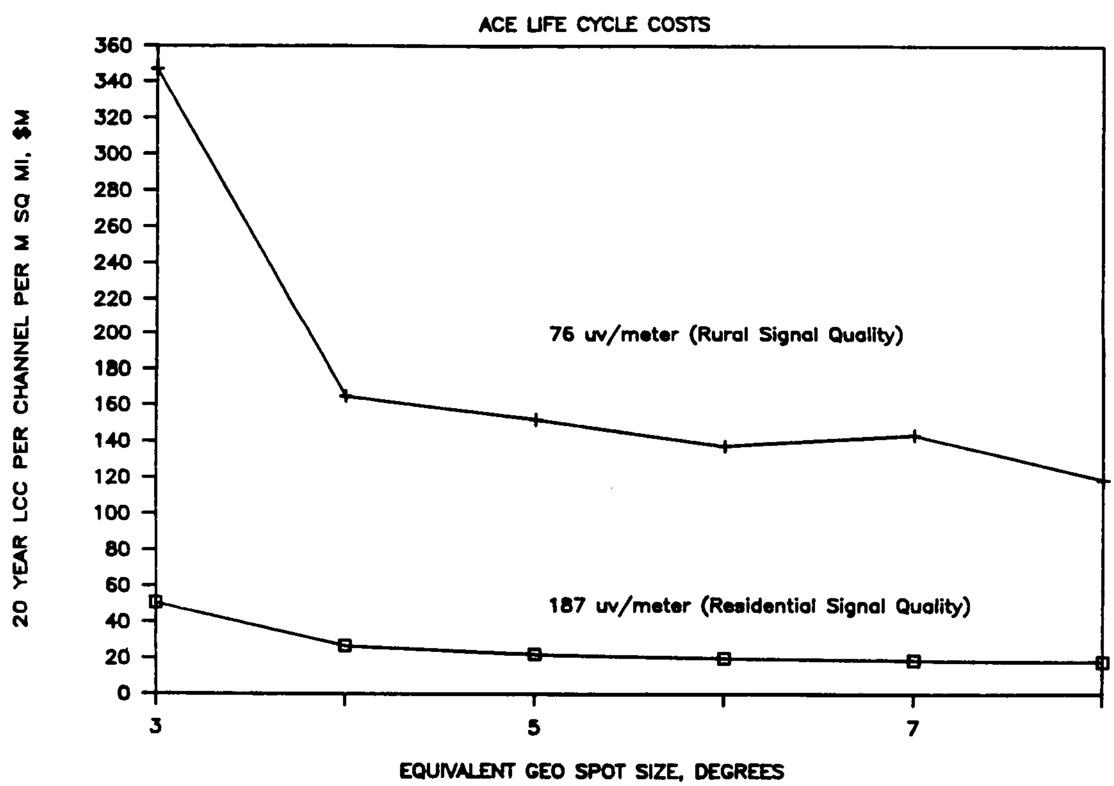
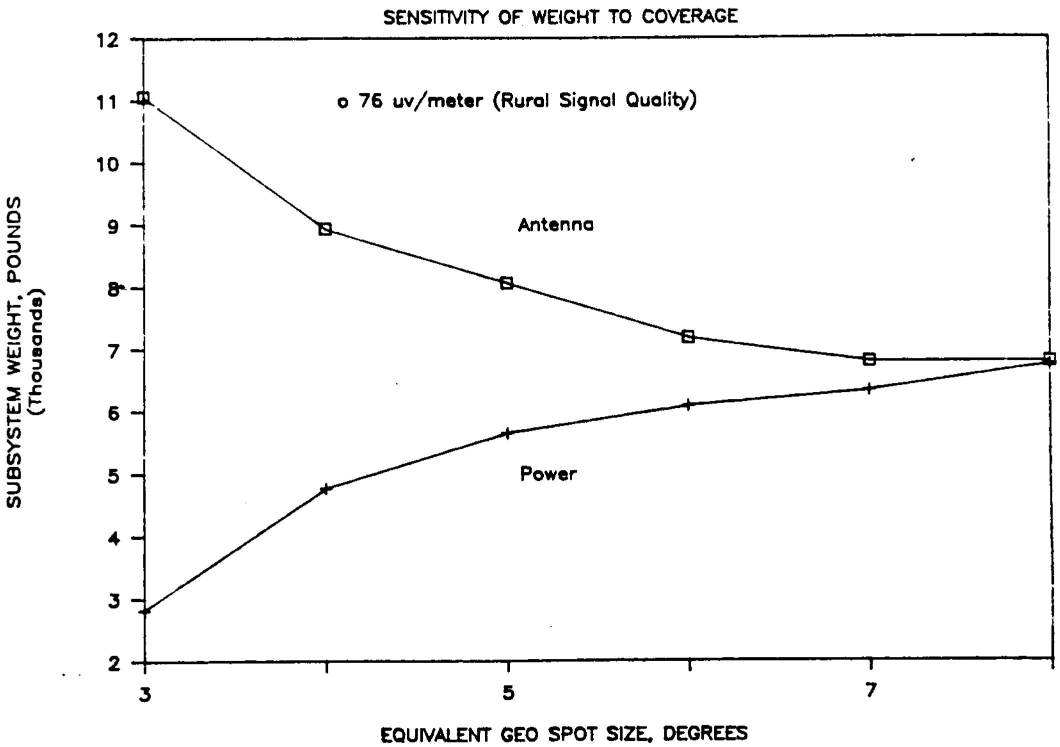
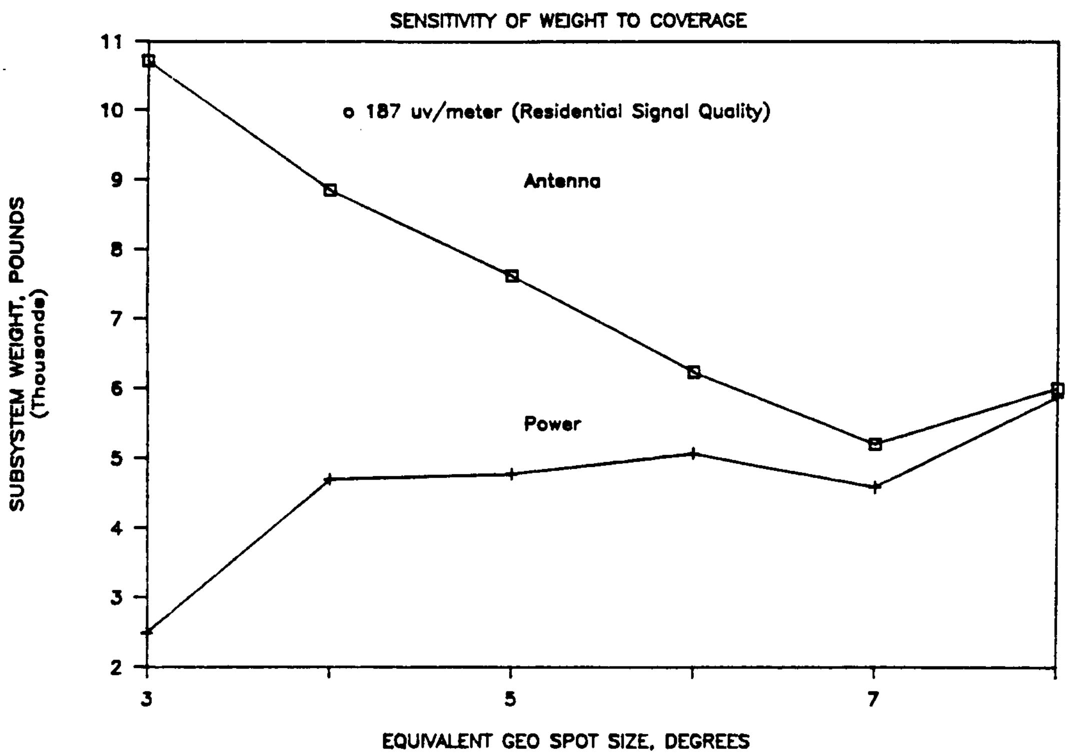


Figure 28 - Comparison of 20 Year LCC for Rural Signal Quality and Residential Signal Quality With an ACE Orbit



(a)



(b)

Figure 29 - Mass Variation With Coverage for ACE Orbit (a) 76 uv/meter (b) 187 uv/meter

