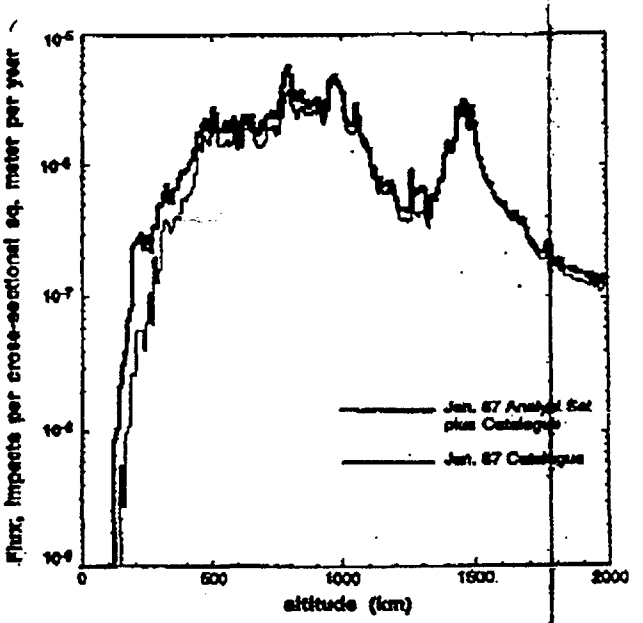


Fig. 2 Comparison of the flux arising from the January 1987 tracked population (Analyst Set plus catalogue) and the January 1987 catalogue.

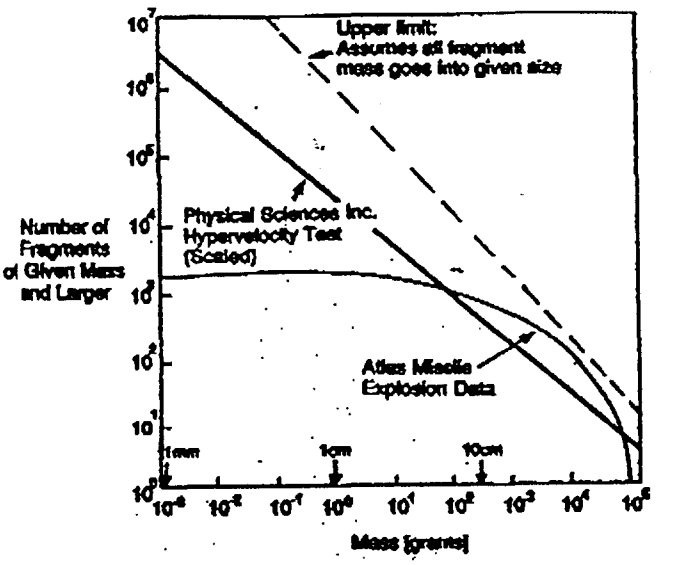


Fig. 3 Expected number of fragments from the breakup of a 1400 kg satellite.

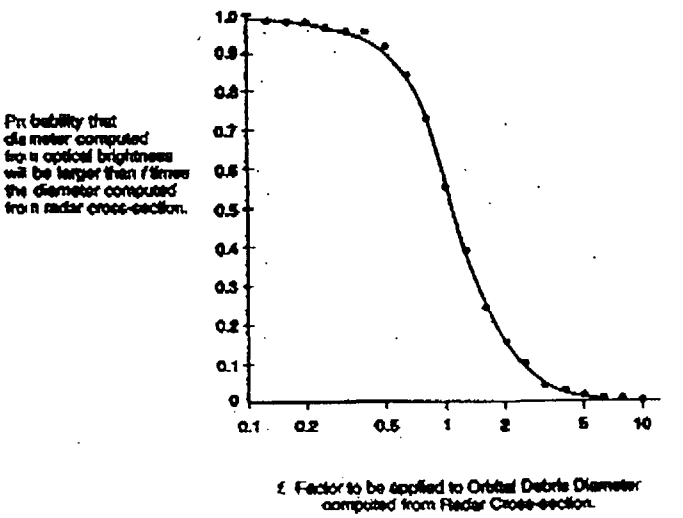


Fig. 4 Probability that an optically measured size will be larger than its radar measured size.

which detected a much lower uncatalogued population. Consequently, the model in NASA TM-100-471[5] assumed that the U.S. Space Command tracked population is essentially complete to 10-cm diam.

In 1984, NASA began sponsoring a program of telescopic observations of orbital debris. The first of these was by the Massachusetts Institute of Technology (MIT),[6] which concluded that the 1 cm orbital debris population was eight times the U.S. Space Command tracked population. A reanalysis of the data at the Johnson Space Center (JSC) concluded that an improper parallax measurement had tagged some meteors as being orbiting objects, and concluded that the correct ratio was five times the tracked population during periods of excellent seeing conditions, and twice the catalogued population during average seeing conditions. In addition, radar, optical, and infrared measurements[7] of known orbital debris lead to the conclusion that orbital fragments are much darker than previously believed, meaning that the debris that MIT detected was larger than 1 cm, being closer to 2–5 cm. This detection size was assumed in TM 100-471. However, recent calibration of the MIT telescopes at JSC has shown that the telescopes were not as sensitive as previously believed; therefore, the objects detected by MIT were larger than 5 cm.

A more complete analysis of telescopic data is given by Henize and Stanley[8] using the slightly less sensitive telescopes of the U.S. Space Command. These telescopic data indicate that there are twice as many objects in orbit larger than 10 cm than are catalogued, and that some 1-m-diam objects are not catalogued. This again appears to conflict with the PARC's radar tests. A possible explanation might be that some fraction of smaller debris might happen to appear brighter as it goes through the telescope field a view, and thus be described as a larger object. Fluctuations in brightness can be expected due to distributions in albedo, phase functions, and orientation as the object goes through the field of view. However, we have measures of these distributions when satellites with known radar cross sections went through the field of view. That is, from the distribution of measured brightness as satellites of a given radar cross section went through the telescope field of view, we can determine the probability that a given radar cross section will appear as an optically larger object.

Using the distribution of optically determined diameters for objects of known radar cross section, as given by Henize and

be larger than its radar measured size was determined, and is given in Fig. 4. Consider, for example, an object 20 cm in diameter, as determined by its radar cross section. Multiplying f in Fig. 4 by 20 cm, the figure shows there is about a 50% probability that any optically determined diameter would be 20 cm or greater, as one would expect if the proper average albedo and phase function had been assumed. There is also a 2% probability that the same size object would appear as a 100 cm ($f = 5$) optical object, or larger. Since over 300 unknown objects were detected, most between 10 and 30 cm, chances are that several of the 10–30 cm objects would appear to be optically 1 m in diameter or larger, and this is what was observed. Therefore, without a more complete analysis, it would be premature to conclude from the telescopic observations that there are objects with radar cross sections as large as 1 m that are not catalogued.

Now consider an object 5 cm in diameter, as determined by its radar cross section. Such an object would have a near zero chance of being detected by U.S. Space Command's 70 cm radar wavelength. However, Fig. 4 shows that there is a 15% probability that such an object would appear optically as a 10

as many 5 cm objects as 10–30 cm objects, then one would expect between 15% and 4% of the unknown objects to actually be 5 cm objects that appeared brighter in the telescope; this is a small fraction of the unknowns. There would have to be 7–25 times as many 5 cm objects as 10–30 cm objects to account for the unknowns observed by these telescopes. Although such a large number of 5 cm objects is highly unlikely, it cannot be ruled out. Similarly, since there is a 0.3% probability that a 1 cm object would appear as bright as a 10 cm object, there would have to be 300 times as many 1 cm objects as 10 cm objects to account for the unknowns observed by these telescopes. Again, such a large number is highly unlikely, but cannot be ruled out. Consequently, there are two possible conclusions: 1) there are twice as many 10 cm objects and larger in orbit than are catalogued by U.S. Space Command; or 2) there are many times the number of catalogued objects in orbit with sizes slightly smaller than 10 cm. The more probable conclusion is the first one, although there is certainly a small fraction of smaller than 10 cm objects that were detected because they appeared to be larger than 10 cm. Therefore, we are faced with question of why the U.S. Space Command radars are not tracking these objects. To answer this question will require further research.

Analysis of Space-Based Sensors

The first orbital debris measurements of very small debris resulted from examining the Skylab IV/Apollo windows,[9] which revealed aluminum-lined pits in about half of the hypervelocity pits found on the window. Other experiments, such as Skylab's S149 Micrometeoroid experiment and the Explorer 46 Meteoroid Bumper Experiment, also showed indications of measuring the orbital debris population of debris smaller than 0.1 mm. The Shuttle windows are examined after every flight for pitting, and some windows have been replaced to ensure an adequate safety margin when the Shuttle is relaunched. The largest pit found to date has a diameter of about 4 mm, and was first noticed on the third day of the STS-7 mission. This was the only pit analyzed today to determine the origin of the impacting particle; this origin was concluded to be orbital debris.

