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THE DETERMINATION OF QUANTITATIVE MICROBIAL SAMPLING REQUIREMENTS FOR APOLLO MODULES

A. L. Roark, 1741

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A. L. Roark*

Planetary Quarantine Department
Sandia Laboratories
Albuquerque, New Mexico

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*Currently Associate Professor of Mathematics at West Virginia University, Morgantown, West Virginia

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INTRODUCTION

One of the main responsibilities which the United States Planetary Quarantine Officer has concerning Apollo is the estimation of the number of microorganisms which are on the surface of each Apollo spacecraft at launch. This problem is composed of two parts. The first is to estimate the bio-loading on the hardware at a given sampling time. The second is to predict, on the basis of this estimate and environmental sampling, the number of microbes which will be on the surface at launch. The second of these models must deal with the problem of fall-out of microbes from the environment and with the transfer of microbes from the workmen and their equipment to the surfaces of the module. This prediction model will be dealt with in a later document. The present work is a possible approach to the first of these models. To be more precise, it deals with the problem of estimating the total number of microorganisms on the surface of an Apollo module based on samples taken from a relatively small percentage of the total area of the module. Another problem related to this which we shall discuss is the problem of establishing ahead of the sampling time the number of samples which will be needed to obtain various accuracies. In doing this, we shall consider both the cotton swab method of sampling which is now used [5] and the vacuum probe method of sampling [1] which is being considered for use.

THE MODEL

When various investigators (for example, McDade, et al [4]) have counted the number of microorganisms per unit area on a surface which sees a uniform environment, they have observed what they term the "plateau effect". This effect is defined to be the phenomenon which is observed as one records the number of microorganisms per unit area as a function of time. They find that as time increases, the density of microorganisms on a surface asymptotically approaches an upper bound. If we wish to explain this plateau, we arrive at the assumption that the majority of microbes which are found on the surface are attached to larger ambient particles. The reason for this conclusion is that the plateau has bean observed when spores are considered. If we assume that microbes are continually deposited, there must be removal of viable microorganisms from the surface in order to obtain the plateau. Since spores are very slow to die, it would seem that physical removal of the microorganisms is what produces the plateau since removal by death is unlikely in the time periods which are observed. The energies necessary to remove spores which are not attached to ambient particles from a surface are much higher than one would expect in a typical experimental (or assembly) environment [9]. Thus, the assumption that most microorganisms which are deposited on a surface are attached to ambient particles is consistent with observations.

The first part of the model which we shall develop deals with the attachment of microorganisms to ambient particles, restricting our attention to "large" particles which can be removed from surfaces under normal assembly conditions or to "naked" microorganisms which die. To do this, let us draw a particle at random from the environment. Let Y be the random variable representing the number of microorganisms which are attached to this particle. We wish to derive an expression for $P(Y = k)$ the probability that k microorganisms are attached to the particle.

We refer the reader to the work of Tukey [11] for many of the details which we shall omit. Assume that there exist m microbes and N ambient particles in the assembly facility where the Apollo module is located.

Let P_i be the probability that one of the microorganisms will attach itself to the i^{th} particle. (We do not require $\sum_{i=1}^{N} P_i = 1$. We only require $\sum_{i=1}^{N} P_i \leq 1$). Define the random variable X_k to be the number of particles in the assembly facility with k microorganisms attached to them. If we assume that P_i does not change as microbes become attached to the i^{th} particle, then we see that $E(X_k)$, the expected value of X_k is given by

$$E(X_k) = \binom{m}{k} \sum_{i=1}^{N} (1-P_i)^m \left(\frac{P_i}{1-P_i}\right)^k \tag{1}$$

The assumption that P_i is independent of the number of organisms on the particle is probably the most questionable of all those we shall make. We shall say more about it later.

Since the Apollo modules are not in a highly controlled microbial environment at Cape Kennedy, it is reasonable that m is very large. Also the attraction between ambient particles and microorganisms is probably very small. For these reasons let $m \to \infty$ and $P_i \to 0$ for $i = 1,2,\ldots,N$ in such a way that $mP_i = \lambda_i$ where λ_i is a constant. The quantity λ_i here would represent the expected number of microorganisms on the i^{th} particle. After taking these limits equation (1) becomes

$$E(X_k) = \sum_{i=1}^{N} \frac{(\lambda_i)^k}{k!} e^{-\lambda_i} . \tag{2}$$

If a_i is determined so that $\lambda_i = \lambda(1+a_i)$ where λ is fixed, equation (2) can be rewritten as

$$E(X_k) = \frac{\lambda^k}{k!} e^{-\lambda} \sum_{i=1}^{N} (1+a_i)^k e^{-\lambda a_i}$$