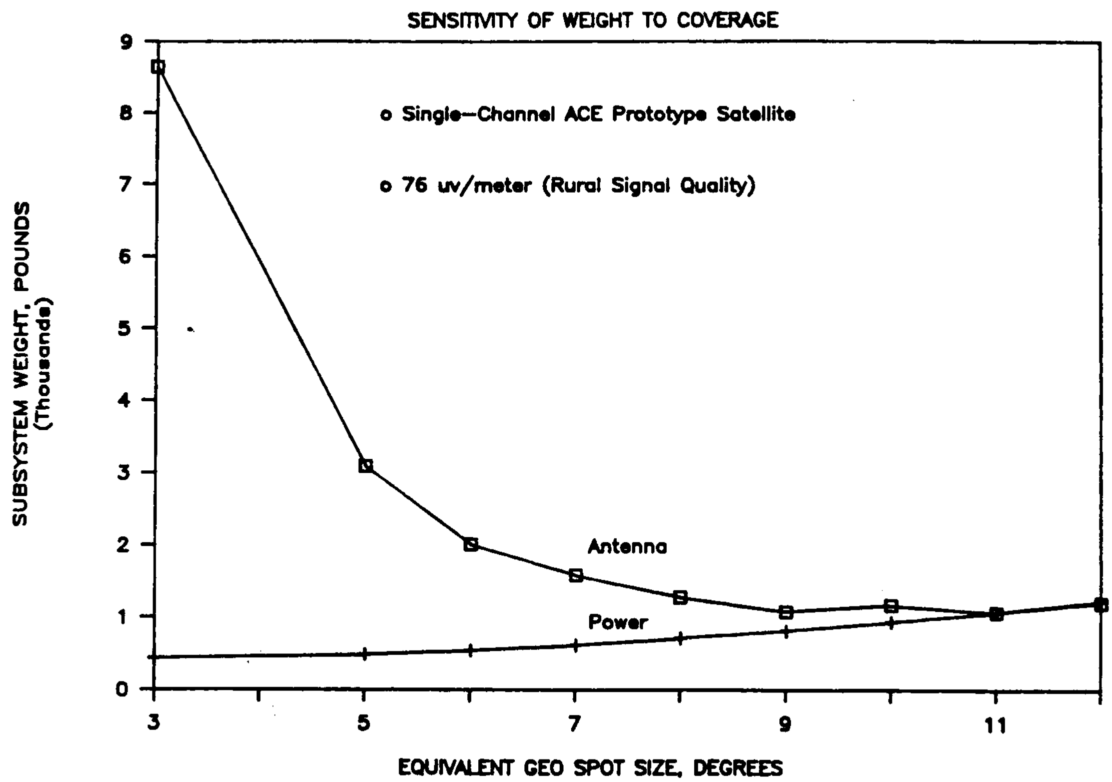


Figure 30 - Mass Viriation With Coverage for Prototype Satellite in ACE Orbit

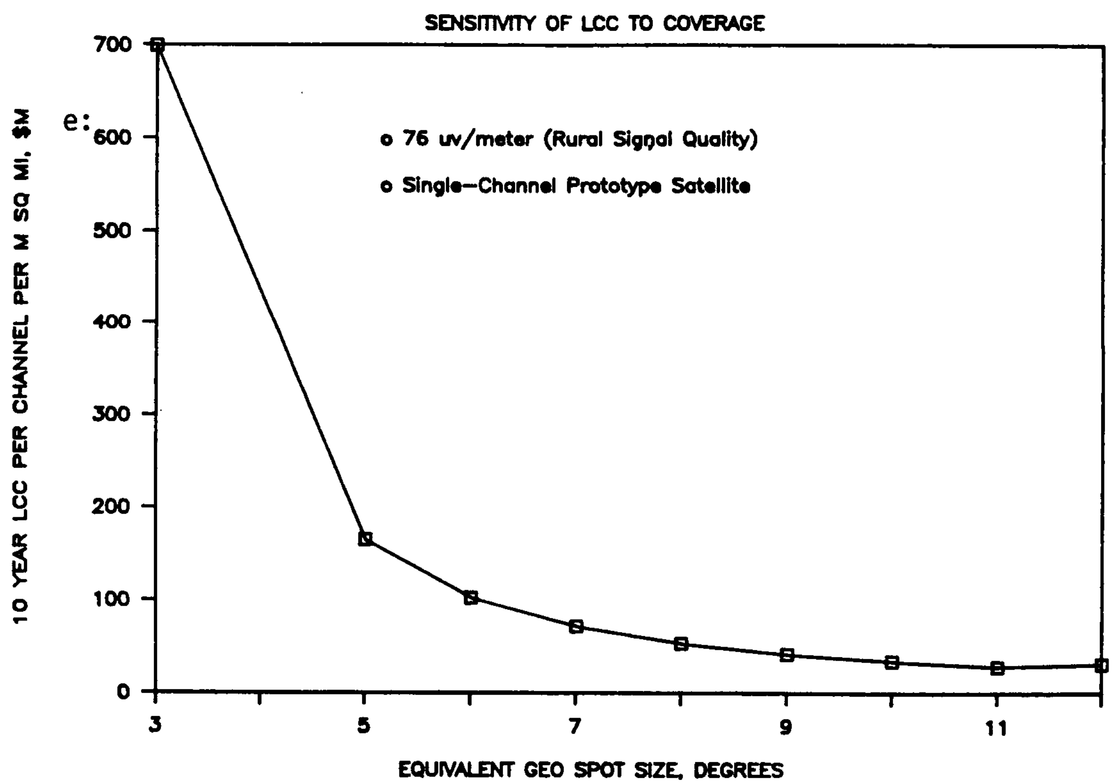


Figure 31 - LCC Variation With Coverage for Prototype Satellite in ACE Orbit

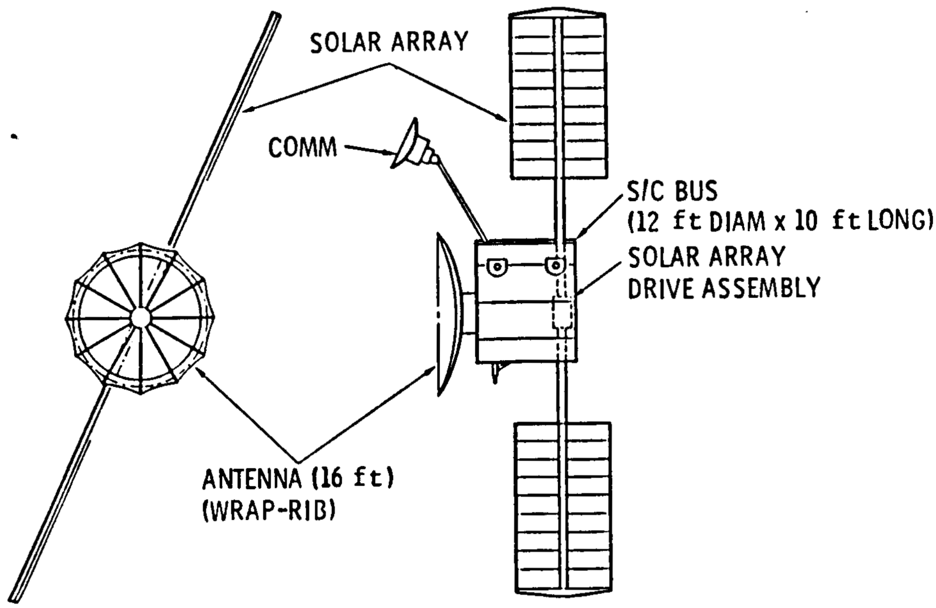


Figure 32 - TRW L-Band Satellite Concept For Sound Broadcasting

APPENDIX 1

Orbit Simulation Software

The software used to determine visibility statistics for each orbit was obtained by modifying an orbit simulation program distributed by AMSAT. The modification involved: addition of observer areas which were relevant to the VOA application; addition of orbits which were of interest to VOA; provision for interactively changing the elevation angle restriction; and a utility for displaying results of simulations.

Though these modifications were performed by NASA, the original program is the property of AMSAT. Hence, it should not be released for public use.

Operation of the program can be initiated in several ways:

1. From disk operating system-

    Put simulation disk in drive A
    Change default drive to drive A (Type A:)
    Load BASIC interpreter and run SATMENU (Type BASIC SATMENU)
        (You may have to copy your version of BASIC onto the simulation disk)

2. From the BASIC interpreter-

    Load and run SATMENU (Type Load "SATMENU",R)
        (You will have to copy all simulation software to the same drive that your BASIC interpreter resides on)

After either of these steps the Main Menu of Figure A1.1 should appear. You have a choice of five operations to choose from: "A" enables you to change the orbits which are available for simulation; "B" begins a simulation for one satellite (multiple satellite capability is not included with this version); "C" creates an ASCII file of the available orbits; "D" displays results of a simulation on the screen; and "E" will print the results on your local printer.

Selecting "E" will cause the generation of the second screen indicated in Figure A1.2. This menu provides for initiating the orbit to any particular year, month, day, and hour. It also enables control of the time steps used for the simulation. The simulation is done in such a way that the size of the time step does not affect the accuracy of the simulation. However, the simulation checks for satellite visibility only at these times. Therefore, for large steps, satellite visibility could be missed. We suggest 10 minute intervals for the orbits included with this software.

After initialization is complete, you will then be asked for an observer site to test visibility. This menu is shown in Figure A1.3. These locations can be changed only by modification of the program ORBIT4.BAS. These locations begin at statement number 1820. After selection of a location, you will be asked for the minimum elevation angle. This is the elevation to the satellite and is a factor in multipath fading. We recommend use of elevation angles no less than 10°.

The type of orbits available will then be displayed as shown in Figure A1.4. These are the orbits judged most appropriate to the VOA application. However, other orbits can be added by selecting the "A" option of the Main Menu.