By far, the best data to date have been recovered from the Solar-Max surfaces.[10] Both the thermal insulation blankets and aluminum louvers contained a significant number of holes caused by hypervelocity impact. Even though there is a problem of calibrating the penetration hole size to the impacting particle size, the analysis of data has determined the relative contributions from meteoroids and orbital debris. The analysis indicates that the orbital debris flux dominated the particle flux for sizes smaller than about 0.01 mm, although some secondary impacts likely contributed to this flux. Meteoroids dominated the flux between about 0.03 and 0.2 mm particle impacts by about a factor of 4. An extrapolation of the data would predict that the orbital debris flux would also dominate for particle sizes larger than about 1 mm. A particle production rate of about 100 kg/yr is required to maintain the measured orbital debris flux, if the particles were in circular orbits; less mass is required if the orbits are elliptical.[11]

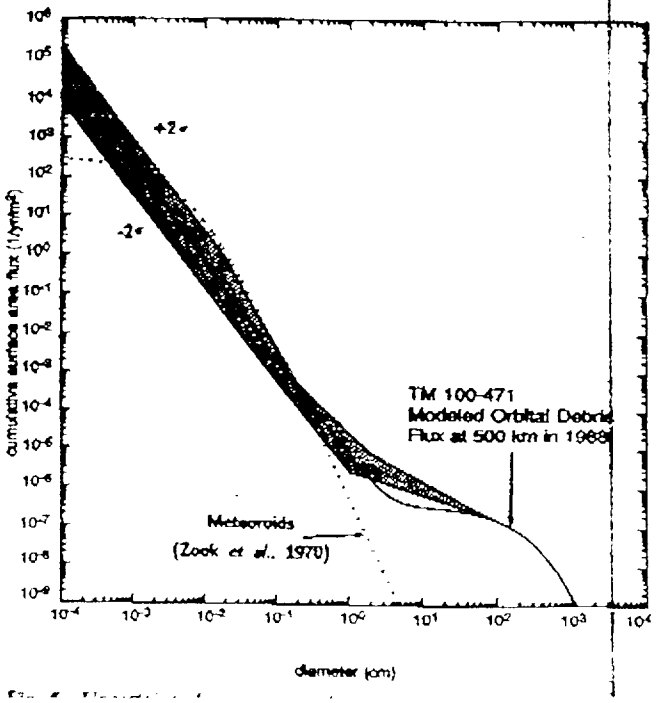
The Long Duration Exposure Facility (LDEF) was exposed to space for a longer time and has a much larger area than the solar-max surfaces. It is expected that analysis of the impacts found on LDEF will improve and expand the measurements of the orbital debris flux in this size range.[12]

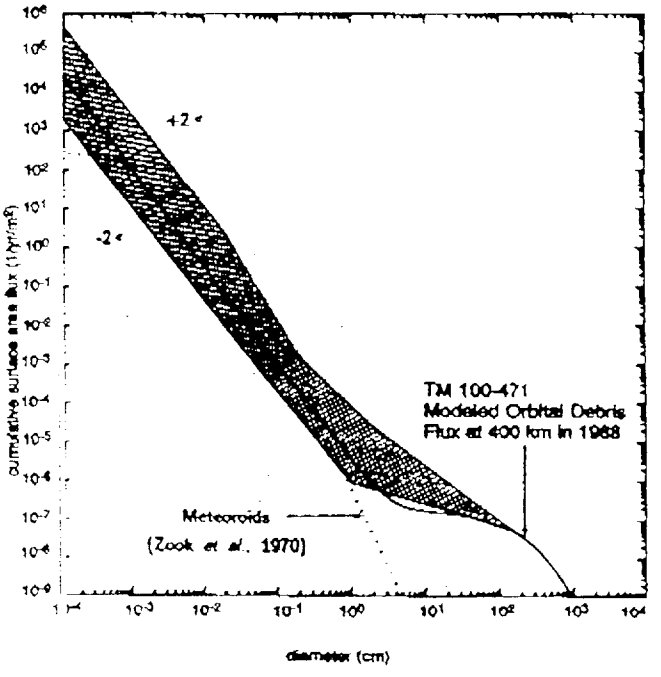
1 mm to 10 cm Flux

Until very recently, the flux between 1 mm and 10 cm was unmeasured. Estimates of this flux were obtained by a combination of modeling and an extrapolation of Solar-Max and ground telescope data. Such an extrapolation was the basis of the environment given in TM 100-471. The extrapolation was reasonable since only a small fraction of the past satellite breakup mass would be required to be in this size region. In 1989, two tests were performed by the Jet Propulsion Lab (JPL) that would partially measure the flux in this size range.[13] One test was with the Arecibo radar, which measured the flux between 2 and 0.5 cm, and the other used the Goldstone radar, measuring the flux between 0.5 and 0.2 cm. Within the errors of the measurements, both tests agreed with the environment in TM 100-471.

Uncertainty in the Current Environment

Based on the measurements to date, an estimate of the uncertainty in the current environment can be made. Figure 5 compares the uncertainty with the environment in TM 100-471





and the meteoroid environment.[14] Except for the size interval between about 2 cm and 1 m, the modeled environment is a good representation of existing measurements; however, it is likely that the model does underestimate the 2 cm to 1 m population. Data that will better define the flux in this region are expected in late 1990 and early 1991.[15]

All of the measurements were near 500 km altitude or higher. How the flux changes with altitude is a function of the types of orbits contributing to the flux. If all orbits are circular and the source of debris is above the altitudes of interest, then the flux will vary as the inverse of the atmospheric density. The reduction in flux of U.S. Space Command tracked objects with decreasing altitude is a reflection of this. However, the flux of tracked objects does not exactly follow this relationship. This is because there are sources of debris within the altitude of interest; in addition, elliptical orbits contribute to the flux. Both of these factors contribute to the flux being more constant with altitude. If there were a large number of elliptical orbits passing through low altitudes, or if there were large sources of debris at low altitudes, it would be possible for the orbital debris environment to be larger at lower altitudes than higher altitudes. Consequently, unless the orbits and sources are known, an additional uncertainty is introduced at altitudes different from 500 km. Figure 6 compares the uncertainty at 400 km with the environment model in TM 100-471. Again, the modeled environment is a good representation of existing data; however, the existing data are highly uncertain when extrapolated to 400 km.

Future Environment

Many assumptions are required in order to estimate the future environment. These include the future traffic model, satellite fragmentation rate, and solar activity. Even if these were known, there may be some unmodeled source of debris that may be important. However, some bounds can be put on the future environment. Since 1960, the rate of catalogued objects has accumulated at the rate of 240 objects per year.[16] However, this has been during two periods of much higher than average peak solar activity, and also includes the period before the world launch rate reached its current value of about 120 per year. If one assumes that future solar cycles are likely to be average, then the period between 1966 and 1977 would be more representative of future growth, if there were no changes in current traffic and satellite fragmentation rates. The accumulation rate during this period was about 300 catalogued objects per year, or about 4% of the current population per year.

However, the U.S., European Space Agency (ESA), China, and other nations plan to increase their activities in space. If these planned traffic models are exercised, they will lead to between 5 and 10% per year increases in the accumulation of mass in low Earth orbit,[17] not including an SDI deployment. Such an increase in traffic could lead to satellite fragmentation rates caused by random collisions to become the major source of debris, perhaps within the next 10 years.

The rate of random collisions was computed from an altitude distribution of catalogued objects in 1989, similar to the altitude distribution shown in Fig. 2. It was assumed that half of the catalogued objects were 10 cm in diameter (explosion fragments), and the other half were 3 m in diameter (payloads, rocket bodies, etc.). It was also assumed that the catalogued population, limited to a size of 10 cm, should be doubled, and that all of these uncatalogued objects were 10 cm in diameter. Finally, it was assumed that a catastrophic collision would result from either the collision between two objects 3 m in diameter, or between 10 cm and 3 m diameter objects. The equations for this type of calculation are given by Kessler.[18] The results of this calculation were 0.12 catastrophic collisions per year, or one every eight years.

This is significantly higher than a previous calculation based

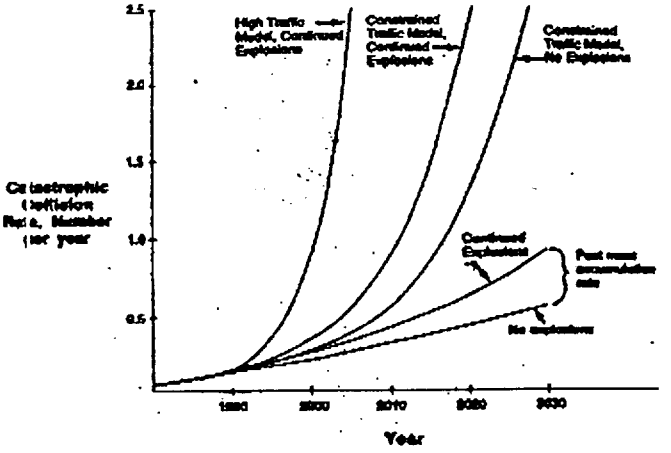


Fig. 7 Rate that payloads, spent rocket stages can be expected to catastrophically break up as a result of random collisions.

doubled since 1976, which alone would quadruple the rate. The introduction of an uncatalogued 10 cm population increased the rate by nearly a factor of two. Finally, using these two sizes to represent the true size distribution will give a slightly higher collision rate. However, by averaging over inclination, and not using the measured inclination distribution (which includes a large number of high inclination orbits that have relatively high collision probabilities) to calculate the collision rates, the calculated collision rate is too low. These last two factors should about cancel one another, so that a rate of 0.12 per year is a realistic number for today's population. Integration over the last 30 years indicates that an average of about 1 catastrophic collision should have occurred to date. That is, from Poisson statistics, there is about a 63% chance that one or more of the 100 catastrophic satellite breakups of the past was due to a collision, based on collision probability alone.