A convenient choice of λ is the mean of the λ_i's. If we use this value for λ, we have $\sum_{i=1}^{N} a_i = 0$. Define $A = \sum_{i=1}^{N} a_i^2$. Expanding the summation in (3) and collecting terms we obtain

$$E(X_k) = \frac{\lambda^k}{k!} e^{-\lambda} \left\{ N + \left[\frac{(k-\lambda)^2-k}{2}\right] \sum_{i=1}^{N} a_i^2 + \left[\frac{(k-\lambda)^3}{6} - \frac{3k-2}{6} + \frac{k\lambda}{2}\right] \sum_{i=1}^{N} a_i^3 + \ldots \right\}.$$

Truncating after powers of a_i^2, this becomes

$$E(X_k) \approx \frac{\lambda}{k!} \; e^{-\lambda} \left\{ N + \left[\frac{(k-\lambda)^2-k}{2}\right] A \right\}. \tag{4}$$

Again, relying on the fact that the environments which the Apollo modules see are relatively "dirty", we shall take N to be large. Thus, observing the fact that

$$P(Y=k) \approx \frac{E(X_k)}{N} \approx \frac{\lambda^k}{k!} \; e^{-\lambda} \left\{ 1 + \frac{1}{N} \left[\frac{(k-\lambda)^2-k}{2}\right] A \right\}.$$

and letting $N \to \infty$ we obtain

$$P(Y = k) = \frac{\lambda^k}{k!} e^{-\lambda} \tag{5}$$

Before continuing with the other aspects of this model, there are two things which should be discussed and emphasized.

The assumption that the attractive forces between ambient particles and microorganisms does not change as microorganisms become attached is not as restrictive as we have indicated earlier since we only use the limit as P_i approaches zero. The second observation is that λ was chosen to be the mean number of microorganisms attached to a particle. This combination of the characteristics of all particles into this one parameter will be useful in our later work.

Tierney has described the use of a simple "Birth and Death" model for the fallout of particles from the environment onto surfaces [8]. What we shall attempt in the remainder of this section is to combine the concept of the attachment of microorganisms to ambient particles with the fallout of ambient particles onto surfaces.

Before proceeding we observe that microorganisms can also be deposited on the surfaces by contact from the workmen and their equipment. We shall also say something about this later in this work.

Let us first assume that, considering only the fallout of the airborne microbial contamination, the surface of the Apollo module can be partitioned into subsections each of which sees a uniform environment. This is possible since the orientation of each module remains the same during its checkout procedures at Cape Kennedy. (This is not true of many of the unmanned spacecraft). Divide the airborne particles into classes such that all of the particles in a given class have the same fallout and removal characteristics. With these conditions Tierney concludes that after a subsection of the module sees the same environment for a "long" period of time, the distribution of the random variable representing the number of particles of a given class approaches a Poisson Distribution (see reference [3] for a more complete discussion of why this is true). Since the sum of a finite number of Poisson distributed random variables is Poisson distributed we see that if W is a random variable representing the number of ambient particles on the entire module after a sufficiently "long" time then

$$P(W = i) = \frac{e^{-\gamma}\gamma^i}{i!} \tag{6}$$

where $\gamma = \frac{n}{\rho}$, n is the average fallout rate of all particles on all sections of the module, and ρ is the average percent removal rate of all particles from all sections of the module by "death", physical removal, etc.

Let Z be the random variable representing the total number of microorganisms on the surface of the entire module. Then we conclude that

$$P(Z=k) = \sum_{i=0}^{\infty} P(Z=k \mid W=i)\, P(W=i). \tag{7}$$

Considering equation (5) we observe that the probability of k microorganisms on i particles is

$$P(Z=k \mid W=i) = \frac{(i\lambda)^k e^{-\lambda i}}{k!}$$

which when combined with equations (6) and (7) yields

$$P(Z=k) = \sum_{i=0}^{\infty} \frac{(i\lambda)^k e^{-i\lambda}}{k!} \frac{\gamma^i e^{-\gamma}}{i!}$$

or

$$P(Z=k) = \frac{\lambda^k e^{-\gamma}}{k!} \sum_{i=0}^{\infty} \frac{i^k}{i!} (e^{-\lambda}\gamma)^i . \qquad (8)$$

The probability of k microorganisms being deposited on a given module by fallout from the environment is thus given by (8). We see that this distribution is what is referred to in the literature as Neyman's Contagious Distribution of Type A [2,6]. Several authors have used a Poisson Distribution to estimate microbial loadings on spacecraft. We note that our model differs from this in the spread (i.e. variance) of the distribution. Equation (8) takes into account the fact that, because of the attachment of microorganisms to ambient particles, if we find one microorganism in a unit area the probability is higher we will find another.