Following orbit selection, the simulation will be initiated. Several orbit parameters will be listed as shown in Figure A1.5. The basic orbit parameters, reference epoch case, are given for January 1, 1986. The major orbit changes have been computed and the parameters updated to the desired start date, 8/17/87 at 18:00:00 UTC. The reference epoch should be changed yearly to maintain accuracy of the simulation. This can be changed through the update feature of the Main Menu. This update has already been done for all orbits except the ACE orbit. The update of the ACE orbit is left to the reader as an exercise.

The orbit simulation will commence at this point. A summary listing of satellite sightings will then be displayed. A more detailed listing is also generated and placed on disk for later retrieval and display or printout. The mnemonic "AOS" refers to acquisition of signal and indicates the time at which the satellite appears on the horizon (elevation angle constraints are ignored here). "LOS" refers to loss of signal and indicates when the satellite is again on the horizon and loss of visibility eminent.

Following completion of the simulation, you will be asked if you wish to perform another run. An "N" or "n" will cause a return to the main menu.

Figures A1.7 and A1.8 provide detailed listings of the particular simulation done. Note that a valid (meets elevation angle constraint) sighting did not occur until the following day, day #230, at 01:00:00 UTC. The satellite remains visible for 2 hours. The satellite appears again at 8:00 UTC as shown in Figure A1.8. It is visible for 40 minutes on this pass.

These detailed listings provide information on azimuth and elevation to the satellite, doppler shift due to relative motion of the satellite, range to the satellite, satellite altitude, latitude and longitude of the satellite, and the mean anomaly (the satellite location in its orbit, measured in degrees from perigee).

Copies may be made of this software for internal VOA use. However, no copies should be distributed outside VOA without NASA approval.

Update/Change of Orbit Files

The simulation software has provisions for up to 20 orbits. Orbits can be added, deleted, or modified by use of the update option of the Main Menu. To perform this operation, it is important to have a local printer to record old data. Once a change is initiated, the old data is lost.

Figure A1.9 shows the menu that appears when the orbit update option is selected from the Main Menu (option "A"). Five orbits are available with the current version of the software. These were judged to be the most useful for the VOA application at the time of this writing. Should others become of interest or the VOA application change, other orbits can easily be added. Also, the orbits provided can easily be changed to obtain different starting positions of the satellites (the most commonly desired change).

As an example, the epoch date (reference date for orbital parameters) will be changed to 1987. We will select the 8Hr/EQU (8Hr Posigrade Equatorial) orbit for the change.

First indicating we desire to change an existing orbit, we type "C". As shown, the program will then request the name of the orbit to be changed. The name must be entered exactly as shown. Capitals and lower case are significant. We type "8HR/EQU".

As shown in Figure A1.10, the program will list the parameters of the orbit designated and request verification for the change. At this point, if you plan to make a change, it is important to print the display at your local printer. Typing "Y" will initiate an input menu and you will lose the current data. This can be inconvenient when you wish to change only one item of the list. Therefore please make a copy before you verify. This copy is easily obtained on most PC's by simply striking the screen print key. After doing this, we type "Y".

Figure A1.11 shows the sequence of queries from the program and the entries made. In this case all entries, except the epoch year, were simply copied from the previous data printed. The epoch year was made the current year by typing the last two digits, "87".

Other changes could have been made. For example the starting position of the satellite is sometimes moved around the earth so that it appears over a specific longitude at a specific time. The right ascension of the orbit, RAAN parameter, is the longitude where the orbit crosses the equator. In this particular case with the orbit in the equatorial plane, such a parameter is not meaningful. However it is necessary, even in this case, to specify the RAAN in order to define the timing of the satellite in its orbit. In this case we have chosen 240° west longitude. The argument of perigee is the angle in degrees, from RAAN, to the lowest point of the orbit. Again, this serves only a timing purpose since this particular orbit is circular. The selection of 180° places perigee opposite to the RAAN. The mean anomaly is the starting position of the satellite with respect to perigee. The selection of 180° forces the starting position to coincide with RAAN. Therefore, as long as the argument of perigee and mean anomaly are left at 180°, the starting position of the satellite will always be at the RAAN and also at apogee, the highest point of the orbit. We recommend that all other parameters be left as shown, unless the user understands the interrelationships between the various parameters.

Making our changes, the program will then ask for verification that all entries are correct. If we affirm by typing "y", the program will return to the editor's main menu. From there we return to the Main Menu by selecting the "E" exit option.

As an exercise, we suggest the reader update the epoch year of the ACE orbit to 1987. Following that, the reader might change the RAAN by 10° and compare simulation runs for the two cases.

```
                    SATELLITE PROGRAMS

             A UPDATE SATELLITE ELEMENTS
             B BATCH OUTPUT - ONE SATELLITE
             C UPDATE FORTRAN ELEMENT DATA FILE
             D DISPLAY RESULTS OF SIMULATION
             E PRINT RESULTS OF SIMULATION




             ENTER SELECTION (ESC TO EXIT TO DOS)
```

FIGURE A1.1 - Main Menu for Orbit Simulator

```
                  AMSAT ORBITAL PREDICTION PROGRAM
   *****************************************************************

Start: Year = 1987       (You Enter Year of Interest in Simulation)
       Month (1-12) = 8 (You Enter Month of Interest)
       Day = 17 (Day of Int)  Day #      229 (Computer Determines Day#)

Start: UTC  Hours = 18  (You Enter Desired Starting Hour)
          Minutes = 00

Duration:   Hours = 24  (You Enter Desired Duration of Simulation)
          Minutes = 00

Time Step:  Min.  = 10  (You Enter Desired Time Step of Simulation)
```

FIGURE A1.2 - Second Menu. Input of Simulation Orbit Parameters

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```
                    SITE SELECTION MENU
         ****************************************
          Entry # 1   for   Bucharest, Rumania
          Entry # 2   for   Cairo, Egypt
          Entry # 3   for   Leningrad, USSR
          Entry # 4   for   Lima, Peru
          Entry # 5   for   Magadan, USSR
          Entry # 6   for   Mexico City, Mex.
          Entry # 7   for   Miami, Florida
          Entry # 8   for   Moscow, USSR
          Entry # 9   for   Nairobi, Kenya
          Entry # 10  for   Novosibrisk, USSR
          Entry # 11  for   Oslo, Norway
          Entry # 12  for   Panama City, Pan.
          Entry # 13  for   Peking, China
          Entry # 14  for   Punta Arenas, Chi.
          Entry # 15  for   Salvador, Brazil
          Entry # 16  for   Santiago, Chile
          Entry # 17  for   Washington, D. C.

      Select Entry # 10 (You Select Location of Observer)
     Elevation Angle, Degrees (Default = 10 )? 10 (You Select Min-
                                                  mum Elevation to
                                                  satellite)
```

FIGURE A1.3 - Third Menu. Input of Observer Location

```
                    SATELLITE SELECTION MENU
**********************************************************************
Entry #   1   for   SUNSYNC         Polar Sunsynchronous
Entry #   2   for   8HR/EQU         8Hr Posigrade Equatorial
Entry #   3   for   8HR/INC         Inclined 8Hr (28 Deg)
Entry #   4   for   STS             Shuttle Altitude (275 Km)
Entry #   5   for   ACE             Apogee at Constant Time/E

Select Entry # 5 (You Select Orbit Type)
```

FIGURE A1.4 - Fourth Menu. Selection of Orbit Type

```
Orbital Elements for   ACE
      Reference ID =   Apogee at Constant Time/E

Reference Epoch = 86 /   1.00000000000
Starting  Epoch = 87 / 229.75000000000  =  08/17/87 at 18:00:00

************************************************************************

Parameter               Reference     Starting

Drag                    .00001
Inclination             0
R.A.A.N.                150          -74.39899
Eccentricity            .4871
Arg. Perigee            180           1348.798
Mean Anomaly            180           261.1231
Mean Motion             5.0016        5.013474999700012
S.M.A., km              14420.26
Orbit Number            1             2974
Freq.,MHz               26
```

FIGURE A1.5 - Fifth Screen. Display of Initial Orbit Parameters

```
 - - - DAY #  230      AUG 18      - - - ORBIT #    2976
                  LOS AT 03:42:20
                  AOS AT 06:34:48
 - - - DAY #  230      AUG 18      - - - ORBIT #    2977
                  LOS AT 09:09:04

