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DESIGNING GROUP ACCEPTANCE SAMPLING PLANS FORTHE WEIBULL AND GAMMA DISTRIBUTION USING MINIMUM ANGLE METHOD

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ABSTRACT: *In this paper, minimum angle method is introduced to find the parameters of a group acceptance sampling plan in which the truncated lifetimes follows a Weibull and gamma distribution. The values of operating ratio corresponding to the producer's risk and consumer's risk are calculated and using minimum angle method and the minimum angle θ is found. Tables are constructed and examples are provided.*

KEYWORDS: Weibull and gamma distribution, Group acceptance sampling: producer's risk, Operating characteristics, Producer's risk, Minimum angle method.

INTRODUCTION

The sampling procedure is turned out to be a life testing, when the quality characteristics are related to product lifetime. It is very often not to observe a failure for a highly reliable product within available experimental time duration.

The ordinary acceptance sampling plan for different distributions have been developed by many researchers including, Kantam et al, [1].Baklizi [2], Balakrishnan et al, [3] and Lio et al. [4] and [5]. However, it requires more cost time and observation to collect the sample items for making a decision of either accepting or rejecting the lot of products. An acceptance sampling plan involves quality contracting on product orders between the producers and consumers. . In order to fix the acceptance number in a sampling plan is very difficult. By the minimum angle criteria the optimum value of the acceptance number was designed. In this paper designing group acceptance sampling plan under weibull and gamma distribution using minimum angle method is presented. GASP plans having minimum angle by keeping the producer's risk below 5% and consumer's risk below 10% for specified AQL and LQL were presented.

WEIBULL AND GAMMA DISTRIBUTION

Weibull Distribution:

The cumulative distribution function (cdf) of the weibull distribution is given by

$$F(t,\lambda) = 1 - e^{-\left(\frac{t}{\lambda}\right)^{m}} \qquad (1)$$

Where λ is the scale parameter and m is the shape parameter and it is equal to 2

GAMMA DISTRIBUTION:

The cumulative distribution function (cdf) of the exponential distribution is given by

$$F(t,\lambda) = 1 - e^{-\frac{t}{\lambda}} \sum_{j=0}^{\gamma-1} \left(\frac{t}{\lambda}\right)^{j} / j! \qquad (2)$$

It is further observed that the weibull and gamma distribution can be used quite effectively in many circumstances, in place of lognormal or generalized Rayleigh distribution also. The closeness properties with other distributions, Statistical inferences, order statistics, have been discussed by several authors. The readers are referred to the recent review article by Gupta and Kundu [6] for a current account on the generalized exponential distribution.

Operating Characteristics Function:

The probability of acceptance can be regarded as a function of the deviation of the specified value λ_0 of the mean from its true value λ. This function is called Operating Characteristic (OC) function of the sampling plan. When the sample size $n = rg$ is known, we can able to find the probability of acceptance of a lot when the quality of the product is sufficiently good. Using the probability of acceptance the corresponding to producer's risk and consumer's risk the values are tabulated to calculate the minimum angle method.

Notation:

g	-	Number of groups
r	-	Number of items in a group
n	-	Sample size
c	-	Acceptance number
t_0	-	Termination time
a	-	Test termination time multiplier
m	-	Shape parameters
β	-	Consumer's risk
P	-	Failure probability
L (p)	-	Probability of acceptance
λ	-	Mean life
λ_0	-	Specified life
θ	-	Minimum angle
δ	-	Shape parameter

Group Acceptance Sampling (Gasp) Under Weibull And Gamma Distribution:

A product is considered as good and acceptable for consumer's use, if the true value λ which is the median of the lifetime distribution of a product is not smaller than the specified median value

λ_0. If the actual value λ is smaller than value λ_0. The following GASP is proposed based on the truncated life test:

1. Select the number of groups *g* and allocate predefined r items to each group so that the sample size for a lot will be n = *g. r.*
2. Select the acceptance number *c* for a group *and* the experiment time t_0.
3. Perform the experiment for the g groups simultaneously and record the number of failures for each group.
4. Accept the lot if atmost c failures occur in each of all groups.
5. Terminate the experiment if more than *c* failures occur in any group and reject the lot.