In order to discuss the deposition of microorganisms by the contact with the module of workmen or their equipment we shall use a very naive approach. Let us assume that each type of contact is a special kind of particle. Then equation (5) would include these in estimating the numbers of microorganisms deposited by each contact, equation (6) would estimate the number of contacts, and (8) would include this in estimating the total microbial loading. The author realizes this analogy is not accurate since it does not take into account the microbes which are generated by the workmen themselves. It is a good approximation in most cases since the workmen wear gloves [7] and we are mostly concerned quantitatively with spores which are not usually generated by humans.

SAMPLING PROCEDURES

If we wish to use the mathematical model given by equation (8) to establish sampling protocol we note that the mean (μ) and the variance σ^2 of the Neyman Contagious Distribution of Type A are given by

$$\mu = \gamma\lambda \tag{9}$$

$$\sigma^2 = \mu(1+\lambda). \tag{10}$$

In order to establish sampling requirements, it shall be necessary to use the Central Limit Theorem [3] to obtain confidence intervals.

Suppose we are given β and θ and we wish to determine the number of square inches n which must be sampled in order to insure that

$$\text{Prob}\left\{\frac{(\overline{X}-\mu)^2}{\mu} < \beta\right\} \geq \theta \tag{11}$$

where $\overline{X}$ is the sample mean which is observed and μ is defined by (9) (and is not observed). Since we cannot sample exactly we shall assume that there is a sampling error ε due to either lack of removal, to the lack of recovery after they are removed or to our failure to grow the colony. The values $\overline{X}$ and μ refer to the entire module. Thus when n inches are sampled with sampling error ε, the number of times m which we sample an area equal to that of the entire module is $\frac{n}{A}(1-\varepsilon)$ where A is the area of the module. Rewriting (11) we obtain

$$\text{Prob}\left(\frac{|\overline{X}-\mu|\sqrt{m}}{\sigma} \leq \frac{\sqrt{\beta\mu m}}{\sigma}\right) \geq \theta \tag{12}$$

where σ is defined by (10). Define χ by the equation

$$\psi(\chi) = \theta$$

where

$$\psi(y) = \phi(y) - \phi(-y)$$

and ϕ is the standard normal distribution. Applying the Central Limit Theorem we see that

$$\text{Prob}\left(\frac{|\bar{X}-\mu|\sqrt{m}}{\sigma} \leq \frac{\sqrt{\beta\mu m}}{\sigma}\right) = \psi\left(\frac{\sqrt{\beta\mu m}}{\sigma}\right) \geq \theta = \psi(\chi).$$

Using the monotonicity of ψ we obtain

$$\chi \geq \frac{\sqrt{\beta\mu\ m}}{\sigma}.$$

Squaring and substituting the definitions of m and σ^2 given in equations (9) and (10) this equation becomes

$$\chi^2 \geq \frac{\beta n(1-\varepsilon)}{(1+\lambda)A},$$

or

$$n \leq \frac{A(1+\lambda)\chi^2}{\beta(1-\varepsilon)}. \qquad (15)$$

This is the result we shall use to establish our sampling protocol.

The modules on which we are interested in estimating the microbial load are [10]

1. the interior of the command module (CM)
2. the exterior of the lunar module (LM) ascent and descent stages
3. the interior of the lunar module ascent stage
4. the interior of the spacecraft - lunar module adaptor (SLA).

The areas of these and other modules are given in Table 1. Some representative values of χ for various values of θ are given in Table 2.

One of the hardest parameters to determine is β since it is not obvious what its relationship is to reality. From equation (11) we know that

$$\frac{(\overline{X}-\mu)^2}{\mu} < \beta .$$

This implies

$$|\overline{X}-\mu| < \sqrt{\beta\mu} \leq \sqrt{\beta\mu}_{max}$$

where μ_{max} is the maximum value which μ can assume. Thus, knowing the error we can accept in the determination of the mean of our distribution and knowing a maximum value for μ, we can determine a β to use. Table 3 lists maximum values which we may wish to use. These are based on actual samples taken by the Public Health Service at Cape Kennedy [7].