Another Run?  N
```

FIGURE A1.6 - Summary Listing of Times Satellite is in View and Query for Continuation

ACE Tracking Data from Novosibrisk, USSR
Apogee at Constant Time/E Page # 1

U.T.C. HH:MM:SS	AZ (deg)	EL (deg)	DOPPLER (Hz)	RANGE (km)	ALTITUDE (km)	LAT (deg)	W.LONG (deg)	M.A. <360>
	- - - DAY #	230	AUG 18		- - - ORBIT #	2976		
01:00:00	189	10	-182	12,575	8,700	0.0	283.3	67
01:10:00	181	13	-177	13,800	10,071	0.0	276.7	80
01:20:00	174	14	-165	14,939	11,276	0.0	271.3	92
01:30:00	169	15	-145	15,942	12,300	0.0	267.0	105
01:40:00	164	16	-126	16,812	13,162	0.0	263.2	117
01:50:00	160	16	-105	17,536	13,859	0.0	260.0	130
02:00:00	157	16	-83	18,109	14,391	0.0	257.1	142
02:10:00	154	15	-62	18,540	14,770	0.0	254.4	155
02:20:00	151	15	-41	18,826	14,994	0.0	251.9	167
02:30:00	148	14	-21	18,972	15,066	0.0	249.4	180
02:40:00	146	13	-1	18,979	14,985	0.0	246.9	192
02:50:00	143	12	19	18,848	14,753	0.0	244.4	205
03:00:00	140	11	38	18,584	14,365	0.0	241.7	217
			LOS AT	03:42:20				
			AOS AT	06:34:48				

FIGURE A1.7 - Listing of Satellite/Observer Parameters During Early Morning UTC Hours. UTC 00:00 Corresponds to 04:32 at Target Area.

ACE Tracking Data from Novosibrisk, USSR
Apogee at Constant Time/E Page # 2

U.T.C. HH:MM:SS	AZ (deg)	EL (deg)	DOPPLER (Hz)	RANGE (km)	ALTITUDE (km)	LAT (deg)	W.LONG (deg)	M.A. <360>
	- - - DAY #	230	AUG 18		- - - ORBIT #	2977		
08:00:00	219	10	99	17,861	13,643	0.0	309.7	233
08:10:00	215	11	122	17,018	12,891	0.0	306.3	246
08:20:00	211	11	144	16,025	11,980	0.0	302.4	259
08:30:00	206	11	168	14,865	10,891	0.0	297.7	271
08:40:00	199	10	188	13,565	9,636	0.0	292.1	284
			LOS AT	09:09:04				

FIGURE A1.8 - Listing of Satellite/Observer Parameters During Later Morning UTC Hours. UTC 08:00 Corresponds to 12:32 at Target Area.

```
Elements for the following satellites are in the file:

SUNSYNC      Polar Sunsynchronous
8HR/EQU      8Hr Posigrade Equatorial
8HR/INC      Inclined 8Hr (28 Deg)
STS `        Shuttle Altitude (275 Km)
ACE          Apogee at Constant Time/E

Do you wish to Add (A), Change (C) or Delete (D) a satellite
record or Exit (E) from this program

C (You Indicate a Desire to Change An Entry)

Which satellite ? 8HR/EQU  (You Indicate The Entry)
```

FIGURE A1.9 - Main Menu for Orbit File Editor

```
Satellite        = 8HR/EQU
ID               = 8Hr Posigrade Equatorial
Epoch year       =  87
Epoch day        =  1
Drag             =  1E-12
Inclination      =  0
R.A.A.N.         =  240
Eccentricity     =  .000001
Arg. of perigee  =  180
Mean anomaly     =  180
Mean motion      =  3
Epoch orbit no.  =  1
Beacon freq.     =  26

Do you wish to update elements for this satellite (Y/N)
Y
```

FIGURE A1.10 - Listing of Current File Entry

```
SATELLITE DESIGNATION   =     8HR/EQU
ID                      =     8Hr Posigrade Equatorial
EPOCH YEAR (YY)         =     87
EPOCH DAY (DD.DDDD-)    =     1.0
DRAG (ORB/DAY^2)        =     1e-12
INCLINATION (DEG.)      =     0
R.A.A.N. (DEG.)         =     240
ECCENTRICITY            =     .000001
ARG. OF PERIGEE (DEG.)  =     180
MEAN ANOMALY (DEG.)     =     180
MEAN MOTION (ORB/DAY)   =     3
EPOCH ORBIT NO.         =     1
BEACON FREQUENCY (Mhz)  =     26

Is this correct? (Y/N)
Y
```

FIGURE A1.11 - Input Screen Showing Prompts and Entries

APPENDIX 2

Mass Estimating Software

Mass estimates of the spacecraft used in this report were based on analyses done by TRW in the previous support to VOA in sound broadcasting. The software described herein applies to HF and VHF spacecraft intended for sound broadcasting applications. This software is a modification of a program originally developed by TRW. The modifications enhanced the modeling of the launch sequence to include a solid apogee kick motor (when needed), enabled the saving and retrieval of satellite configuration files, added the useful ACE orbit, enabled the user specification of power technology, and provided speed enhancement of the analysis process.

The mass estimating program is written in BASIC, and can only be executed through your resident BASIC interpreter. Two methods of initiating are available:

1. From disk operating system -

    a. change default drive to A drive (or whichever drive the mass estimating program is to reside on.

    b. enter BASIC SVBS (Your BASIC interpreter may have to be copied to the mass estimating program disk)

2. From BASIC interpreter -

    a. enter LOAD "SVBS.BAS",R (You must copy all the mass estimating software to the disk where BASIC resides)

After either of these procedures the program will load and initialize itself. It will then display the Main Menu shown in Figure A2.1. This lists the actions which are available to the user. For a new user, option #1 will be the first to be used. Selecting this option we will get the menu shown in Figure A2.2. This menu defines the currently available orbital transfer vehicles and it also provides for the definition of one new vehicle, item 7. The default for this menu is no change at all. Striking the "Return" or "Enter" will preserve this data and switch to the orbit selection menu shown in Figure A2.3. As can be seen there are seven defined orbits available, and provision exits for adding a user defined orbit. The included orbits are those believed most applicable to VOA sound broadcasting. The default selection is no change to the orbit list.

Defaulting out of the orbit selection causes a switch to the scenario definition menu shown in Figure A2.4. The analysis of this software operates on three scenarios simultaneously. This has been found very convenient for evaluating differences between systems and to evaluate sensitivity to certain parameter changes. Eleven parameters are user selected from the top table or defined by the user. For example, the OTV choices are 1-7. 1-6 are the choices seen in the orbit selection table. Since we chose to default out of that menu, there was no entry for the 7th orbit. Consequently, the 7th choice appears blank here. The STS lift capacity can be any value the user chooses.

Sixty-five thousand pounds is the long range goal for lift capability and this would be the maximum one would choose. Smaller values can be selected, however, to force the software to design small satellites. This feature was used to obtain satellite designs of only one channel for the rural field strength case. The antenna coverage is defined in item 21. This is the broadcast area diameter, in degrees, as seen by an observer in geostationary orbit (36,000Km). Three degrees would be approximately 1000 miles. From the analysis in the main text, it was found that coverage of about 4° was optimum from a cost viewpoint. 17° would correspond to earth coverage.

Figure A2.5 shows a completed menu with three new systems defined. They are all identical except for field strength. Being satisfied with these inputs, and striking the "return" key, we are then asked how the transmitters are loaded in terms of peak/average ratio for power. For multiple channels this ratio would be about 1.7, and for a single channel this ratio would be 1.0. We choose to default for all three scenarios.

Figure A2.6 shows the fifth menu which provides for selection of power technology. We choose to select the far term silicon blankets (2).

Following this, the program will return to the Main Menu. From this menu we choose to save the current configurations as shown in Figure A2.7. Had the dataset already been in existence, the program would have warned the user and requested verification for overwrite. Since this dataset is new, the dataset is filed immediately.

We then choose item #4 of the Main Menu to initiate execution of the analysis on the current configurations. Upon completion of the analysis we choose to do a quick review by displaying a summary of the results on the screen. We select item #5. The results are displayed as in Figure A2.8. As can be seen by comparing the first two items, the OTV weight consumes most of the STS lift capability. This would suggest a poorly performing OTV, and we might choose to go back to the Main Menu and initiate another configuration definition using more advanced OTV's. However, to be concise, we will continue with these configurations.

The maximum number of channel-beams of each configuration can be seen in the fifth line from the bottom. System #1 has no capability, system #2 has capability for two channels, and system #3 has capability for 17 channels. The difference in these systems is the field strength selected for each. Consequently, the power per channel and the power system weight per channel will be correspondingly different. The bottom line indicates there is a fixed weight overhead of 7097 pounds for each configuration. That leaves 4164 pounds for payload in each case (second line from bottom). Based on the power requirements for each case, the payload required is given in the third line from the bottom. In system #1, the payload capability is just under 300 pounds shy of enabling one channel. This may seem small, but to increase payload allowance by 300 pounds the total launch weight may increase three to five times as much, depending on the orbit.

Returning to the Main Menu, we choose to generate a printout of the results by selecting option #6. The print menu shown in Figure A2.9 provides for printer control. If you do not have an Epson compatible printer you should select item #4 from this menu. Otherwise, you can select from draft quality to bold correspondence quality for your printout. We choose to select item #3.

Figure A2.10 shows the summary listing which is generated in the bold correspondence mode. The amount of information provided is about doubled. The printer will continue with a more detailed listing as shown in Figure A2.11. The mass of all subsystems is listed as well as some of the analysis assumptions.

After completion of the printout, the program automatically returns to the Main Menu. We then choose to switch to a previous dataset, one named ACEEXP1. We do this by selecting option #2. The program will list all the existing datasets, including CUSTBIPP which we had just saved. Typing aceexp1 and hitting "Return" will make the selection for us. We can immediately display a summary of that run (assuming one had been made before the save) by selecting item # 5. This summary listing is shown in Figure A2.13. Here we see three configurations which had been optimized for one channel, but had made use of different antenna sizes (lines 7 and 8). Note that the STS launch capability had been diminished to achieve this optimization (line 1).

This software is quite versatile and can be modified for other orbits and other launch systems. However, for maximum accuracy, changes should not be made without consulting with NASA-Lewis for evaluation of probable accuracy.

TRW HF/VHF VOICE BROADCAST ANALYSIS

1-Create A New Scenario File
2-Retrieve Old Scenario File
3-Save Current Scenario as a File
4-Execute Current File
5-Display Summary of Last Run
6-Print Details of Last Run
7-Terminate (Default Case)

Your choice? 1

FIGURE A2.1 - Main Menu of Weight Estimating Program

** Define OTV parameters - Screen #2 **

The following OTV options are available to you:
OTV 1 & 2: Mission Customized for the full specified STS capability
(ie, The OTV is designed specifically for the Mission)
OTV 3 thru 6 are fixed, standard performance boosters
OTV 7 Can be any fixed booster of your choice
(To change any of the values, access program @ line 20000..)

	1	2	3	4	5	6	7	(a)
	OTV Class	Example	ISP -Sec-	DriWt -Lb-	ASE -Lb-	Capacity Fuel	Resid (Lb)	TMF %
1	CustCryo	Centaur	450	6163	7462	29707	557	10
2	CustBiPp	BiProp	300	2500	1500	11000	200	14
3	CentaurG	Centaur G	450	6163	7462	29707	557	8
4	HPPM	Aerojet	328	1656	948	11506	200	14
5	TOS	LSolid	293	2388	5500	21400	400	14
6	Pam-A	SSolid	276	700	4090	7751	100	11
7			0	0	0	0	0	0

Note (a): Tankage Mass Fraction=Tankage/Fuel

> Enter 7 for New OTV of your choice, ELSE Enter <CR>:

FIGURE A2.2 - Second Menu Describing Current Orbital Transfer Vehicles (OTV). Also Provides for Defining New OTV.