The catastropic collision rate can then be projected into the future for different growth conditions. It is assumed that the "constrained" and "high" traffic models can be approximated by 5 and 10% per year growth rates in the amount of mass to orbit, respectively. (These two functions fit well until the year 2010.) It is also assumed that the ratio of the number of 10 cm to 3 m objects remain constrained under a "continued explosion" policy, and the absolute number of 10 cm remains constant under a "stop explosion" policy. Also considered is a traffic model that would result in an accumulation of 300 catalogued objects per year if explosions were continued, and an accumulation of 150 objects (all 3 m in diameter) per year if explosions were eliminated. Collision fragments were not added to the population since, initially, their number would be small. The results are shown in Fig. 7.

The catastrophic collisions that would take palce would nearly all be major in the sense that they would produce a large number of fragments at altitudes where the fragments would remain for a long period of time. Under this definition, there have only been five major satellite breakups during the past 10 years, or an average rate of 0.5 per year. Consequently, when the random catastrophic collision rate exceeded this value, it could represent a source of debris exceeding that of past explosions. This is important because the random collision rates are proportional to the square of the number of objects in space; consequently, the rate of growth of fragments will be twice the rate of intact objects, to a first approximation. With a high-traffic model or a constrained-traffic model, both with continued explosions, this could happen in either 1997 or 2005, respectively. By eliminating explosions, the constrained-traffic model could continue until 2009 before reaching a 0.5 rate. Maintaining a growth of 300 catalogued

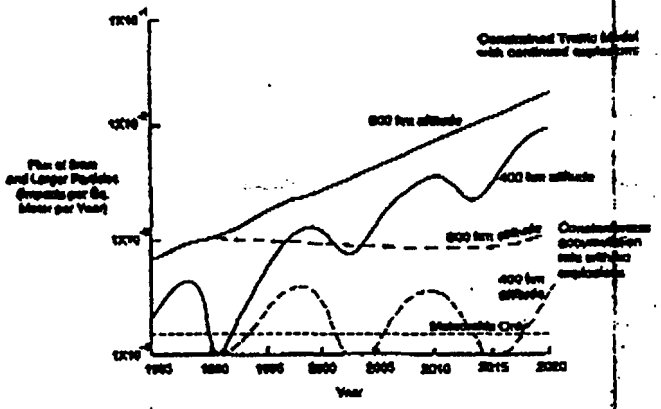


Fig. 8 Predicted future environments of debris 3 mm diameter and larger for two growth conditions.

of the conditions represents the future causes a very large uncertainty in the future population.

Figure 8 predicts the future 3 mm population under two possibilities: the constrained-traffic model with continued explosions (the recommended model in TM 100-471), and a continuation of the current accumulation of mass rate (i.e., 150 objects/yr, 3 m in diameter), but no explosions. By the year 2020, there is a factor of 10 difference in these two fluxes.

Because of the positive response from recent efforts by the U.S. to inform other nations about orbital debris, it is becoming less realistic to assume that explosions will continue at their past rate. In addition, future controls may be adopted so that even high traffic into space would result in a small accumulation rate of debris. If so, the environment 30 years from now may not be too different from today's environment.

Conclusions

Recent measurements tend to confirm the current orbital debris environment described in NASA TM-100-471, with one exception. The new telescopic data indicate that the model is too low for sizes slightly larger than 10 cm, and may be too low for sizes between 2 and 10 cm. However, there is still a significant uncertainty in the current environment, especially for sizes smaller than 10 cm, and at altitudes different from 500 km. There is an even larger uncertainty in the future environment that depends on the debris control measures taken and, to a lesser extent, on the amount of traffic to orbit.

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COLLISIONAL CASCADING: THE LIMITS OF POPULATION GROWTH IN LOW EARTH ORBIT

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ABSTRACT

Predictions have been made by several authors that random collisions between made-made objects in Earth orbit will lead to a significant source of new orbital debris, possibly within the next century. The authors have also concluded that there are a number of uncertainties in these models, and additional analysis and data are required to fully characterize the future environment. However, the nature of these uncertainties are such that while the future environment is uncertain, the fact that collisions will control the future environment is less uncertain. The data that already exist is sufficient to show that cascading collisions will control the future debris environment with no, or very minor increases in the current low Earth orbit population. Two populations control this process: Explosion fragments and expended rocket bodies and payloads. Practices are already changing to limit explosions in low Earth orbit; it is now necessary to begin limiting the number of expended rocket bodies and payloads in orbit.

INTRODUCTION

In 1978, collisional cascading was predicted to be an important source of new orbital debris, possibly before the year 2000, if debris control techniques were not adopted /1/. These predictions were reenforced in 1986 and 1990 /2,3,4,5/. In 1981, NASA adopted procedures which would minimize the possibility of explosions in orbit. By 1989, most other nations and organizations appear to have adopted similar procedures. These procedures will result in a near-term reduction in the projected debris environment; however, they do not address the long term problem. In the long term, once a critical population density of objects is reached, the rate of fragment production from random collisions exceeds the rate of removal by atmospheric drag, and the procedures to prevent explosions becomes less important. Once this critical density is reached, the debris population will increase without placing any more objects into orbit. This increase will stop only when the population of large objects is sufficiently reduced, either by active removal, or by fragmentation. However, by the time fragmentation reduces the population of large objects, the resulting debris environment is likely to be too hostile for future space use. Consequently, it is important to develop operational techniques which maintain a population below the critical density. The objective of this paper is to define the conditions producing this critical density.

KEY OBSERVATIONS AND ASSUMPTIONS

By definition, a critical population density is reached when that population will produce fragments from random collisions at an increasing rate and at a rate that is greater than the rate of removal by natural processes. The rate of fragment production will be controlled in the size regions where mass and area are concentrated. More than 99% of the orbiting population mass and area is contained in orbital debris larger than 10 cm /6/. The average payload or rocket body mass is about 1000 kg /7/, and the average 10 cm to 20 cm mass is estimated to be about 1 kg /1/. At an average velocity of 10 km/sec, an average collision between any two orbiting objects would result in the catastrophic breakup of both objects. Consequently, the rate that collision fragments are generated will be controlled by the collision rate in this size range, and the conditions describing the critical density can be defined in terms of the density of objects 10 cm and larger. Following a collision, the amount of the mass that go into smaller than 10 cm sizes depends on a large number of factors, and is significantly uncertain. However, most fragments larger than 10 cm to 20 cm are observed by US Space Command following a breakup, and the number is not as uncertain. Therefore, the current data is capable of describing the conditions of critical density with more certainty than the time dependant consequence of the smaller than 10 cm population. A fundamental assumption of this analysis is that the current population of large, intact objects, is maintained by replacement when they decay, reducing the analysis to determining the source and sink rates for fragments.

Breakup models have been developed to describe the number and velocity of fragments relative to the center of mass. These models are based on observations of satellite breakups in space and in the lab, and attempt to cover a large range of sizes /8,9/. The velocity of 10 cm fragments ranges from 0 to 200 m/sec. The velocity distribution given in /9/ was used and new orbits calculated for 10 cm fragments. An atmospheric model, assuming a solar activity of 110 F10.7 units, was used to propagate these orbits as a function of time. Spatial density was calculated at various time intervals using the techniques in /10/. It was assumed that the breakup of a 1000 kg spacecraft would produce 300 fragments larger than 10 cm, and that the fragment area to mass ratios are given by the expression given in /1/. The results for a break-up at 1000 km altitude is show in figure 1. As

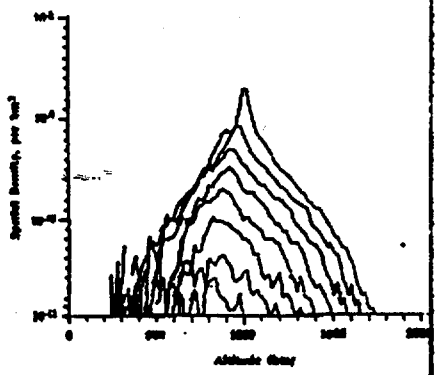

Fig.1. Satellite breakup at 1000 km. Top curve is initial spatial density distribution with altitude. Time interval between lower curves is 400 years.