The probability of rejecting a good lot is called the producer's risk, whereas it is represented as α. The probability of accepting a bad lot is known as the consumer's risk, which is represented as β. We will determine the number of groups *g* in the proposed sampling plan so that the consumer's risk does not exceed the value β = 0.10 since the lot size is large enough; we can use the binomial distribution to develop the GASP. According to the GASP the lot of products is accepted only if there are atmost c failures observed in each of the g groups. The probability of acceptance of GASP is given by

$$\mathbf{L}\,(\boldsymbol{p}) = \left(\sum_{i=0}^{r}\binom{r}{i}\boldsymbol{p}^{i}(\mathbf{1}-\boldsymbol{p})^{r-i}\right)^{g} \qquad \text{----------------(3)}$$

Where p is the probability that an item in a group fails before the termination time $t_0 = a\lambda_0$.

MINIMUM ANGLE METHOD

The practical performance of a sampling plan is revealed by it operating characteristic curve. Norman Bush et. al. [8] have used different techniques involving comparison of some portion of the OC curve to that of the ideal curve. The approach of minimum angle method by considering the tangent of the angle between the lines joining the points (AQL, 1- α) (LQL β) is shown in Figure where p_1 = AQL, p_2=LQL. By employing this method one can get a better discriminating plan with the minimum angle. Tangent of angle made by lines AB and AC is

tanθ = BC/AC

tanθ = $(p_2-p_1) / (Pa(p_1) - Pa(p_2))$ ________________ (4)

The smaller the value of this tanθ, closer is the angle θ approaching zero and the chord AB approaching AC, the ideal condition through (AQL, 1-α). This criterion minimizes simultaneously the consumer's and producer's risks. Thus both the producer and consumer favour the plans evolved by the criterion.

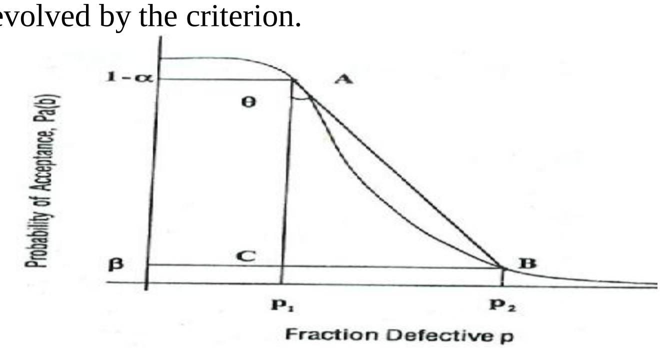

Figure.1. Minimum Angle for given p_1 and p_2

DESIGNING GASP FOR THE WEIBULL AND GAMMA DISTRIBUTION USING MINIMUM ANGLE METHOD.

- First calculate the mean ratio λ/λ_0 corresponding to d_1 and d_2, Where the mean ratio, $d_1 = \lambda_1/\lambda_0$, be the acceptable reliability level (ARL) at the producer's risk and the mean ratio, $d_2 = \lambda_2/\lambda_0$ which is equal to 1, be the lot tolerance reliability level (LTRL) at the consumer's risk.
- Select the values for termination ratio a, *r* for given shape parameter $\delta = 2$.
- Locate the value of mean ratio corresponding to the probability of acceptance of GASP along with producer's and consumer's risk.
- Find $\tan\theta$ from the table.
- Calculate the value $\theta = \tan^{-1}(\tan\theta)$
- Select the parameter of the sampling plan corresponding to the smallest value of θ.

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Construction of Tables:

The Tables are constructed using OC function for GASP plans the probability of failure under weibull and gamma distribution is given by the equation (1 to 3). Using the above values the minimum angle $\tan\theta$ is calculated using the equation (4) Tables 1 and 4 give the proposed values of $\tan\theta$ for various values c and g corresponding to the mean ratio and α below 5% and β below 10% for the given p_1 and p_2 . Numerical value in these tables reveals the following facts.

The parameter n= rg and θ can be obtained from the selected table corresponding to μ/μ_0 a, r and g along with producer's risk and consumer's risk.

Example 1: Suppose one want to design GASP under Weibull distribution for given $\alpha = .005$, $\beta = .002$, $\lambda/\lambda_0 = 4$, and $a = .7$ $r = 6$ among the various values of θ the Minimum angle corresponds to $c = 2$ and $g = 11$ the value $\theta = 19.79819^0$ Thus, the desired sampling plan has parameters as (4,.6, 2, 11) as mean ratio, Number of items, Acceptance number, Number of groups respectively

Example 2: Suppose one want to design GASP under Gamma distribution for given $\alpha = .003$, $\beta = .08$, $\lambda/\lambda_0 = 4$, and $a = .7$ $r = 9$ among the various values of θ the Minimum angle corresponds to $c = 2$ and $g = 15$ the value $\theta = 8.832866^0$ Thus, the desired sampling plan has parameters as (4,.9, 2, 15) as mean ratio, Number of items, Acceptance number, Number of groups respectively.