```
          *** Select Spacecraft Orbit - Screen #3 ***
          ------------------------------------------
            Orbits 1 thru 7 are your Standard Options.
  You can Add an Orbit (#8) of Your Choice! But! The Solar array
                 & batteries will be approximated
   *----------*--------*---------*------------*-------------------*
   *  Orbit   * Apogee * Perigee * Inclination * Launch Inclination *
   *----------* (NMi) -*- (NMi) -*---- (Deg) --*------- (Deg) ------*
 1 * Geosync  *  22767 *   22767 *      0.00   *       28.00        *
 2 * Molniya  *  24732 *    3934 *     63.44   *       28.00        *
 3 * 6Hrs     *   9043 *    9043 *     28.00   *       28.00        *
 4 * 8Hrs     *  10958 *   10958 *     28.00   *       28.00        *
 5 * 12Hrs    *  14359 *   14359 *     28.00   *       28.00        *
 6 * 8Hr/Inc  *  10958 *   10958 *     28.00   *       28.00        *
 7 * ACE      *  11597 *    4000 *      0.00   *       28.00        *
 8 *          *      0 *       0 *      0.00   *        0.00        *
   *----------* (NMi) -*- (NMi) -*---- (Deg) --*------- (Deg) ------*

    >Enter 8 for New Orbit ELSE Press <CR>:
```

FIGURE A2.3 - Third Menu Describing Current Orbits. Also Provides for Defining New Orbits.

```
                  *** Configuration options coding: - Screen #5 ***
OTV Choice: 1=CustCryo  2=CustBiPp  3=CentaurG 4=HPPM 5=TOS 6=Pam-A 7=
Orbit:1=Geosync 2=Molniya 3=6Hr 4=8Hr 5=12Hr 6=8Hr/Inc 7=ACE    8=
RF Band (MHz): 1=15.45    2=17.90    3=21.75    4=26.10    5=68.00
Antenna -----: 1=Cable-catn  2=Cross-beam  3=Inflatable
Power storage: 1=NiH2       2=RFC         3=HEDRB
Operation during Eclipse: 1=Yes    2=No

      System Analysis Parameters:        * System 1 * System 2 * System 3 *
      --------------------------         * -------- * -------- * -------- *
  6.  * OTV choice ---------------------- :      1.0       1.0       1.0
  7.  * Orbit choice -------------------- :      1.0       1.0       1.0
  8.  * Power storage choice ------------ :      1.0       1.0       1.0
  9.  * Antenna choice ------------------ :      2.0       2.0       2.0
 10.  * Operate during eclipse ---------- :      2.0       2.0       2.0
 17.  * STS KSC nominal lift capacity -(Lb):  65000.0   65000.0   65000.0
 19.  * Max # of beams (shown=Unlimited) --:   1000.0    1000.0    1000.0
 20.  * Field strength -------- (micro-V/M):    300.0     300.0     300.0
 21.  * Ref GEO beamwidth ----------- (Deg):      3.0       3.0       3.0
 26.  * Elevation angle ------------- (Deg):     20.0      20.0      20.0
 36.  * Operating frequency --------- (MHz):      4.0       4.0       4.0

       Enter Parameter Line # for change!  Else press <CR>:
  * OTV choice ---------------------- : > Change System 1, 2, or 3: ? 1
       Enter new value (See Options above): ? 2
```

FIGURE A2.4 - Fourth Menu Describing Current Scenarios. Provides for Defining New Scenarios.

```
            *** Configuration options coding: - Screen #5 ***
OTV Choice: 1=CustCryo  2=CustBiPp  3=CentaurG 4=HPPM 5=TOS 6=Pam-A 7=
Orbit:1=Geosync 2=Molniya 3=6Hr 4=8Hr 5=12Hr 6=8Hr/Inc 7=ACE    8=
RF Band (MHz): 1=15.45    2=17.90    3=21.75    4=26.10    5=68.00
Antenna -----: 1=Cable-catn  2=Cross-beam  3=Inflatable
Power storage: 1=NiH2        2=RFC          3=HEDRB
Operation during Eclipse: 1=Yes    2=No

       System Analysis Parameters:        * System 1 * System 2 * System 3 *
       ----------------------------       * -------- * -------- * -------- *
  6. * OTV choice ---------------------- :       2.0        2.0        2.0
  7. * Orbit choice -------------------- :       7.0        7.0        7.0
  8. * Power storage choice ------------ :       1.0        1.0        1.0
  9. * Antenna choice ------------------ :       2.0        2.0        2.0
 10. * Operate during eclipse ---------- :       2.0        2.0        2.0
 17. * STS KSC nominal lift capacity -(Lb):  65000.0    65000.0    65000.0
 19. * Max # of beams (shown=Unlimited) --:   1000.0     1000.0     1000.0
 20. * Field strength -------- (micro-V/M):    328.0      187.0       76.0
 21. * Ref GEO beamwidth ----------- (Deg):      4.0        4.0        4.0
 26. * Elevation angle ------------- (Deg):     20.0       20.0       20.0
 36. * Operating frequency --------- (MHz):     26.1       26.1       26.1

        Enter Parameter Line # for change!  Else press <CR>:
 * Enter Peak/Avg Power ratio for system # 1  (Default=1.70):

 * Enter Peak/Avg Power ratio for system # 2  (Default=1.70):

 * Enter Peak/Avg Power ratio for system # 3  (Default=1.70):

        >> Are you satisfied with inputs? <N>o or <Any Key> to proceed:
```

FIGURE A2.5 - Completed Fourth Menu with Three New Systems Defined.

```
                   SELECTION OF SOLAR ARRAY TECHNOLOGIES
                 --------------------------------------------------
                 1-Near Term Technology Silicon Blankets, Now-1995
                 2-Far Term Technology Silicon Blankets >1995

Your choice ? 2
```

FIGURE A2.6 - Fifth Menu Providing for Selection of Power Technology

```
TRW HF/VHF VOICE BROADCAST ANALYSIS
-----------------------------------
 1-Create A New Scenario File
 2-Retrieve Old Scenario File
 3-Save Current Scenario as a File
 4-Execute Current File
 5-Display Summary of Last Run
 6-Print Details of Last Run
 7-Terminate (Default Case)


Your choice? 3
File name or default to MAIN? CustBiPp
```

FIGURE A2.7 - Using Save Option of Main Menu to Store Current Configurations on Disk.