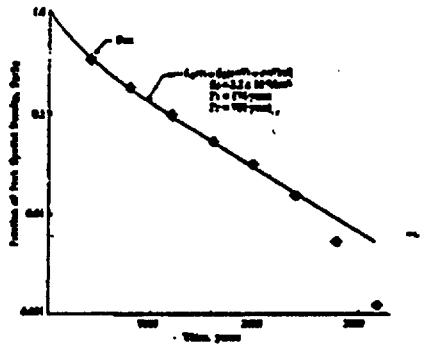

Fig. 2. Decay in Spatial Density following a breakup. Spatial density decays exponentially until it reaches .01 its initial value.

shown in figure 2, the decay in spatial density at the break-up altitude can be accurately expressed as the sum of two exponentials containing a "mean life", just as in natural radioactivity. That is, Spatial density at the breakup altitude as a function of time following a breakup can be expressed as

$$S_B(t) = S_0 \left(e^{-t/\tau_1} + e^{-t/\tau_2}\right)/2 \qquad (1)$$

where S_0 is the initial spatial density following the breakup, t is time and τ_1 and τ_2 are constants and can be thought of as the mean life of two components of the debris cloud. These two components are the half of the cloud that go into higher orbits, and the half that go into lower orbits. The mean life of the half that go into higher orbits is controlled by the atmospheric density at the breakup altitude, while the mean life of the half that go into lower orbits is controlled by the atmospheric density at some lower altitude. For 500 fragments, $S_0 = 2.2 \times 10^{-9}/km^3$, and at 1000 km $\tau_1 = 174$ years and $\tau_2 = 700$ years. At 500 km, $\tau_1 = .72$ years and $\tau_2 = 7.2$ years. Each mean life is approximately inversely proportional to the atmospheric density at the breakup altitude.

If the satellite breakup rate is given by dB/dt, and breakups are equally likely to occur within some small altitude band (small enough not to significantly change the mean life), then by integrating over time, the equilibrium spatial density of the break-up fragments is given by

$$\bar{S}_B = \frac{dB}{dt}\bar{S}_0\tau = \frac{dB}{dt}\frac{\bar{N}_0}{\Delta U}\tau \qquad (2)$$

where $\bar{S}_0$ is the initial spatial density averaged over breakups within the altitude band. The value of τ is simply the average of τ_1 and τ_2. It is convenient to write $\bar{S}_0$ in terms of the average number of fragments, $\bar{N}_0$, which are initially in the volume element ΔU defined by the altitude band. The value of $\bar{N}_0$ asymptotically approaches the number of fragments generated per average breakup as ΔU increases. The value of ΔU should be large, to account for all of the fragments; however, if too large, the value of τ will significantly change within the volume element. A value corresponding to an altitude band of about 100 km accounts for about one third of the fragments and is sufficiently small that mean life fairly accurately represents an average for the altitude band.

SATELLITE BREAKUP RATE

The satellite breakup rate due to random collisions is a function of spatial density, and can be calculated the following two ways:

$$\frac{dB}{dt} = \frac{1}{2}S^2 V\sigma\Delta U = \sum_{i=1}^{n}\sum_{j=i+1}^{n-1}\int_{volume} S_i S_j V_{ij}\,\sigma_{ij}\,dU \qquad (3)$$

The first expression assumes spherical symmetry about the Earth, and some average size and velocity. The value of S is the average spatial density at some altitude, and is calculated using the objects in the US Space Command catalogue by the techniques given in /10/. Values for the relative velocity v and collision cross-section σ, can either be assumed, or calculated by setting the first expression equal to the more exact, 2nd expression. In this expression, S_i is the spatial density of object i at some altitude and latitude, n is the number of catalogued objects in orbit, and V_{ij} and σ_{ij} are the calculated relative velocities and collision cross-sections, respective, between objects i and j in volume element dU.

Satellite physical dimensions and mass were obtained from /1/. When no physical dimensions were available, the radar cross-section was assumed to be a measure of the physical dimensions as described in /1/ and /9/. A numerical program which used a series of 10% random samples to perform the integrations and summations in

(3). A collision rate for catalogued objects of 0.05 collisions per year between 300 km and 1800 km altitude was obtained. By requiring the first expression to equal the same collision rate, the properly weighted average velocity and cross-section are $v = 7.5$ km/sec and $\sigma = 10$ sq m. In addition, the amount of mass involved with each collision was used to determine the amount of mass that would become fragments. It was assumed that if the ratio of the mass of the larger satellite times the relative velocity squared to the mass of the smaller satellite times 10 km/sec squared was less than 1000, than all of the mass of both satellites went into fragments. If this ratio was greater than 1000, then none of the mass went into fragments. This calculation determined that an average collision between 300 km and 1800 km produced 1600 kg of fragments. This means that a significant fraction of the collisions are between larger objects, so that an average collision would produce about 480 fragments larger than 10 cm, with 1/3 of them initially within a 100 km altitude band, or $\bar{N}_0 = 160$.

Combining equations (2) and (3), and assuming that one-half of the catalogue is intact satellites and the other half is breakup fragments, the average critical density of catalogued objects is given by

$$S = \frac{1}{V\tau\,\sigma\,\bar{N}_0} \qquad (4)$$

Using the values previously discussed, figure 3 compares the resulting average critical density with the spatial density of the current catalogue. The results indicate that much of the current population above 900 km is in the unstable region. This is an "average" critical density because it assumes that the satellite size and orbital inclination distributions are independent of altitude. We know this is not exactly true. For example, larger spacecraft are generally launched to lower altitudes, and orbital inclinations do vary with altitude, producing varying collision velocities. Assuming that these local size and inclination preferences will always exist, then an adjusted critical density can be calculated. Effective values for v, σ and $\bar{N}_0$ were obtained as a function of altitude by requiring the two expression in (3) to be equal to one another. It was concluded that the inclination effects do increase the collision rates over the average around 900 km and 1500 km by about 30%, and decreased it slightly at other altitudes. However, the effects of size were more dramatic...slightly increasing the average fragment generation rates at low altitudes, and significantly decreasing the rate at higher altitudes. These adjustments are shown in figure 4.

The results leave the 900 km to 1000 km altitude region firmly in the unstable region, while reducing the region of instability between 1000 km and 1400 km. This latter region of space contains mostly breakup fragments and few large satellites. Because of the low number density in these regions, it has been suggested that they might be used as the region to discard nuclear payloads. Such an action would change the current size distribution, decreasing the critical density line from that shown in figure 4, as well as increase the spatial density; consequently a more limited amount of material could be placed into the region than suggested by figure 4...figure 3 would be more representative, if we could be sure that there were no other factors to consider, such as a significant uncatalogued population.

Recent telescopic measurements, discussed in /11/ indicate that the US Space Command catalogue is only about 50% complete down to a limiting size of 10 cm. Although this means that the current population density should be double over that shown in figures 3 and 4, the corresponding critical density lines would also increase. By placing smaller objects into the population, the effective values for both σ and $\bar{N}_0$ would decrease, increasing the allowable critical density. Consequently, although this uncatalogued population will have an effect, it will be less than a factor of two. In addition, it is difficult to make meaningful statements about the number and size of objects when these objects are near the threshold of the measurements capabilities, especially when the quantity of interest is mass, and the limits of the sensors are expressed in terms of radar cross-section or limiting magnitude. A full analysis must include all of the distributions which effect the returned signal strength, such as object shape, albedo, and a number of other parameters /5/. Similar difficulties occur in /12/ which show the average fragment mass decreasing more rapidly than in /1/ (which is based on ground explosion data) as the 10 cm threshold is approached.

CONCLUDING REMARKS

This analysis indicates that certain regions of low Earth orbit are already unstable. Most of the larger debris generated in these regions will be confined to the unstable regions...this is one of the reasons they are unstable. However, smaller debris will be ejected to greater distances than large debris, and these unstable regions will act as an increasing source of small debris in all of low Earth orbit for centuries. If nothing more is added to the unstable regions, the rate that the debris environment will grow is slow...about one collisional breakup every 10 to 20 years, depending on the nature of the uncatalogued population, with about half of these breakups occurring within the unstable regions. Therefore, if objects are removed from these altitudes, it may still be possible to reverse the instability. However, if objects are continued to be placed into the unstable and surrounding regions,

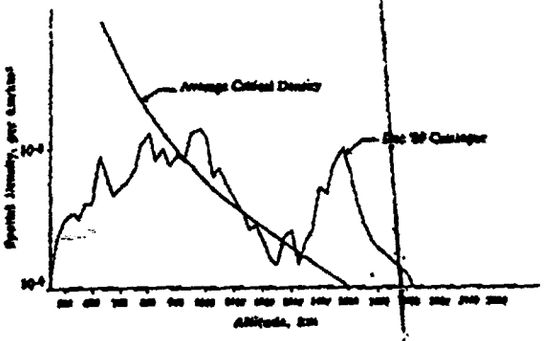

Fig. 3. Average Critical Density. Assumes size and orbital inclinations are independent of altitude.