From the above values we come to know that Minimum angle plan of GASP under Weibull & the minimum occurs at gamma distribution is given by (4, 9, 2, 15) corresponding to (λ/λ_0, *r*, *c*, *g*). Thus we design the Group sampling plan with weibull and gamma distribution for the given values termination ratio *a* and the number of testers r corresponding to the groups using minimum angle method. Moreover, the operating characteristics function increases disproportionately when the Group sampling plan can be used to test multiple number of items, which would be beneficial in terms of test time and test cost.

CONCLUSION

The procedure and necessary tables for the selection of GASP under weibull and gamma distribution is presented for the given acceptable quality. This plan reduces time cost and cost of the tester. This criterion minimizes simultaneously the consumer's and producer's risk. This minimum angle plan provides better discrimination of accepting good lots among minimum number of groups.

TABLE – 1: MINIMUM ANGLE GASP UNDER WEIBULL DISTRIBUTION FOR r=6, c=2, δ=2

a	λ/λ_0	g	$L(p_1)$	$L(p_2)$	tanθ	θ
0.7	4	7	0.996419	0.019666	0.365715	20.08821
0.7	4	8	0.995908	0.011219	0.362767	19.93911
0.7	4	10	0.994888	0.003651	0.360371	19.81769
0.7	4	11	0.994378	0.002083	0.359986	19.79819
0.7	6	8	0.999617	0.011219	0.378243	20.71879
0.7	6	7	0.999665	0.019666	0.381485	20.88111
0.7	6	9	0.999569	0.006401	0.376426	20.62766
0.7	6	10	0.999521	0.003651	0.375405	20.5764
0.7	8	8	0.99993	0.011219	0.384083	21.01091
0.7	8	6	0.999948	0.034473	0.393326	21.47102
0.7	8	7	0.999939	0.019666	0.387389	21.17581
0.7	8	9	0.999922	0.006401	0.382223	20.91801
0.7	10	7	0.999984	0.019666	0.390165	21.31399
0.7	10	10	0.999977	0.003651	0.383896	21.00161
0.7	10	8	0.999982	0.011219	0.386833	21.1481
0.7	10	9	0.999979	0.006401	0.384958	21.05459
0.7	12	10	0.999992	0.003651	0.385387	21.07601
0.7	12	11	0.999991	0.002083	0.384781	21.0458
0.7	12	12	0.999991	0.001188	0.384437	21.02861
0.7	12	9	0.999993	0.006401	0.386453	21.12916
0.8	4	8	0.991213	0.000607	0.437608	23.63458
0.8	4	6	0.993402	0.003869	0.438082	23.65737
0.8	4	5	0.994499	0.009765	0.440217	23.75992
0.8	4	9	0.99012	0.000241	0.437929	23.65001
0.8	6	4	0.999579	0.024645	0.466787	25.02255
0.8	6	5	0.999474	0.009765	0.459818	24.69385
0.8	6	7	0.999264	0.001533	0.456122	24.51876
0.8	6	9	0.999054	0.000241	0.455628	24.49531