```
> Weight Pld+AKM+OTV+ASE-------- (Lb): *  65000   *  65000   *  65000   *
> OTV Weight--------------------(Lb): *  48987   *  48987   *  48987   *
> OTV fuel ratio: Used/Rated------(%): *    388   *    388   *    388   *
> STS + OTV ASE-----------------(Lb): *   2500   *   2500   *   2500   *
> Payload Weight---------------- (Lb): *  13513   *  13513   *  13513   *
> AKM Weight------------------- (Lb): *      0   *      0   *      0   *
> Antenna weight -------------- (Lb): *   4541   *   4541   *   4541   *
>   Number of feeds (Cross-Beam only): *    121   *    121   *    121   *
> TT&C, DHS, Comm subsystems -   (Lb): *    269   *    269   *    269   *
> Attitude control ------------ (Lb): *    275   *    275   *    275   *
> Propulsion ------------------ (Lb): *    827   *    827   *    827   *
> Structures (Excl Antenna) ---- (Lb): *    845   *    845   *    845   *
> Thermal control weight ------- (Lb): *     50   *    315   *    421   *
> EDI total weight ------------- (Lb): *    145   *    340   *    418   *
> EPDS total weight ------------ (Lb): *    140   *   1131   *   1528   *
> PAYLOAD weight/channel-beam -- (Lb): *   2211   *    719   *    119   *
>            ========================   ========   ========   ========
>     Maximum number of channel-beams: *      0   *      2   *     17   *
>                 Residual weight (Lb): *   4164   *   1276   *    118   *
> Total weight/channel-beam ---- (Lb): *   4441   *   1444   *    238   *
> Available payload weight ----- (Lb): *   4164   *   4164   *   4164   *
> Non-beam-related weight ------ (Lb): *   7097   *   7097   *   7097   *
                    Press any key to continue
```

FIGURE A2.8 - Summary Display of Computation Results

```
                    PRINT QUALITY
----------------------------------------------------
1-Standard Elite (Draft Quality)
2-Enhanced Elite (Darker)
3-Correspondence Quality Elite (Good but Very Slow)
4-***PRINTER NOT EPSON COMPATIBLE--EXIT***


Your choice ? 3
```

FIGURE A2.9 - Sixth Menu Providing for Printer Control

SVBS (VOA) STUDY

System Analysis Parameters:	System 1	System 2	System 3
* OTV choice ---------------------- :	CustBiPp	CustBiPp	CustBiPp
* Orbit choice --------------------- :	ACE	ACE	ACE
* Power storage choice ------------- :	NiH2	NiH2	NiH2
* Antenna choice ------------------- :	Cross-beam	Cross-beam	Cross-beam
* Operate during eclipse ----------- :	No	No	No
* STS KSC nominal lift capacity -(Lb):	65000.0	65000.0	65000.0
* Max # of beams (shown=Unlimited) --:	1000.0	1000.0	1000.0
* Field strength -------- (micro-V/M):	328.0	187.0	76.0
* Ref GEO beamwidth ----------- (Deg):	4.0	4.0	4.0
* Elevation angle ------------- (Deg):	20.0	20.0	20.0
* Operating frequency --------- (MHz):	26.1	26.1	26.1
* Peak/Avg solar array power ratio :	1.7	1.7	1.7
> Orbit inclination ---------- (Deg):	0.0	0.0	0.0
> Beamwidth ------------------ (Deg):	7.8	7.8	7.8
> RF power/channel-beam: Peak --(kW):	41.5	13.5	2.2
> RF power/channel-beam: Average (kW):	24.4	7.9	1.3
> Wavelength ------------------ (Ft):	38	38	38
> Weight Pld+AKM+OTV+ASE-------- (Lb):	65000	65000	65000
> OTV Weight--------------------(Lb):	48987	48987	48987
> OTV fuel ratio: Used/Rated------(%):	388	388	388
> STS + OTV ASE-----------------(Lb):	2500	2500	2500
> Payload Weight---------------- (Lb):	13513	13513	13513
> AKM Weight------------------- (Lb):	0	0	0
> Weight reserve ----------------(Lb):	2252	2252	2252
> Antenna aperture -------------- (M):	104	104	104
> Antenna weight --------------- (Lb):	4541	4541	4541
> Number of feeds (Cross-Beam only):	121	121	121
> TT&C, DHS, Comm subsystems - (Lb):	269	269	269
> Attitude control ------------- (Lb):	275	275	275
> Propulsion ------------------- (Lb):	827	827	827
> Structures (Excl Antenna) ---- (Lb):	845	845	845
> Thermal control weight ------- (Lb):	50	315	421
> Total weight/channel-beam --- (Lb):	408	133	22
> EDI total weight ------------- (Lb):	145	340	418
> Total EDI weight/channel-beam (Lb):	300	97	16
> EPDS total weight ------------ (Lb):	140	1131	1528
> Total weight/channel beam --- (Lb):	1523	495	82
> Power storage/channel beam - (Lb):	0	0	0
> PAYLOAD weight/channel-beam -- (Lb):	2211	719	119
> Maximum number of channel-beams:	0	2	17
> Residual weight (Lb):	4164	1276	118
> Total weight/channel-beam ---- (Lb):	4441	1444	238
> Available payload weight ----- (Lb):	4164	4164	4164
> Non-beam-related weight ------ (Lb):	7097	7097	7097

FIGURE A2.10 - Summary Listing Provided on Printer

*** Detailed Analysis Output ***

No.	Item			
6.*	OTV choice ---------------------- :	2.0	2.0	2.0
7.*	Orbit choice -------------------- :	7.0	7.0	7.0
8.*	Power storage choice ------------ :	1.0	1.0	1.0
9.*	Antenna choice ------------------ :	2.0	2.0	2.0
10.*	Operate during eclipse ---------- :	2.0	2.0	2.0
12.	Orbit Apogee --------------- (NMi):	11597.0	11597.0	11597.0
13.	Orbit Perigee -------------- (NMi):	4000.0	4000.0	4000.0
14.>	Orbit inclination ---------- (Deg):	0.0	0.0	0.0
15.	Launch inclination --------- (Deg):	28.0	28.0	28.0
16.	Orbit Period --------------- (Hrs):	4.8	4.8	4.8
17.*	STS KSC nominal lift capacity -(Lb):	65000.0	65000.0	65000.0
18.	Inclination change (Lch-Orbit)(Deg):	28.0	28.0	28.0
19.*	Max # of beams (shown=Unlimited) --:	1000.0	1000.0	1000.0
20.*	Field strength -------- (micro-V/M):	328.0	187.0	76.0
21.*	Ref GEO beamwidth ---------- (Deg):	4.0	4.0	4.0
22.	RF Output/Beam (Subsat point)- (kW):	21.3	6.9	1.1
23.>	Beamwidth ------------------ (Deg):	7.8	7.8	7.8
24.>	RF power/channel-beam: Peak --(kW):	41.5	13.5	2.2
25.>	RF power/channel-beam: Average (kW):	24.4	7.9	1.3
26.*	Elevation angle ------------ (Deg):	20.0	20.0	20.0
27.	Slant range ---------------- (NMi):	9958.4	9958.4	9958.4
28.>	Wavelength ------------------ (Ft):	37.7	37.7	37.7
29.	STS lift to parking orbit -----(Lb):	65000.0	65000.0	65000.0
36.*	Operating frequency --------- (MHz):	26.1	26.1	26.1
60.>	Weight Pld+AKM+OTV+ASE-------- (Lb):	65000.0	65000.0	65000.0
61.>	OTV Weight--------------------(Lb):	48986.9	48986.9	48986.9
62.>	OTV fuel ratio: Used/Rated------(%):	388.2	388.2	388.2
63.>	STS + OTV ASE------------------(Lb):	2500.0	2500.0	2500.0
64.>	Payload Weight---------------- (Lb):	13513.1	13513.1	13513.1
65.>	AKM Weight-------------------- (Lb):	0.0	0.0	0.0
73.>	Weight reserve ----------------(Lb):	2252.2	2252.2	2252.2
74.	Weight reserve ---------- (Percent):	20.0	20.0	20.0
80.	Antenna aperture --------------(Ft):	340.4	340.4	340.4
81.>	Antenna aperture -------------- (M):	103.7	103.7	103.7
82.>	Antenna weight --------------- (Lb):	4540.7	4540.7	4540.7
85.	Inflatable Parabolic Antenna - (Lb):	0.0	0.0	0.0
90.	Cross-Beam Ant(incl. feed str.)(Lb):	4540.7	4540.7	4540.7
92.>	Number of feeds (Cross-Beam only):	121.0	121.0	121.0
94.	Ratio of Feed spacing/Wavelength :	0.8	0.8	0.8
96.	Cross-beam antenna, max span (Ft):	340.4	340.4	340.4
97.	Cross-beam antenna Structure (Lb):	2807.9	2807.9	2807.9
98.	Cross-beam antenna Feeds --- (Lb):	1732.7	1732.7	1732.7
100.	Cable-Catenary Ant(apert+mast) (Lb):	0.0	0.0	0.0
110.>	TT&C, DHS, Comm subsystems - (Lb):	269.4	269.4	269.4
120.>	Attitude control ------------- (Lb):	275.5	275.5	275.5
122.	CMG -------------------------- (Lb):	0.0	0.0	0.0
124.	Propulsive ------------------- (Lb):	17.8	17.8	17.8
126.	Sensors and controls -------- (Lb):	257.7	257.7	257.7
128.	Antenna area permeability --- (%):	95.0	95.0	95.0

FIGURE A2.11 (a) - Items 6-128 of Detailed Listing

130.>	Propulsion ------------------- (Lb):	827.4	827.4	827.4
132.	ISP ---------------------- (Sec):	300.0	300.0	300.0
133.	Ratio aperture/thrusters spacing - :	1.0	1.0	1.0
135.>	Structures (Excl Antenna) ---- (Lb):	845.3	845.3	845.3
136.	Structure mass fraction (percent):	10.0	10.0	10.0
140.>	Thermal control weight ------- (Lb):	50.0	315.1	421.4
141.>	Total weight/channel-beam --- (Lb):	407.8	132.5	21.9
142.	Payload thermal load/beam -- (kW):	12.2	4.0	0.7
143.	Payload cooling/channel-beam (Lb):	407.8	132.5	21.9
144.	Secondary thermal load/Beam (kW):	0.0	0.0	0.0
145.	Secondary Power cooling/Beam (Lb):	0.0	0.0	0.0
147.	Housekeeping radiator weight (Lb):	3.5	3.5	3.5
148.	Blankets/Heaters ----------- (Lb):	50.0	50.0	50.0
150.>	EDI total weight ------------- (Lb):	145.0	340.0	418.2
151.>	Total EDI weight/channel-beam (Lb):	299.9	97.5	16.1
152.	Percent cabling voltage drop --- :	10.0	10.0	10.0
154.	Ratio of SA spacing/aperture ----- :	1.0	1.0	1.0
155.	EDI(Ex. SA Cable) Beam indepd(Lb):	145.0	145.0	145.0
156.	EDI(Ex. SA Cable)/Beam depend(Lb):	194.6	63.2	10.4
157.	EDI SA cable/Beam ---------- (Lb):	105.4	34.2	5.7
160.>	EPDS total weight ------------ (Lb):	140.4	1130.6	1527.6
161.>	Total weight/channel beam --- (Lb):	1522.8	495.0	81.8
162.	Solar Array/Beam (excl. mast)(Lb):	984.5	320.0	52.9
163.	Solar Array Area/Beam ---- (Ft^2):	0.0	0.0	0.0
164.	Mast from Solar Array to Bus (Lb):	85.1	85.1	85.1
165.	Peak/Avg solar array power ratio :	1.7	1.7	1.7
168.>	Power storage/channel beam - (Lb):	0.0	0.0	0.0
172.	Pwr Control Unit weight/beam (Lb):	538.3	175.0	28.9
173.	Housekeeping EPDS weight --- (Lb):	55.3	55.3	55.3
174.	Housekeeping power --------- (kW):	0.5	0.5	0.5
175.	Battery charging power ----- (kW):	0.0	0.0	0.0
177.	PCU input power ------------ (kW):	64.9	21.1	3.5
178.	Load Power to payload/Beam - (kW):	63.0	20.5	3.4
179.	Solar Array power output/Beam(Kw):	71.3	23.2	3.8
180.>	PAYLOAD weight/channel-beam -- (Lb):	2210.8	718.6	118.7
182.	Transmitter-RF component/Beam(Lb):	1912.6	621.7	102.7
184.	Feed Stucture/Beam --------- (Lb):	0.0	0.0	0.0
186.	RF/DC cabling/beam --------- (Lb):	298.2	96.9	16.0
>	========================	========	========	========
192.>	Maximum number of channel-beams:	0.0	2.0	17.0
>	========================	========	========	========
196.>	Residual weight (Lb):	4163.8	1276.0	118.0
>	--------------------	--------	--------	--------
200.>	Total weight/channel-beam ---- (Lb):	4441.3	1443.6	238.4
202.>	Available payload weight ----- (Lb):	4163.8	4163.8	4163.8
204.>	Non-beam-related weight ------ (Lb):	7097.2	7097.2	7097.2

FIGURE A2.11 (b) - Items 130-204 of Detailed Listing