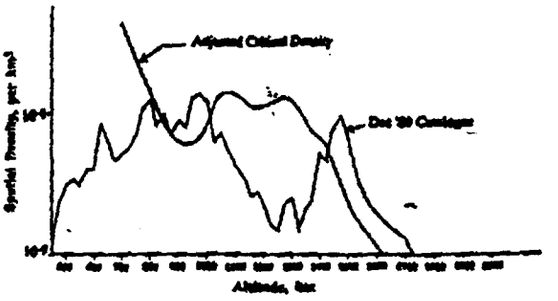

Fig. 4. Adjusted Critical Density. Assumes local size and orbital inclinations.

the breakup rate would be significantly higher and the region of instability would expand. In the last 9 years, the population density between 900 km and 1000 km has doubled. If the current population above 800 km were to double, the region of instability could expand, to include 700 km, and the breakup rate would increase to one every 2.5 years to 5 years. Under these conditions, it would be more difficult to reverse the instability.

There is some uncertainty in the exact threshold of instability; however, this uncertainty is small compared to the certainty that actions must begin now in order to be effective. Some actions could almost begin immediately. Future upper stages that have restart capability, such as the Delta 2nd stage, could be reentered after delivering their payload. Other actions, such as the controlled reentry at the end-of-life of payloads, or the retrieval of payloads will require at least 10 years of engineering development. That engineering development should begin now, since there is little uncertainty that it will be required.

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FEDERAL COMMUNICATIONS COMMISSION

WASHINGTON, D.C. 20554

September 18, 1992

IN REPLY REFER TO:

Cheryl A. Tritt
Chief, Common Carrier Bureau
Federal Communications Commission
1919 M Street, N.W.
Washington, D.C. 20554

Dear Cheryl:

Enclosed herewith is the Report of the Below 1 GHz LEO Negotiated Rulemaking Committee, chartered by the Federal Communications Commission to negotiate proposed, relevant FCC regulations. The attachment constitutes the Report of the Committee; this letter represents the impressions of the Co-Facilitators.

It was the purpose of this Committee, a first for the Commission, to help speed uncontested implementation of commercial and humanitarian non-voice, nongeostationary (NVNG) satellite communication services which will benefit the world far beyond existing communications capabilities. The Committee was able to complete its work on a consensual basis within the time frame foreseen by the Commission. This Report has, in fact, the unanimous endorsement of all the Committee members (with two additional views presented in Part II of the Report). This first effort by the Commission at negotiated rulemaking was an unqualified success. The Commission is to be congratulated for moving ahead with this new process, and bringing more modern communications technology, not only to the public directly served by the Commission, but as well by the inherent technological nature of rapid, globe-girdling satellites, to all of mankind. By this action, the United States advances its lead in improving communications opportunities the world over. It has been a privilege to be part of this process.

The Committee was tasked by its Charter to recommend, so far as agreement could be achieved, methods that would maximize the sharing of these frequencies. To this end, the proponents presented two different sharing proposals, and agree that either plan can accommodate additional NVNG users. Whether a specific system can be so accommodated, however, will depend on its design. The Committee further concluded that only actual experience with the spectrum will determine the additional capacity available. The proposed sharing plans used two different modulation techniques. The Committee was not requested to recommend a preferred type of modulation nor did it choose to do so of its own volition.

It should be pointed out that in its discussions, the Committee quickly realized that changes should be recommended to Part 2 of Title 47 of the Code of Federal Regulations, as well as to Part 25, which is under your purview. For this reason, liberty is taken of forwarding a copy of this Report directly to Thomas Stanley, the Commission's Chief Engineer, who has responsibility for Part 2.

We would be remiss if we did not mention the very significant contributions to this negotiated rulemaking process by three individuals; Edward R. Jacobs of the Private Radio Bureau, Kristi Kendall of the Common Carrier Bureau, and Thomas Tycz of the Common Carrier Bureau. Ed Jacobs acted as coordinator of the informal working group where initial discussions were held; Kristi Kendall was the administrative officer for the Committee; and Tom Tycz was the Commission's representative on the Committee. Without the dedicated work of these three individuals, the Committee work could not have been so successful, so timely.

Sincerely,

Richard Barth
Co-Facilitator
Department of Commerce

for William A. Luther
Co-Facilitator
Federal Communications Commission

Enclosure

Report of the

BELOW 1 GHz LEO NEGOTIATED RULEMAKING COMMITTEE

September 16, 1992

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A. Introduction

The Below 1 GHz LEO Negotiated Rulemaking Committee (Committee) was chartered by the Federal Communications Commission (FCC or Commission) to recommend to the FCC technical rules governing the licensing and provision of non-voice, non-geostationary (NVNG) satellite services operating in the frequency bands below 1 GHz (see Appendix 1). Recommendations of the Committee are intended to serve as the basis for a Notice of Proposed Rulemaking in accordance with the Negotiated Rulemaking Act of 1990, Pub.L. 101-648, November 28, 1990. Through negotiated rulemaking techniques, the FCC desires more rapidly to develop better regulations that may be implemented in a less adversarial setting. Negotiations are conducted through a Federal Advisory Committee, chartered in accordance with the Federal Advisory Committee Act, 5 U.S.C. App.2. The goal of the Committee is consensus on both the language of, and the issues involved in, the proposed rules. If consensus is reached, the FCC will use it as the basis of its proposal. If consensus is not reached, all views will be considered by the FCC in formulating its Notice of Proposed Rulemaking.

By Public Notice dated April 16, 1992, the FCC announced its intent to establish this negotiated rulemaking Committee and requested that all parties that will be significantly affected by the proposed rules identify themselves for inclusion on the Committee. Interested parties requesting representation included four NVNG satellite service applicants (three current and one dismissed (reconsideration pending)), two users of adjacent frequency bands, and six Federal government users of the identified frequency bands. A list of Committee members is attached as Appendix 2.

The FCC announced the formation and scope of, and proposed meeting schedule for, the Below 1 GHz LEO Negotiated Rulemaking Committee by Public Notice dated July 23, 1992. In that Notice, the FCC announced that the Committee's purpose would be to provide expert advice and recommendations on technical matters related to the establishment and regulation of an NVNG satellite service. The Committee's charter was filed on August 10, 1992, the date of the Committee's initial meeting, and expired by its own terms on September 16, 1992.

The Committee held six full Committee meetings in the course of its 37 day duration. In addition, two informal working groups were formed to collect information and draft proposals for deliberation by the Committee. These groups, the Informal Working Group (IWG) (Edward Jacobs, Coordinator) and the Editorial Working Group (EWG) (Richard Barth, Coordinator) collectively held sixteen meetings. A schedule of the Committee and working group meetings is attached as Appendix 3. All of these meetings were open to the public, including participation in informal working groups. During its deliberations, the Committee addressed, from all represented perspectives, the various technical issues involved in the licensing and regulation of this new satellite service. A Work Program discussing in greater detail the scope of Committee and working group deliberations is attached as Appendix 4, and a list of documents identified by the Committee as pertinent to its deliberations is attached as Appendix 5.

The Co-Facilitators of the Committee were William A. Luther and Richard Barth. The designated representative of the FCC on the Committee was Thomas S.

Tycz. Administrative support, technical guidance and coordination were provided by Kristi L. Kendall.

The recommendations of the Committee are discussed in narrative form in Section B below, and the proposed text of the new rules is set forth in Section C. Unless otherwise specified, all recommendations in this portion of the Committee's report represent the unanimous views of the participants. A separate section, Additional Views, has been reserved for the presentation of opinions contrary to, or in addition to, those presented in this report.

The Committee believes the Commission was correct in its decision to utilize Negotiated Rulemaking Act procedures as a means of expediting the adoption of rules for these valuable services, and hence the provision of service to the public. Particularly in light of the positive attention that NVNG satellite service received at the recent World Administrative Radio Conference (WARC) and the strong public interest in expediting the availability of these services, the Committee also believes it is imperative that the Commission continue to move ahead quickly in order to maintain the U.S. lead in this promising new small satellite technology. Therefore, the Committee urges the Commission, promptly following the submission of this Report to the Chief of the Common Carrier Bureau, to complete the regulatory actions necessary to inaugurate Non-Voice Non-Geostationary Satellite Service (<1 GHz), including release of a notice of proposed rulemaking containing the proposed rules, adoption of a final allocation order, conduct of parallel processing of the applications, and coordination of the use of this spectrum with the Federal government users. These are the necessary and appropriate steps to further the public interest and the Commission's goal of expeditiously making these important new services available to the public.

B. Discussion

This section of the report addresses those proposed rules (see Section C, below) where the Committee believes further elaboration may be necessary or helpful, explains why rules were not proposed or amended in certain circumstances, and discusses the consensus views of the Committee regarding a number of policy issues involved in the licensing of NVNG systems.