0.8	8	8	0.999846	0.000607	0.46311	24.84933
0.8	8	6	0.999884	0.003869	0.464609	24.91999
0.8	8	5	0.999904	0.009765	0.467366	25.04979
0.8	8	4	0.999923	0.024645	0.474487	25.38375
0.8	10	6	0.999969	0.003869	0.468154	25.08681
0.8	10	7	0.999964	0.001533	0.467061	25.03543
0.8	10	5	0.999974	0.009765	0.470939	25.21755
0.8	10	8	0.999959	0.000607	0.466631	25.01519
0.8	12	5	0.999991	0.009765	0.472895	25.30922
0.8	12	9	0.999984	0.000241	0.468393	25.09806
0.8	12	8	0.999986	0.000607	0.468564	25.1061
0.8	12	6	0.99999	0.003869	0.470097	25.17806
0.9	4	8	0.982936	0.000138	0.514565	27.22875
0.9	4	6	0.987174	0.000226	0.512466	27.13358
0.9	4	5	0.9893	0.000916	0.511721	27.09978
0.9	4	9	0.980823	0.000134	0.515668	27.27869
0.9	6	4	0.999163	0.003712	0.535328	28.16141
0.9	6	5	0.998953	0.000916	0.533941	28.0996
0.9	6	7	0.998535	0.000128	0.533705	28.08906
0.9	6	9	0.998117	0.000134	0.5339	28.09778
0.9	8	8	0.999691	0.000124	0.542741	28.49049
0.9	8	6	0.999768	0.000226	0.542814	28.49373
0.9	8	5	0.999807	0.000916	0.543168	28.5094
0.9	8	4	0.999845	0.003712	0.544671	28.57586
0.9	10	6	0.999938	0.000226	0.547232	28.6889
0.9	10	7	0.999928	0.000125	0.547145	28.68504
0.9	10	5	0.999948	0.000916	0.547605	28.70531
0.9	10	8	0.999918	0.000138	0.547127	28.68427
0.9	12	5	0.999983	0.000916	0.550046	28.81283
0.9	12	9	0.999969	0.000134	0.549552	28.79108
0.9	12	8	0.999972	0.000138	0.549556	28.79124
0.9	12	6	0.999979	0.000226	0.549669	28.79621
1.2	4	3	0.968982	0.000130	0.698697	34.94188
1.2	4	2	0.979213	0.000968	0.69206	34.68554
1.2	4	5	0.948839	0.000129	0.713507	35.50813
1.2	4	4	0.958858	0.000138	0.706053	35.22411
1.2	6	4	0.995597	0.000137	0.727064	36.01954
1.2	6	5	0.994499	0.000192	0.727866	36.04959
1.2	6	2	0.997796	0.000968	0.726165	35.98585
1.2	6	3	0.996696	0.000134	0.726283	35.99028

1.2	8	2	0.999581	0.000968	0.741853	36.56996
1.2	8	2	0.999581	0.000968	0.741853	36.56996
1.2	8	5	0.998953	0.000192	0.7416	36.56062
1.2	8	4	0.999163	0.000137	0.741445	36.55491
1.2	10	3	0.99983	0.000102	0.748925	36.83046
1.2	10	2	0.999887	0.000968	0.749586	36.85472
1.2	10	5	0.999717	0.000137	0.748987	36.83275
1.2	10	2	0.999887	0.000968	0.749586	36.85472
1.2	12	5	0.999904	0.000129	0.753195	36.98686
1.2	12	2	0.999961	0.000968	0.753881	37.01195
1.2	12	3	0.999942	0.000134	0.753188	36.98663
1.2	12	4	0.999923	0.000138	0.753181	36.98636
1.5	4	1	0.966827	0.001553	0.790879	38.33975
1.5	6	1	0.996129	0.001553	0.838562	39.9819
1.5	6	3	0.988433	0.000174	0.843774	40.15679
1.5	6	2	0.992274	0.000142	0.84051	40.04738
1.5	6	3	0.988433	0.000137	0.843774	40.15679
1.5	8	2	0.998476	0.000241	0.86137	40.74062
1.5	8	1	0.999238	0.001553	0.862051	40.76301
1.5	8	1	0.999238	0.001553	0.862051	40.76301
1.5	8	2	0.998476	0.000241	0.86137	40.74062
1.5	10	3	0.999372	0.000137	0.8729	41.11772
1.5	10	2	0.999581	0.000124	0.87272	41.11184
1.5	10	1	0.999791	0.001553	0.873892	41.14995
1.5	10	2	0.999581	0.000127	0.87272	41.11184
1.5	12	3	0.999784	0.000174	0.879287	41.32475
1.5	12	3	0.999784	0.000137	0.879287	41.32475
1.5	12	2	0.999856	0.000124	0.879226	41.32277
1.5	12	2	0.999856	0.000141	0.879226	41.32277