```
ACEEXP  .DAT ACEEXP2 .DAT ACEEXP3 .DAT EQU8EXP .DAT ACEOPER .DAT ACEOPER1.DAT
ACEOPER2.DAT ACEOPER3.DAT ACEOPER4.DAT EQU8OP3 .DAT EQU8OP1 .DAT EQU8OP2 .DAT
EQU8EXP1.DAT EQU8EXP2.DAT EQU8EXP3.DAT ACEEXP1 .DAT CUSTBIPP.DAT

File name or default to MAIN? aceexp1
```

FIGURE A2.12 - Switching to Previous System Set ACEEXP1.

```
> Weight Pld+AKM+OTV+ASE-------- (Lb): *  21500   *  19300   *  22000   *
> OTV Weight---------------------(Lb): *  11407   *  10162   *  11690   *
> OTV fuel ratio: Used/Rated------(%): *    101   *     89   *    104   *
> STS + OTV ASE------------------(Lb): *   3900   *   3900   *   3900   *
> Payload Weight---------------- (Lb): *   4003   *   3386   *   4143   *
> AKM Weight-------------------- (Lb): *   2190   *   1853   *   2267   *
> Antenna weight --------------- (Lb): *    282   *    869   *   1774   *
>   Number of feeds (Cross-Beam only): *      9   *     25   *     49   *
> TT&C, DHS, Comm subsystems -   (Lb): *    235   *    247   *    256   *
> Attitude control ------------- (Lb): *    202   *    226   *    245   *
> Propulsion ------------------- (Lb): *    239   *    203   *    250   *
> Structures (Excl Antenna) ---- (Lb): *    218   *    131   *    138   *
> Thermal control weight ------- (Lb): *    247   *    138   *     99   *
> EDI total weight ------------- (Lb): *    204   *    173   *    162   *
> EPDS total weight ------------ (Lb): *    773   *    398   *    280   *
> PAYLOAD weight/channel-beam -- (Lb): *    925   *    418   *    239   *
>          ========================    ========   ========   ========
>     Maximum number of channel-beams: *      1   *      1   *      1   *
>                Residual weight (Lb): *      8   *     17   *      6   *
> Total weight/channel-beam ---- (Lb): *   1894   *    850   *    484   *
> Available payload weight ----- (Lb): *   1902   *    867   *    490   *
> Non-beam-related weight ------ (Lb): *   1433   *   1954   *   2962   *
                     Press any key to continue
```

FIGURE A2.13 - Summary Display of Previous System Set ACEEXP1.

APPENDIX 3

LOTUS 123 Worksheet for Life Cycle Costs

The life cycle costs were computed by making use of costing algorithms developed by Martin-Marietta, TRW, and the Space Division of the Air Force. Automation of these algorithms was accomplished by making use of the LOTUS 123 spreadsheet program. With this, several systems could be evaluated simultaneously and comparisons made very readily.

It is assumed that the reader is familiar with the use of LOTUS 123. Therefore, in the text that follows, the LOTUS operations, needed to produce the displays shown, will not be discussed.

Nine worksheets have been included on the floppy disk provided VOA. Any of these can be retrieved using the retrieve feature of LOTUS. Using this operation to retrieve the worksheet ACEOP3, you should obtain the display shown in Figure A3.1. ACEOP3 is a collection of ACE orbit scenarios of different coverage size, but all providing a field strength of 187 uv/meter. Line number 5 indicates that all use this orbit, and line number 9 indicates the common field strength. The specific spot size, in degrees, is indicated in line 14. Each item of information has been copied from runs made with the TRW mass estimating program. The data given here indicate that a set of six runs were made with the TRW software. This was found to be sufficient to illustrate the trend of mass and cost versus coverage.

The RF Kw/Beam is the peak RF power per beam and is obtained either from the summary sheet or item 24 of the detailed listing from the TRW program. The DC Kw/Beam is obtained from item 179 of the detailed listing. Similarly, each of the items needed can be obtained from the TRW listings.

Switching to the next screen (by shifting down one page), you should obtain a listing of subsystem weights as shown in Figure A3.2. Each of these items is also obtained from the TRW listings. A summary listing of these inputs is generated by LOTUS and can be seen by displaying the third screen (by shifting down one page) as shown in Figure A3.3. To complete this screen, the user must supply the OTV, ASE (aerospace equipment - mechanical interfaces, electrical interfaces, mounting platforms, etc), and the design margin. These also are obtained from the TRW listings.

With all these inputs completed, LOTUS will automatically compute the life cycle costs. These are determined in three stages. The non-recurring costs are given in screen four (shift down one page) shown in Figure A3.4. These are the costs associated with construction and testing of the engineering model(s), and only occur once for any particular satellite configuration. The recurring costs are given in screen five (shift down one page) shown in Figure A3.5. These are costs that associated with production and occur for each spacecraft built.

The non-recurring and recurring costs are combined with other costs to generate the life cycle costs in screen six (shift down one page), as shown in Figure A3.6. The rule of computation is quite simple. To the non-recurring costs we add: recurring and launch costs for each spacecraft (two in this case); the cost of the master control center(s) (MCC); and the operations and maintenance for the specified life cycle (20 years in this case). As can be seen, all scenarios are within 10% of 1880 $million. At first sight, it would appear there is little sensitivity to changes in coverage. However, from screen one, we find that the capacity of each of these spacecraft are significantly different (2-5 channels). Hence, a better parameter for comparison would be one which accounted for differences in capacity, as well as differences in coverage. Toward that end, we chose to use the life cycle cost prorated over the number of channels and the area covered in square degrees.

The computation of this parameter is shown in Figure A3.7 (screen seven). The data needed for the computation is automatically extracted from the appropriate screens by LOTUS. The final parameter of interest is given in line 127 and is the life cycle cost per channel per million square miles.

The other parameters indicated on the screen are labels for plots generated by the graphics option of LOTUS.

The user can obtain hardcopies of these screens by using the screen print key or he may use the print option provided by LOTUS.

These LOTUS worksheets apply only to data generated by the TRW software and should not be expected to produce accurate results for data generated in other ways.

	A	B	C	D	E	F	G
1	ACEOP3		OPERATIONAL CONCEPT SCENARIOS				
2	Item	1	2	3	4	5	6
3	-------	-------	-------	-------	-------	-------	-------
4	SYSTEM:						
5	Orbit	ACE	ACE	ACE	ACE	ACE	ACE
6	Ant Code	2	2	2	2	2	2
7	OTV	Cryo	Cryo	Cryo	Cryo	Cryo	Cryo