1. Allocation Issues. The Committee noted that the intention to allocate spectrum for NVNG satellite services in the bands 137-138 MHz, 148-150.05 MHz, 399.9-400.05 MHz and 400.15-401 MHz, together with conditional U.S. footnotes, is being considered in a separate FCC rulemaking, ET Docket 91-280. Because Federal agency member participants in this current proceeding were not empowered by the NTIA to negotiate resolution of topics under consideration in that docket, the Committee did not discuss the content of any U.S. footnotes regarding conditions of operations for the NVNG satellite service. The Committee received briefings on sharing aspects in the various bands from each of the applicants. Adoption of international and other footnotes is discussed below.

2. International Footnote 608Z. Footnote 608Z was adopted at WARC-92 in response to concerns of many countries relative to the 148-149.9 MHz MSS allocation. This footnote allowed individual countries (those named in the

footnote) to ensure protection of their existing services in the allocation and still maintain the overall allocation on a primary Mobile Satellite Service basis. Since the U.S. is not part of this footnote, and will adopt its own rules regarding the existing services, the Committee considered it unnecessary to place this footnote in the U.S. Domestic Table.

3. International Footnotes 608X and 608Y. International footnotes 608X and 608Y (adopted at WARC-92) impose several conditions on the NVNG satellite service operating in the 148.0 - 149.9 MHz and the 149.9 - 150.05 MHz bands, respectively. One of these conditions states that mobile earth stations in the NVNG satellite service not produce a power flux density in excess of -150 dB(W/m^2/4 kHz) outside of national boundaries. The Committee believes that this condition was put in place, at WARC-92, as a means to ensure that international coordination would take place, and not to protect any specific terrestrial system. Since the NVNG satellite service systems will be internationally coordinated, where necessary, by the FCC and the licensee, the Committee recommends that this condition should not be used as a basis for acceptance or rejection of any application in this radio service.

4. §25.202 - Frequencies. The Committee examined the proposal for allocation of the 399.9-400.05 MHz band. This band was not allocated internationally to the mobile-satellite service at WARC-92. However, since the TRANSIT system is the only domestic system operating in the 149.9-150.05 MHz and 399.9-400.05 MHz bands, the proponents of NVNG believe that the 399.9-400.05 MHz band should also be allocated domestically to the NVNG satellite service in the Earth-to-space direction. The proponents recognize that any satellite use of this band outside of the United States will need to be on a secondary, non-interference basis.

5. §25.203 - Choice of Sites and Frequencies. The Committee considered modifications to the reference to "earth stations" in §25.203 and decided that no change to this section is necessary if "user transceivers" are exempted from the provisions of §25.203(a)-(e). Such an exemption is recommended by the Committee in proposed new Section 25.409.

6. §25.208 - Power Flux Density Limits. The Committee considered changes to §25.208, but decided that no changes are necessary to this section. Power flux density limit considerations are being handled through appropriate changes to Part 2 and by reference in the service rules.

7. §25.111 - Additional Information. The Committee considered § 25.111 and decided that no changes are needed to this provision. The Committee also believes that the information needed to perform any coordination necessary under FNs 608X or 608Y can be requested by the Commission under § 25.111.

8. Proposed §25.401 - Space Station Application Requirements. The Committee requests that the Commission clarify the relationship between the issuance of authorization to construct and any multi-stage financial showing that the Commission might adopt in this proceeding. This will affect when "protection" from interference by future applicants under proposed section 25.401(a) will arise, which, while outside the purview of this Committee, has

been proposed to occur at the time that a conditional authorization has been issued.

9. Proposed §25.408(d) - Safety and Distress Communications. The Committee was asked to consider Sections 321 and 359 of the Communications Act of 1934, as amended (47 U.S.C. §§321 and 357) in its creation of technical rules. These provisions establish the primacy of maritime distress signals over all other communications and mandate, subject to certain exceptions, that such communications be provided free of charge. The Committee unanimously supports the continuing importance of the need to ensure that all communications providers, satellite or otherwise, heed this basic principle; safety of life should not be compromised for any reason.

The Committee has provided the Commission with a proposed rule in the new NVNG satellite service that references these statutes and explains their importance. At the same time, the Committee wishes to alert the Commission of its concerns. First, the relevance of this rule and the statutory provisions extends well beyond NVNG services. While it is beyond the mandate of this Committee, it may well be that such a rule should be incorporated in the general section of Part 25 to apply to all satellite services. Second, the Committee is aware that Part 2 of the Commission's Rules -- in particular §2.401 et seq. -- seems to incorporate the guidance of Sections 321 and 359 and apply it to all radio services. In this respect, the Committee's proposed §25.408(d) may be a needless repetition of a longstanding Commission rule.

10. Proposed §25.409(b) - Operation of Hand-Held Transceivers on Civil Aircraft. The Committee discussed at length the growing problem of the operation of electronic devices, including transceivers, on board civil aircraft. It was noted that the frequency band from 108 to 137 MHz is used for civil and military aeronautical safety communications and navigation and that this band is adjacent to the 137 to 138 MHz band to be used by the NVNG satellite service as a downlink band. Depending upon the specific design, the receiver portion of the portable transceiver may emit radiation in the 108 to 137 MHz band.

The Committee recommends a labeling rule to ensure that the hand held transceivers, or devices that contain transceivers, are not to be operated on board civil aircraft. This rule is similar to that used with cellular telephones. It was also noted that Section 15.101(a) applies to the receivers, associated with any of the NVNG satellite service transceivers, and therefore the level of radiation from these receivers is already regulated by the FCC.

11. Spectrum Efficiency. The Committee concluded that spectrum efficiency for the NVNG satellite service is an important goal that should be addressed by the Commission in the application process. The proposed service rules submitted by ORBCOMM, STARSYS and VITA contained a provision intended to ensure that commercial applicants for NVNG satellite service would design systems that will make full use of the spectrum to be assigned to each system. Alternative rules proposed by Committee members included (1) a requirement that the applicant demonstrate that service would be available in the U.S. at least 75% of the time, (2) a requirement that the application merely include a demonstration of the percentage of time service would be available, and (3) a

more generalized requirement that the application include a demonstration of efficient use of the assigned spectrum. (See LEOAC-38). These proposed provisions engendered a fair measure of dispute, however, because although there was consensus as to the need for the Commission to consider spectrum efficiency for commercial NVNG satellite services, there was not an agreement as to the particular minimum percentage availability selected, whether such a percentage should apply and/or under what circumstances, whether orbit management techniques will be necessary, what standards or measures the FCC should utilize to determine spectrum efficiency, or how the results of such considerations should be used by the Commission in the application process. Because the issue was viewed primarily as a policy (and not a technical) matter, the Committee is not recommending a specific rule, but does urge the Commission to consider adopting a regulation, or issuing a policy statement, that will promote efficient use of the limited amount of spectrum presently available for this service.

12. Feeder Link or Gateway Link Requirements. The NVNG satellite service applicants identified in the proposed frequency sharing plan a requirement for spectrum for narrowband "feeder" link or "gateway" link operations. The links contemplated by ORBCOMM, STARSYS and LEOSAT would connect the respective systems' earth stations or gateways with the satellites, and their operations would be separate and distinct, within the allocated bands, from the systems' user transceiver-to-satellite links. VITA did not propose such separate feeder link operations.

In order to accommodate the data rates necessary for the communications between the gateways and the satellites (and to compensate for Doppler shift), ORBCOMM, STARSYS and LEOSAT identified a requirement of 50 kHz assignments for both the uplink and downlink of the gateway operations.[1] VITA, due to the different nature of its operations (transmitting longer messages among fixed and transportable earth stations rather than short messages to and from individual user transceivers) will not be utilizing separate feeder link spectrum. VITA instead proposes to utilize 90 kHz for an uplink in the 148-149.9 MHz band, and 90 kHz for a downlink in the 400.15-401 MHz band, and the earth stations effectively combine the functions of user and feeder or gateway links. For the reasons set forth below, the Committee recommends that the Commission decline to adopt technical rules that require systems to share gateway or feeder links, or that otherwise inhibit the applicants' ability to locate such links within the available spectrum.

The spectrum required by ORBCOMM, STARSYS and LEOSAT for their gateway and feeder link operations was separate from the feeder link operations of the

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[1] ORBCOMM proposes to use 50 kHz in the 137-138 MHz band for its gateway downlink operations, and 50 kHz in the upper portion of the 148-149.9 MHz band for its gateway uplink operations. STARSYS proposes to use 50 kHz in the 400.15-401 MHz band for its narrowband downlink operations, and 50 kHz in the lower portion of the 148-149.9 MHz band for its narrowband uplink operations. In its September 1, 1992 presentation, LEOSAT also proposed to use 50 kHz in the 137-138 MHz band for its narrowband downlink operations, and 50 kHz in the 148-149.9 MHz band for its narrowband forward link operations.

other NVNG systems. The applicants did, however, indicate that they would operate the feeder links within the frequency bands proposed to be allocated to NVNG satellite service. While the proposed frequency sharing plan included specific frequencies for these gateway operations, the applicants indicated that there was a fair measure of flexibility in the geographic and spectral locations of the gateways in order to accommodate coordination with the government users.[2]

The question was raised as to whether it would be possible for the NVNG satellite service systems to share the feeder link or gateway link frequencies with each other. Due to the nature of the proposed operations, such a suggestion of sharing was rejected. ORBCOMM and STARSYS, at least, will require continuous communications between an operational spacecraft and at least one gateway to provide for the real time relay of messages between users and the gateway. Multiple satellites within a single system will, at times, appear in the beam width of a gateway earth station antenna. This situation will occur because some satellites will pass relatively physically close to other satellites, with one satellite on an ascending pass, and another satellite from the same system (but from a different orbital plane) on a descending pass. Nor will it be possible to utilize earth station antenna discrimination to minimize these occurrences, because in these frequencies the broad main beams of the antennas will be in the range of 20 to 25 degrees.