The sampling error ε will vary depending on the method used. The methods we shall consider are the vacuum probe and the cotton swab. If we consider only the possibilities of either not removing the microbes in the area being samples or not recovering them from the sampling equipment then an error of 5% appears reasonable for the vacuum probe method of sampling. For the cotton swab method of sampling, there appears to be a large discrepancy in the data which is available. Thus, we shall use errors of 50% and 70% for this method.

The only other value we need is λ. This is the mean number of micro-organisms per particle. Little information is known about what this value should be. We shall estimate that it lies between one and ten.

To aid in the establishment of sampling protocol, Tables 1 through 9 contain representative data for the modules in which there appears to be an interest. All of these tables are based on a β of one and the entries represent the number of inches n which must be sampled. To obtain n when more realistic values of β are used; we must divide the table entries by β.

CONCLUSIONS

Since 10^8 appears to be an upper bound on the loading on all of the modules except the SLA and, since being within 10^6 appears to be well within any stated goals, a value of 10^4 for β appears to be appropriate. A combination of other variables which might prove useful is

$$\lambda = 4$$

$$\varepsilon = .50$$

$$\theta = .80 \text{ or } \theta = .90$$

This means that the cotton swab method is being used. If four square inches are defined to be a standard sample, then Table 10 gives the number of samples necessary to achieve the desired results on the various modules. All of these are within the sampling capabilities which exist.

The interior of the SLA appears to have a maximum loading of 10^7, and thus β can be chosen to be 10^5 to obtain the same accuracy as we have on the other modules. If we adopt the same set of values for the other parameters, we obtain the fact that only nine samples are needed to get the desired results.

FURTHER REMARKS

The model we have presented yields a probability distribution which takes into account the fact that most microorganisms which are on the surface of spacecraft are attached to ambient particles. As Tierney pointed out, the "birth and death" fallout model is not adequate because it does not take this fact into account. In order for the model to be predictive, work still needs to be done to extend the fallout concept to account for this fact. Hopefully, when this is done, it will be possible to show that the solution of the equations approaches (8) asymptotically.

Some questions have been asked concerning the attachment of microorganisms to particles and the number of microorganisms on surfaces in ultra clean areas such as one finds in laminar flow rooms. If we consider equation (1) and let

$$P(Y=k) \approx \frac{E(X_k)}{N}$$

we obtain a probability distribution for the number of microorganisms on a particle. By using Poisson mixing, as we have in (7), we obtain a distribution for microorganisms on surfaces. Observe that in this case more knowledge is required from the field of small particle physics. This is to be expected. There are very few particles, and thus one cannot look at the "gross" effects as we have in our model for "dirty" areas.

Table 1 - Surface Area of Apollo Module in Square Feet

Module	Number of Square Feet of Surface Area
Interior CM	549
Exterior LM ascent stage	600
Exterior LM descent stage	532
Interior LM ascent stage	280
Interior SLA	1500
Engine Bell on LM descent stage	103

Table 2 - Values of x Corresponding to Various Values of θ

θ	x
.99	2.58
.95	1.96
.90	1.64
.85	1.44
.80	1.28
.75	1.15
.70	1.04

Table 3 = Maximum Microbial Loading on Apollo Modules

Module	Number of Microorganisms
Interior CM	7.56×10^7
Exterior LM ascent stage	3.69×10^7
Exterior LM descent stage	3.31×10^7
Interior LM ascent stage	4.67×10^7
Interior SLA	6.21×10^6