8	Band	26	26	26	26	26	26
9	uv/meter	187	187	187	187	187	187
10	Feeds	25	36	49	81	121	225
11	Channels	2	2	3	4	6	5
12	RF Kw/Beam	54	41.4	30.4	21.1	13.5	7.6
13	DC Kw/Beam	92.8	71	52.2	36.2	23.2	13
14	Bm, Deg	8	7	6	5	4	3
15							

FIGURE A3.1 - Screen One Defining Satellite Scenarios to be Analyzed for Costs

	A	B	C	D	E	F	G
21			WEIGHT PROPERTIES OF CONCEPTS, POUNDS				
22	Item	1	2	3	4	5	6
23	-------	-------	-------	-------	-------	-------	-------
24	Xmit/Beam	2486.7	1903.9	1398.8	1072.2	621.7	349.7
25	Feed/Beam	0	0	0	0	0	0
26	Cable/Beam	76.5	64.3	86.8	100.8	96.9	77.6
27	Antenna	868.5	1265.7	1773.8	2924.3	4540.7	8582.6
28	Bat's	0	0	0	0	0	0
29	EPDS	4041	3122.3	3443.0	3211.6	3110.9	1569.2
30	EDI	719.4	600.9	674.6	677.3	730.1	494.0
31	Thermal	1110.2	861.9	944.7	878.5	845.4	422.7
32	Struct	1538.5	1514.5	1482.3	1413.1	1308.7	1053.4
33	ADS	216.7	224.1	232.9	243.7	257.7	276.9
34	RCS	8.9	10.2	11.9	14.2	17.8	23.7
35	TT&C	247.1	251.2	256.1	262	269.4	279.3
36	Prop.	1215.5	1218.2	1222.2	1229	1241.3	1268.1
37	AKM	0	0	0	0	0	0
38							
39							

FIGURE A3.2 - Screen Two Containing Subsystem Mass Estimates

	A	B	C	D	E	F	G
41			SUMMARY WEIGHT PROPERTIES, POUNDS				
42	Item	1	2	3	4	5	6
43	------------	------------	------------	------------	------------	------------	------------
44	Payload	5126.4	3936.4	4456.8	4692.0	4311.6	2136.5
45	Buss, dry	3121.4	2861.9	2927.9	2811.5	2699.0	2056.0
46	Antenna	868.5	1265.7	1773.8	2924.3	4540.7	8582.6
47	Power	4760.4	3723.2	4117.6	3888.9	3841.0	2063.2
48	AKM	0.0	0.0	0.0	0.0	0.0	0.0
49							
50	Tot, Dry	13876.7	11787.2	13276.1	14316.7	15392.3	14838.3
51	Tot, Wet	15092.2	13016.2	14517.4	15584.8	15392.3	14838.3
52							
53	OTV	36264	36264	36264	36264	36264	36264
54	ASE	8462	8462	8462	8462	8462	8462
55	Margin	3379	3379	3379	3379	3379	3379
56							
57	STS, Tot	63197.2	61121.2	62622.4	63689.8	63497.3	62943.3
58							
59							

FIGURE A3.3 - Screen Three Providing Summary of Mass Properties

	A	B	C	D	E	F	G
61		NON-RECURRING SATELLITE SYSTEM COSTS, $M					
62	Item	1	2	3	4	5	6
63	------------	------------	------------	------------	------------	------------	------------
64	Payload	31	20	18	13	9	4
65	Antenna	25	28	31	35	40	47
66	EPDS	88	77	81	78	76	58
67	EDI	15	14	15	15	15	12
68	Thermal	19	17	18	17	17	11
69	Struct.	24	23	23	22	21	19
70	ADS	46	47	49	52	55	59
71	RCS	1	1	1	1	2	2
72	TT&C	7	7	7	7	7	7
73	Comm	8	8	8	9	9	9
74	DHC	8	8	8	9	9	9
75	AKM	0	0	0	0	0	0
76							
77	Subtotal	272	251	258	257	259	237
78	Pgm Mgmt	98	90	93	92	93	85
79	Tot NR	370	341	351	349	352	322

FIGURE A3.4 - Screen Four Providing Subsystem Non-recurring Cost Estimates

	A	B	C	D	E	F	G
81			RECURRING SATELLITE COSTS, $M				
82	Item	1	2	3	4	5	6
83	------------	------------	------------	------------	------------	------------	------------
84	Payload	18	14	16	16	15	7
85	Antenna	9	13	18	30	46	87
86	EPDS	108	90	96	91	88	56
87	EDI	3	2	2	2	3	2
88	Thermal	3	3	3	3	3	2
89	Struct.	4	4	4	4	4	3
90	ADS	13	13	13	14	15	16
91	RCS	0	0	1	1	1	1
92	TT&C	3	4	4	4	4	4
93	Comm	5	5	5	5	5	5
94	DHC	5	5	5	5	5	5
95	AKM	0	0	0	0	0	0
96							
97	Subtotal	172	153	167	175	189	190
98	Pgm Mgmt	57	50	55	58	62	63
99	Tot Rec	228	203	222	233	251	252

FIGURE A3.5 - Screen Five Providing Subsystem Recurring Cost Estimates

	A	B	C	D	E	F	G
101			LIFE CYCLE COSTS (LCC), $M				
102	Item	1	2	3	4	5	6
103	------------	------------	------------	------------	------------	------------	------------
104	Pgm Yrs	20	20	20	20	20	20
105	Sat Life	10	10	10	10	10	10
106	#Sats	2	2	2	2	2	2
107	NR	370	341	351	349	352	322
108	REC	228	203	222	233	251	252
109	STS	97	94	96	98	98	97
110	OTV	44	44	44	44	44	44
111	MCC	10	10	10	10	10	10
112	O&M/YR	3	3	3	3	3	3
113							
114	20YR LCC	1916	1773	1869	1916	1992	1962
115							
116							
117							
118							
119							

FIGURE A3.6 - Screen Six Providing Computation of Life Cycle Costs

	A	B	C	D	E	F	G
121		COMPARISION OF SUMMARY PROPERTIES WITH COVERAGE					
122	Spot, Deg	8	7	6	5	4	3
123	-------------	-------------	-------------	-------------	-------------	-------------	-------------
124	LCC, $B	2	2	2	2	2	2
125	Channels	2	2	3	4	6	5
126	Ch-MSQM	16	12	14	13	12	6
127	LCC/CAP $M	119.13	143.96	137.72	152.50	165.08	346.99
128	Ant Mass	5994.90	5202.10	6230.60	7616.30	8852.30	10719.10
129	Pwr Mass	5870.60	4585.10	5062.30	4767.40	4686.40	2485.90
130						40	
131						o 187 uv/meter (R	
132					9000		
133					5500		
134					Antenna		
135					Power		
136						10000	
137							
138							

FIGURE A3.7 - Screen Seven Providing Comparison of Cost Performance of Systems

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16. Abstract
Satellite concepts are examined which can offer potentially significant sound broadcast coverage of audio as a complementary system to the Voice of America's existing and planned terrestrial sound broadcasting system. HF frequency bands are emphasized but additional discussion is included for systems which would use higher frequencies. It is shown that low altitude satellites, shuttle altitude (275 Km) and sun synchronous (about 1600 to 1800 Km), would not be practical for international broadcasting as many satellites would be needed for reliable and widespread coverage. Two concepts are discussed which would offer significant and practical broadcast coverage at HF. One, an 8 hour posigrade equatorial orbit, would offer about 1 hour of widespread, twice daily, coverage to three areas of the globe. The time of coverage is even greater when confined to densely populated areas only (about 2 to 3 hours). Another orbit, the Apogee at Constant Time/Equatorial (ACE), provides about the same coverage as the 8 hour orbit, but only once daily to each area. This latter orbit is highly elliptical, which allows the insertion of a greater payload (more broadcast channels) with the existing launch capability. For comparison purposes, it was found beneficial to compare system life cycle costs on the basis of costs per channel of a typical VOA Coverage Area. Making use of this method, the ACE and 8 hour orbit concepts led to systems of about equal costs, with the ACE being slightly better. For a 20 year life cycle, this amounted to about $175M per channel per million square miles of coverage (typical of VOA coverage areas). The use of higher frequencies such as L-band at 1.5 GHz, would reduce costs significantly to about $52M per channel per million square miles. A hybrid satellite system is recommended which would carry both HF and a higher frequency payload (either L-Band or Ku-Band). The HF payload would be designed to provide acceptable quality broadcasts to rural or residential areas (primarily to developing nations), and the higher frequency payload would be designed to provide coverage to urban and residential areas (primarily in developed nations).

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