TABLE – 2: MINIMUM ANGLE GASP UNDER WEIBULL DISTRIBUTION FOR r=9, c=2, δ=2

a	λ/λ_0	g	L (p_1)	L(p_2)	tanθ	θ
0.7	4	7	0.986014	0.000126	0.362306	19.91578
0.7	4	8	0.984032	0.000122	0.363016	19.95172
0.7	4	4	0.991984	0.004314	0.361672	19.88366
0.7	4	3	0.993982	0.016833	0.365567	20.08073
0.7	6	8	0.998439	0.000182	0.374446	20.52822
0.7	6	7	0.998634	0.000126	0.374393	20.52556
0.7	6	9	0.998244	0.000124	0.374514	20.53163
0.7	6	5	0.999024	0.001106	0.374635	20.53768
0.7	8	8	0.999712	0.000182	0.379863	20.79994
0.7	8	6	0.999784	0.000283	0.379936	20.8036
0.7	8	7	0.999748	0.000124	0.37987	20.80028
0.7	8	9	0.999676	0.000174	0.379871	20.80036
0.7	10	7	0.999933	0.000126	0.382539	20.93381
0.7	10	4	0.999962	0.004314	0.384158	21.01466
0.7	10	8	0.999923	0.000186	0.382522	20.93296
0.7	10	9	0.999914	0.000147	0.38252	20.93287
0.7	12	3	0.99999	0.016833	0.390555	21.33337
0.7	12	4	0.999987	0.004314	0.385645	21.0889
0.7	12	5	0.999984	0.001106	0.384408	21.02715
0.7	12	9	0.999971	0.000177	0.38399	21.00627
0.8	4	3	0.987341	0.001717	0.43982	23.74084
0.8	4	6	0.974843	0.000195	0.444685	23.97402
0.8	4	5	0.978991	0.000152	0.442811	23.88428
0.8	4	4	0.983157	0.000206	0.441016	23.79822
0.8	6	4	0.998304	0.000206	0.455954	24.51081
0.8	6	5	0.99788	0.000126	0.456065	24.51607
0.8	6	7	0.997033	0.000001	0.456442	24.53393
0.8	6	6	0.997456	0.000195	0.456249	24.52478
0.8	8	4	0.999684	0.000206	0.462999	24.84409
0.8	8	6	0.999525	0.000124	0.462979	24.84312
0.8	8	5	0.999604	0.000146	0.462952	24.84187
0.8	8	3	0.999763	0.001717	0.463664	24.87544
0.8	10	6	0.999873	0.000195	0.466389	25.00381
0.8	10	3	0.999936	0.001717	0.46716	25.04009
0.8	10	5	0.999894	0.000146	0.466389	25.00382
0.8	10	4	0.999915	0.000206	0.466463	25.00733

0.8	12	5	0.999964	0.000126	0.468301	25.09376
0.8	12	3	0.999978	0.001717	0.469089	25.13073
0.8	12	2	0.999986	0.014339	0.475092	25.41202
0.8	12	6	0.999957	0.000195	0.468295	25.09344
0.9	4	4	0.968108	0.000171	0.522441	27.58441
0.9	4	2	0.983925	0.002171	0.515177	27.25649
0.9	4	3	0.975985	0.000101	0.518276	27.39663
0.9	6	4	0.996658	0.000171	0.534683	28.13264
0.9	6	3	0.997493	0.000101	0.534287	28.11501
0.9	6	5	0.995824	0.000001	0.535128	28.15249
0.9	6	2	0.998328	0.002171	0.534949	28.14453
0.9	8	3	0.999526	0.000101	0.542877	28.49654
0.9	8	2	0.999684	0.002171	0.543918	28.54258
0.9	8	5	0.999211	0.00001	0.542999	28.50193
0.9	8	4	0.999369	0.000171	0.542911	28.49801
0.9	10	4	0.99983	0.000176	0.54717	28.68617
0.9	10	3	0.999872	0.000101	0.5472	28.68747
0.9	10	2	0.999915	0.002171	0.548312	28.73648
0.9	10	5	0.999787	0.00001	0.547196	28.68732
0.9	12	4	0.999942	0.000171	0.549567	28.79175
0.9	12	3	0.999957	0.000101	0.549612	28.79373
0.9	12	2	0.999971	0.002171	0.550745	28.84353
0.9	12	5	0.999928	0.00001	0.549578	28.79222
1.2	4	1	0.963939	0.000001	0.702331	35.08156
1.2	6	1	0.995762	0.000949	0.727636	36.04097
1.2	6	3	0.987341	0.0001	0.733217	36.24949
1.2	6	2	0.991543	0.000101	0.730036	36.1308
1.2	8	2	0.998328	0.000101	0.742065	36.57782
1.2	8	1	0.999163	0.000949	0.742149	36.58091
1.2	8	3	0.997493	0.0001	0.74276	36.60349
1.2	10	1	0.99977	0.000949	0.749659	36.85741
1.2	10	2	0.99954	0.000124	0.749121	36.83765
1.2	10	3	0.99931	0.00001	0.7493	36.84422
1.2	12	1	0.999921	0.000949	0.753897	37.01254
1.2	12	2	0.999842	0.000127	0.753242	36.98859
1.2	12	3	0.999763	0.0001	0.753376	36.9935
1.5	6	1	0.985834	0.000129	0.846002	40.23127
1.5	6	2	0.97187	0.000001	0.858155	40.63471
1.5	8	1	0.99704	0.000129	0.862613	40.78147
1.5	8	2	0.994088	0.000001	0.865171	40.86542