Table 4 - Number of Square Inches Required in Sampling of CM Interior $\beta=1$

θ	λ	ε	number of square inches
.9	1	.05	447640
.8	1	.05	272685
.75	1	.05	220109
.7	1	.05	180015
.9	4	.05	1119100
.8	4	.05	681712
.75	4	.05	550271
.7	4	.05	450037
.9	6	.05	1566740
.8	6	.05	954397
.75	6	.05	770380
.7	6	.05	630051
.9	10	.05	2462020
.8	10	.05	1499770
.75	10	.05	1210600
.7	10	.05	990081
.9	1	.5	850516
.8	1	.5	518101
.75	1	.5	418206
.7	1	.5	342028
.9	4	.5	2126290
.8	4	.5	1295250
.75	4	.5	1045520
.7	4	.5	855070
.9	6	.5	2976810
.8	6	.5	1813350
.75	6	.5	1463720
.7	6	.5	1197100
.9	10	.5	4677840
.8	10	.5	2849560
.75	10	.5	2300130
.7	10	.5	1881150
.9	1	.7	1417530
.8	1	.7	863502
.75	1	.7	697010
.7	1	.7	570046
.9	4	.7	3543820
.8	4	.7	2158760
.75	4	.7	1742530
.7	4	.7	1425120
.9	6	.7	4961340
.8	6	.7	3022260
.75	6	.7	2439540
.7	6	.7	1995160
.9	10	.7	7796400
.8	10	.7	4749260
.75	10	.7	3833560
.7	10	.7	3135260

Table 5 - Number of Square Inches Required in Sampling
LM Interior $\beta=1$

θ	λ	ε	number of square inches
.9	1	.05	228305
.8	1	.05	139074
.75	1	.05	112259
.7	1	.05	918108
.9	4	.05	570761
.8	4	.05	347686
.75	4	.05	280648
.7	4	.05	229527
.9	6	.05	799066
.8	6	.05	486760
.75	6	.05	392908
.7	6	.05	321338
.9	10	.05	1255680
.8	10	.05	764909
.75	10	.05	617427
.7	10	.05	504959
.9	1	.5	433779
.8	1	.5	264241
.75	1	.5	213293
.7	1	.5	174440
.9	4	.5	1084450
.8	4	.5	660603
.75	4	.5	533232
.7	4	.5	436101
.9	6	.5	1518230
.8	6	.5	924844
.75	6	.5	746525
.7	6	.5	610542
.9	10	.5	2385780
.8	10	.5	1453330
.75	10	.5	1173110
.7	10	.5	959422
.9	1	.7	722964
.8	1	.7	440402
.75	1	.7	355488
.7	1	.7	290734
.9	4	.7	1807410
.8	4	.7	1101000
.75	4	.7	888720
.7	4	.7	726835
.9	6	.7	2530300
.8	6	.7	1541410
.75	6	.7	1244210
.7	6	.7	1017570
.9	10	.7	3976300
.8	10	.7	2422210
.75	10	.7	1955180
.7	10	.7	1599040

Table 6 - Number of Square Inches Required in Sampling of Exterior of LM Ascent Stage $\beta=1$

θ	λ	ε	number of square inches
.9	1	.05	489224
.8	1	.05	298016
.75	1	.05	240556
.7	1	.05	196737
.9	4	.05	1223060
.8	4	.05	745041
.75	4	.05	601389
.7	4	.05	491843
.9	6	.05	1712280
.8	6	.05	1043060
.75	6	.05	841945
.7	6	.05	688581
.9	10	.05	2690730
.8	10	.05	1639090
.75	10	.05	1323060
.7	10	.05	1082060
.9	1	.5	929526
.8	1	.5	566231
.75	1	.5	457056
.7	1	.5	373801
.9	4	.5	2323810
.8	4	.5	1415530
.75	4	.5	1142640
.7	4	.5	934502
.9	6	.5	3253340
.8	6	.5	1981810
.75	6	.5	1599700
.7	6	.5	1308300
.9	10	.5	5112390
.8	10	.5	3114270
.75	10	.5	2513810
.7	10	.5	2055910
.9	1	.7	1549210
.8	1	.7	943718
.75	1	.7	761760
.7	1	.7	623002
.9	4	.7	3873020
.8	4	.7	2359300
.75	4	.7	1904400
.7	4	.7	1557500
.9	6	.7	5422230
.8	6	.7	3303010
.75	6	.7	2666160
.7	6	.7	2180510
.9	10	.7	8520650
.8	10	.7	5190450
.75	10	.7	4189680
.7	10	.7	3426510

Table 7 - Number of Square Inches Required in Sampling of Exterior of LM Descent Stage $\beta=1$