Within a system, it will be possible to coordinate these instances of multiple satellites within the beam width of the gateway antennas through the use of modulation, packet rates and signalling techniques. ORBCOMM, for example, will use a FDMA/TDMA uplink format that will permit such intrasystem reuse of the 50 kHz gateway link spectrum. During the period of near-conjunction of the two satellites, however, the maximum uplink data rate must be shared by both satellites, briefly reducing the system capacity. Such brief periods of reduced capacity can be tolerated within a system because both ORBCOMM and STARSYS will know in advance when such reductions will occur, due to the station keeping design of the respective systems and the tracking that will occur. As a result of the sharing of the gateway spectrum among satellites in the same system, ORBCOMM, STARSYS and LEOSAT believe that they will each be making highly efficient use of the gateway link spectrum, since the intrasystem coordination effectively results in multiple reuse of the frequencies. However, because of the system technology and operational constraints, it would be practically impossible to share the gateway spectrum with another system.

In order for multiple NVNG satellite service systems to share the same gateway uplink spectrum, it would be necessary for them to pre-coordinate on an uplink signal structure, including packet rates, modulation techniques and signalling techniques. It would also be necessary to attempt to coordinate operationally on a real time basis, since there would be times when there would be a need to share the uplink data rate among numerous satellites (two or more

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[2] As one operational-level constraint, the applicants indicated that the ORBCOMM 50 kHz feeder link in the 137-138 MHz band should be located outside of the center of the STARSYS spread spectrum operations in that band.

from each system), thereby effectively resulting in system outages. However, such intersystem operational coordination would be practically impossible, since the satellites from the different systems will not be station kept with respect to each other.[3] Particularly in light of the intrasystem reuse of the gateway link spectrum already accomplished under the proposed sharing plan and system designs of ORBCOMM and STARSYS, requiring intersystem feeder link sharing (necessitating additional severe compromises) would be an unsatisfactory approach because it would render the service unreliable and impractical. Thus, the Committee recommends against sharing of the gateway feeder links among the NVNG satellite service systems.

13. Multiple Entry. Among its many tasks, the Commission asked the Committee to consider ways to promote multiple entry and co-existence with other space and terrestrial systems, and to avoid mutual exclusivity with present and future applicants. These discussions were important because the amount of allocated spectrum for NVNG services is so limited. The amount of spectrum available to the applicants for the NVNG satellite service was only 2.585 MHz as co-primary, plus 455 kHz as secondary after the METSAT, TRANSIT and DMSP frequencies are subtracted from the 1992 WARC allocation of 3.45 MHz primary and 475 kHz secondary allocation. Two sharing plans were presented that were intended to promote the goals identified by the Commission. The Committee agreed that some sharing was possible in the plans presented, but it neither agreed nor attempted to agree on how such sharing should be implemented, or which sharing plan represented the most efficient use of the spectrum. The Committee did reach consensus on proposing procedural protections for future applicants -- such as requiring coordination between applicants and licensees upon the direction of the Commission and recognizing that future applicants need to prepare their applications based upon information that is publicly available at the Commission.

What follows is a synopsis of the sharing plans presented by the private sector parties. Both plans can accommodate additional users. In addition, the NVNG service spectrum has some unused spectrum now, and will have a modest amount of additional spectrum available in the future. Accordingly, the proposed sharing plans can accommodate additional users now, but it is unclear how many or what size those other systems could be. Finally, system operators and applicants will have the opportunity to seek additional frequency allocations at future WARCs for system expansion as the systems prove successful in the marketplace. In other respects, these plans should not be viewed as reflecting a consensus of the Committee, but only as possible methods of sharing this limited spectrum among NVNG satellite system licensees, other satellite users and terrestrial systems.

(a) LEOSAT Sharing Plan. LEOSAT presented the Committee with a sharing plan using CDMA for all but gateway uplinks and VITA's service. (The LEOSAT plan is contained in the Minutes of the September 1, 1992 Negotiated Rulemaking Committee Meeting.) This plan may accommodate up to four CDMA applicants in

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[3] The arguments of perigee and right ascension of ascending nodes will be uncoordinated, and will precess at different rates, making simultaneous visibility a likely but random event with respect to busy hours of traffic loading.

the 148-149.9 MHz uplink band and in the 137-138 MHz downlink band, using 900 kHz of bandwidth in each direction. Only actual experience with the spectrum, however, will determine the additional capacity available. Under this plan, 910 kHz of bandwidth remains unassigned and available in the 148-149.9 MHz band for other users or applicants.

(b) ORBCOMM/STARSYS/VITA Sharing Plan. The frequency sharing plan presented to the Committee by ORBCOMM, STARSYS and VITA in LEOAC-15 (LEOAC-15 plan) provides an example of a scheme whereby at least two different types of modulation techniques, Code Division Multiple Access (CDMA) and Frequency Division Multiple Access (FDMA), can share the same limited amount of spectrum and may allow for entrants in addition to the three applicants who submitted LEOAC-15, using either approach. Several compromises from the original applications were made by these applicants in order to achieve a frequency sharing plan which could accommodate two types of modulation techniques within the limited spectrum available.

Additional CDMA Applicants. The LEOAC-15 plan contains 855 kHz for spread-spectrum use in the 148-149.9 MHz uplink band. Theoretically, this spectrum will be able to accommodate as many as three additional CDMA users depending upon the amount of noise in the band from existing users. Only actual experience with the spectrum, however, will determine the additional capacity available. This spectrum is assigned as co-primary allocation to the NVNG satellite service. CDMA is also accommodated in the downlink direction with 855 kHz in the 137-138 MHz band for CDMA, but the services will have to operate, in part, in portions of the band which are designated as secondary for the NVNG satellite service. The downlink spectrum will also accommodate additional CDMA entrants within the limits of existing noise levels and will be subject to sharing the spectrum on a secondary basis with the METSATs that already use several frequency bands in the spectrum. Services desiring to use pure CDMA for all links are therefore accommodated using these two bands as described. Should CDMA applicants desire to use FDMA feeder links, additional spectrum in the 149.9-150.05 MHz uplink band may be available for that purpose, and there may be unused spaces for one or more 50 kHz FDMA feeder links in the 137-138 MHz downlink band.

Additional FDMA Applicants. The LEOAC-15 plan contains 1045 kHz for FDMA use in the 148-149.9 MHz uplink band, of which 855 kHz is available for users of a dynamic channel assignment system (DCAS). (90 kHz is for VITA's uplink, 50 kHz is for the uplink feeder link of STARSYS and 50 kHz would be used by ORBCOMM for gateway feeder links.) The DCAS FDMA spectrum should be able to accommodate additional applicants on a shared basis depending upon the degree of use of the channels by the existing users in the band, and the degree of use proposed by additional applicants. Only actual experience with the spectrum, however, will determine the additional capacity available. Additional spectrum in the 149.9-150.05 MHz band may be available for users. In the downlink direction, DCAS FDMA uses channels in the portion of the 137-138 MHz band where NVNG is currently co-primary. Additional DCAS FDMA systems should be able to share these channels or use other unused channels in the co-primary portion of the same band for transmitting downlink data. Feederlinks are employed in the uplink band and in the 137-138 MHz band. The downlink band activity must share the spectrum with CDMA by using reverse polarity, geographical separation of

the satellites, and location of feederlinks away from the center of the CDMA signal.

(c) Future Additional Spectrum. Additional co-primary spectrum will become available to the NVNG service when (a) the METSAT service moves from the center of the 137-138 MHz band to the edges about the year 2000; and (b) when the TRANSIT service phases out at the end of 1996. These two actions will make additional 130 kHz and 150 kHz segments available to NVNG as primary spectrum. Although this is not a large amount of additional spectrum, it will augment the existing available spectrum, and will be valuable for future expansion of the service. The use of the 399.9-400.05 MHz frequency band is being considered in the FCC's allocation rulemaking in docket 91-280.