θ	λ	ε	number of square inches
.9	1	.05	433779
.8	1	.05	264241
.75	1	.05	213293
.7	1	.05	174440
.9	4	.05	1084450
.8	4	.05	660603
.75	4	.05	533232
.7	4	.05	436101
.9	6	.05	1518230
.8	6	.05	924844
.75	6	.05	746525
.7	6	.05	610542
.9	10	.05	2385780
.8	10	.05	1453330
.75	10	.05	1173110
.7	10	.05	959422
.9	1	.5	824180
.8	1	.5	502058
.75	1	.5	405256
.7	1	.5	331437
.9	4	.5	2060450
.8	4	.5	1255150
.75	4	.5	1013140
.7	4	.5	828592
.9	6	.5	2384630
.8	6	.5	175720
.75	6	.5	1418400
.7	6	.5	1160030
.9	10	.5	4532900
.8	10	.5	2761320
.75	10	.5	2228910
.7	10	.5	1822900
.9	1	.7	1373630
.8	1	.7	836764
.75	1	.7	675427
.7	1	.7	552395
.9	4	.7	3434080
.8	4	.7	2091910
.75	4	.7	1688570
.7	4	.7	1380900
.9	6	.7	4807710
.8	6	.7	2928670
.75	6	.7	2364000
.7	6	.7	1933380
.9	10	.7	7554980
.8	10	.7	4602200
.75	10	.7	3714850
.7	10	.7	3038170

Table 8 - Number of Square Inches Required in Sampling Engine Bell on LM Descent Stage $\beta=1$

θ	λ	ε	number of square inches
.9	1	.05	839835
.8	1	.05	511595
.75	1	.05	412954
.7	1	.05	337732
.9	4	.05	209959
.8	4	.05	127899
.75	4	.05	103239
.7	4	.05	844331
.9	6	.05	293942
.8	6	.05	179058
.75	6	.05	144534
.7	6	.05	118206
.9	10	.05	461909
.8	10	.05	281377
.75	10	.05	227125
.7	10	.05	185753
.9	1	.5	159569
.8	1	.5	97203
.75	1	.5	784613
.7	1	.5	641692
.9	4	.5	398921
.8	4	.5	243007
.75	4	.5	196153
.7	4	.5	160423
.9	6	.5	558490
.8	6	.5	340210
.75	6	.5	274614
.7	6	.5	224592
.9	10	.5	877627
.8	10	.5	534616
.75	10	.5	431537
.7	10	.5	352930
.9	1	.7	265948
.8	1	.7	162005
.75	1	.7	130769
.7	1	.7	106949
.9	4	.7	664869
.8	4	.7	405012
.75	4	.7	326922
.7	4	.7	267372
.9	6	.7	930817
.8	6	.7	567017
.75	6	.7	457691
.7	6	.7	374320
.9	10	.7	1462710
.8	10	.7	891027
.75	10	.7	719228
.7	10	.7	588217

Table 9 - Number of Square Inches Required in Sampling of Interior of SLA $\beta=1$

θ	λ	ε	number of square inches
.9	1	.05	1223060
.8	1	.05	745041
.75	1	.05	601389
.7	1	.05	491843
.9	4	.05	3057650
.8	4	.05	1862600
.75	4	.05	1503470
.7	4	.05	1229610
.9	6	.05	4280710
.8	6	.05	2607640
.75	6	.05	2104860
.7	6	.05	1721450
.9	10	.05	6726830
.8	10	.05	4097720
.75	10	.05	3307640
.7	10	.05	2705140
.9	1	.5	2323810
.8	1	.5	1415530
.75	1	.5	1142640
.7	1	.5	934502
.9	4	.5	5809540
.8	4	.5	3538940
.75	4	.5	2856600
.7	4	.5	2336260
.9	6	.5	8133350
.8	6	.5	4954520
.75	6	.5	3999240
.7	6	.5	3270760
.9	10	.5	12781000
.8	10	.5	7785690
.75	10	.5	6284520
.7	10	.5	5139760
.9	1	.7	3873020
.8	1	.7	2359300
.75	1	.7	1904400
.7	1	.7	1557500
.9	4	.7	9682560
.8	4	.7	5898240
.75	4	.7	4761000
.7	4	.7	3893760
.9	6	.7	13555600
.8	6	.7	8257540
.75	6	.7	6665400
.7	6	.7	5451260
.9	10	.7	21301600
.8	10	.7	12976100
.75	10	.7	10474200
.7	10	.7	8566270

Table 10 - Number of Samples for Various Modules

$\beta=10^4$, $\lambda=4$, $\epsilon=.50$.

Module	$\theta=0.80$ Number of Samples	$\theta=0.90$ Number of Samples
CM Interior	33	54
LM Interior	17	27
LM Exterior Descent	32	52
LM Exterior Ascent	36	59
Engine Bell-LM Descent	7	10

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