(d) Additional Sharing Schemes. Portions of the NVNG spectrum may also be used on a time-share basis. For example, the Air Force is planning to use 710 kHz in the 400.15-401 MHz downlink band for a two-satellite Defense Meteorological Satellite Program (DMSP). Each DMSP satellite will be in a different polar orbit, and utilize a different 355 kHz portion of this spectrum. Theoretically, it may be feasible for an additional NVNG constellation consisting of a small number of satellites to effectively time share with DMSP (or the 90 kHz proposed for VITA). Since 137-138 MHz METSATs also operate in a similar manner, time sharing in that frequency band may also be possible. However, such sharing would be dependent on the ability to place the additional systems' satellites into precise orbits and to maintain them in those relative orbital locations, and/or other technical factors.

14. Coordination With Existing NVNG Satellite Service Systems. The Committee considered whether a rule requiring coordination between new applicants for NVNG satellite systems and permittees, licensees, and earlier applicants for NVNG systems should be recommended to the Commission. The Committee concluded that coordination should be encouraged, but at the same time was concerned that requiring coordination too early in the process, for example, among several mutually exclusive applicants, would be unduly burdensome and wasteful. Accordingly, the proposed rule requires coordination, but only after the Commission determines that the process would be useful to commence.

The Commission has adopted a policy for geostationary fixed-satellite systems that leaves the resolution of inter-system interference questions to the private sector in the first instance. In Assignment of Orbital Locations to Space Stations in the Domestic Fixed-Satellite Service, 5 FCC Rcd 179 (1990), the Commission addressed concerns raised by existing satellite operators that new satellites to be authorized would cause them unacceptable interference. It stated that:

> We expect domestic satellite operators to resolve potential interference problems because they can best weigh the technical and economic tradeoffs involved in negotiating a coordination agreement. We do not become involved unless the parties are unable to reach an agreement. . . . If a coordination agreement cannot be reached after exhaustive good faith effort, the parties may then request that we intervene.

Id. at 183 (¶ 32) (footnote omitted). See also Orion Satellite Corp., 5 FCC Rcd 4937, 4938 (1990) (footnote omitted) (Commission refuses to delay authorization of new satellite pending resolution of interference concerns raised by another U.S.-licensed system or to intervene; leaves it to the parties "to resolve potential interference problems through informal coordination prior to seeking Commission involvement").

The policy articulated in the above-cited decisions is that coordination is a matter best accomplished on an informal basis. Applicants, particularly start-up ventures, often lack the financial and personnel resources to do a thorough satellite system coordination, and existing licensees and permittees lack incentive to expend their time and resources in intensive technical negotiations with an entity that may never receive an authorization. Inasmuch as the coordination between two domestic systems is very similar to the type of coordination that is to be completed under the international frequency coordination regime, it is both preferable and economical for the domestic coordination also to be deferred until such time as the Commission deems coordination to be useful and practical, and without unnecessary burden, for the participants to undertake.

Accordingly, this Committee recommends that the Commission extend the informal coordination policy it has applied to domestic and international geostationary satellite systems to the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz), and adopt proposed section 25.408(c) that requires the initiation of coordination at the FCC's direction. This Committee has discussed, but did not resolve, the issues of whether the results of any coordinations would be reported to the Commission, and if so, how the confidential, proprietary, and commercially-sensitive information contained in such reports would be protected from public disclosure.

15. Coordination With Federal Government Users. The Committee discussed coordination methodologies between NVNG users and Federal Government agencies. The Committee concluded (see proposed §25.408(b)) that the existing NTIA/IRAC structure is best suited for this purpose.

C. Proposed Rules

PART 2

1. Add international RR FN 608X to the domestic frequency allocations table in § 2.106 of the FCC rules in the 148-149.9 MHz band under the "Non-Government" column.

2. Add international RR FN 608Y to the domestic frequency allocations table in § 2.106 of the FCC rules in the 149.9-150.05 MHz band under the "Non-Government" column.

3. Add international RR FN 599A to the domestic frequency allocations table in § 2.106 of the FCC rules in the 137-138 MHz band under the "Non-Government" column.

4. Add international RR FN 647X to the domestic frequency allocations table in § 2.106 of the FCC rules in the 400.15-401 MHz band under the "Non-Government" column.

5. Add international RR FN 599B to the domestic frequency allocations table in § 2.106 of the FCC rules in the 137-138 MHz, 148-149.9 MHz, 149.9-150.05 MHz, and 400.15-401 MHz band under the "Non-Government" column.

6. Add a new US footnote to domestic frequency allocations table in § 2.106 of the FCC rules in the 137-138 MHz, 148-149.9 MHz, 149.9-150.05 MHz, and 400.15-401 MHz bands under the "Non-Government" column. The footnote would read:

> "USxxx Use of this frequency band by the mobile-satellite service in the United States is limited to Non-Voice, Non-Geostationary Satellite Systems."

7. Add international RR FN 609B to the domestic frequency allocations table in § 2.106 of the FCC rules in the 149.9-150.05 MHz band under the "Non-Government" column.

PART 25 (Existing Rules)

8. The Committee recommends adding a new item (27) under paragraph (c) of § 25.114 that would read as follows:

§ 25.114. Applications for space station authorizations

(c) The following information shall be contained in the separate applications:

(27) Applications for authorizations in the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) shall also provide all information specified in § 25.401.

9. The Committee recommends adding a new item (3) under paragraph (a) of § 25.202 that would list the frequencies available for the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) that would read as follows:

§ 25.202. Frequencies, frequency tolerance and emission limitations

(a)(3) The following frequencies are available for use by the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz):

137-138 MHz:	space-to-Earth
148-149.9 MHz:	Earth-to-space
149.9-150.05 MHz:	Earth-to-space
399.9-400.05 MHz:	Earth-to-space
400.15-401 MHz:	space-to-Earth

Until January 1, 1997, the allocations in the 149.9-150.05 MHz and 399.9-400.05 MHz bands may be used on a secondary basis only. The 399.9-400.05

MHz band was not allocated internationally to the mobile-satellite service at WARC-92.

10. The Committee noted an editorial error in § 25.202(f)(4). The reference to "(g)" in (f)(4) of this section should be corrected to read "(f)", as follows:

(f) Emission limitations. .....

(4) .... than specified in paragraphs (f)(1), (2), and (3) of this section.

PART 25 (Proposed New Rules)

11. The Committee considered new service rules for the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) and recommends that the following new series of rules be considered for this service:

§ 25.401. Space Station Application Requirements for the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz)

(a) Each application for a space station license in the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) shall describe in detail the proposed Non-Voice, Non-Geostationary Satellite system, setting forth all pertinent technical and operational aspects of the system, and the technical, legal, and financial qualifications of the applicant. In particular, each application shall include the information specified in Section 25.114, except that in lieu of the information concerning orbital locations requested in Section 25.114(c)(6), the applicant shall specify the number of space stations and applicable information relating to the altitude(s), argument(s) of perigee, service arc(s), right ascension of ascending node(s), eccentricity, and inclination of the space stations (all referenced to the same time) that will comprise its system. Applicants must also file information demonstrating compliance with all requirements of this section, and showing, based on existing system information publicly available at the Commission at the time of filing, that they will not cause unacceptable interference to any Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) system authorized to construct or operate.

(b) Reserved.

(c) Applicants for Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) system must identify the power flux density produced at the Earth's surface by each space station of their system in the frequency bands 137-138 MHz and 400.15-401 MHz, to allow determination of whether coordination with terrestrial services is required under footnotes 599A and 647X of Section 2.106 of the FCC Rules. In addition, applicants must identify the measures they would employ to protect the radio astronomy service in the 150.05-153 MHz

and 406.1-410 MHz bands from harmful interference from unwanted emissions.

(d) Emission limitations

(1) Applicants in the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) shall show that their space stations will not exceed the emission limitations of paragraphs (f)(1), (2), and (3) of Section 25.202, as calculated for a fixed point on the Earth's surface in the plane of the space station's orbit, considering the worst-case frequency tolerance of all frequency determining components, and maximum positive and negative Doppler shift of both the up link and down link signals, taking into account the system design.

(2) Applicants in the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) shall show that no signal received by their satellites from sources outside of their system shall cause an output signal to be generated that is not in conformance with paragraph (f) of Section 25.202 and paragraph (d)(1) of this section.

§§25.402-406. These sections, as proposed in LEOAC-14 (and a proposed **§ 25.410)** were not considered by this Committee.

§ 25.407. Reserved.

§ 25.408. Operating Conditions for Systems Operating in the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz)

In order to ensure compatible operations with authorized users in the frequency bands to be utilized for operations in the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz), Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) systems must operate in accordance with the conditions specified in this section.

(a) Service limitation. Voice services may not be provided.

(b) Coordination requirements with Federal Government users.

(1) The frequency bands allocated for use by the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) are also authorized for use by agencies of the Federal government. The Federal use of frequencies in the Non-Voice, Non-Geostationary Satellite Service (< 1 GHz) frequency bands is under the regulatory jurisdiction of the National Telecommunications and Information Administration (NTIA).

(2) The Commission will use its existing procedures for liaison with NTIA to reach agreement with respect to achieving compatible operations between Federal Government users under the jurisdiction of NTIA and Non-Voice, Non-Geostationary Satellite