1.5	10	1	0.999163	0.000145	0.873086	41.12376
1.5	10	2	0.998328	0.00001	0.873822	41.14768
1.5	12	1	0.999708	0.000126	0.879358	41.32703
1.5	12	2	0.999416	0.000001	0.879611	41.33523

TABLE – 3: MINIMUM ANGLE GASP UNDER GAMMA DISTRIBUTION FOR r=6, c=2, δ=2

a	λ/λ_0	g	L (p_1)	L(p_2)	tanθ	θ
0.7	4	43	0.997887	0.099329	0.158217	8.990635
0.7	4	44	0.997838	0.094136	0.157316	8.940281
0.7	6	43	0.999788	0.099329	0.166033	9.42702
0.7	6	44	0.999783	0.094136	0.165082	9.37397
0.7	8	43	0.99996	0.099329	0.168985	9.591513
0.7	8	44	0.999959	0.094136	0.168016	9.53754
0.7	10	43	0.999989	0.099329	0.170393	9.669945
0.7	10	44	0.999989	0.094136	0.169416	9.615543
0.7	12	43	0.999996	0.099329	0.171171	9.713259
0.7	12	44	0.999996	0.094136	0.17019	9.658621
0.8	4	25	0.997417	0.098947	0.193312	10.94099
0.8	4	26	0.997314	0.090203	0.19147	10.83924
0.8	6	25	0.999736	0.098947	0.203234	11.488
0.8	6	26	0.999725	0.090203	0.201283	11.38057
0.8	8	25	0.999949	0.098947	0.207024	11.69637
0.8	8	26	0.999947	0.090203	0.205035	11.58702
0.8	10	25	0.999986	0.098947	0.208841	11.79614
0.8	10	25	0.999986	0.098947	0.208841	11.79614
0.8	12	25	0.999995	0.098947	0.209847	11.85137
0.8	12	26	0.999995	0.090203	0.20783	11.74064
0.9	4	16	0.996842	0.097281	0.228667	12.88021
0.9	4	17	0.996645	0.084097	0.225413	12.70289
0.9	6	16	0.99967	0.097281	0.240841	13.54126
0.9	6	17	0.999649	0.084097	0.237378	13.35359
0.9	8	16	0.999936	0.097281	0.245547	13.79589
0.9	8	17	0.999932	0.084097	0.242014	13.60477
0.9	10	16	0.999982	0.097281	0.247815	13.91833
0.9	10	17	0.999981	0.084097	0.244248	13.72563
0.9	12	16	0.999994	0.097281	0.249073	13.98627
0.9	12	17	0.999994	0.084097	0.245488	13.79269
1.2	4	6	0.994454	0.092405	0.33306	18.42085

1.2	4	7	0.993532	0.062131	0.322564	17.87783
1.2	6	6	0.99938	0.092405	0.352655	19.42548
1.2	6	7	0.999276	0.062131	0.341302	18.84488
1.2	8	6	0.999876	0.092405	0.360548	19.82666
1.2	8	7	0.999855	0.062131	0.348916	19.23469
1.2	10	6	0.999965	0.092405	0.364409	20.02222
1.2	10	7	0.999959	0.062131	0.352648	19.42512
1.2	12	6	0.999988	0.092405	0.366571	20.13148
1.2	12	7	0.999986	0.062131	0.354739	19.5316
1.5	4	3	0.991235	0.095692	0.43236	23.38174
1.5	4	4	0.988331	0.043769	0.409923	22.28984
1.5	6	3	0.998949	0.095692	0.460196	24.71172
1.5	6	4	0.998599	0.043769	0.43534	23.52542
1.5	8	3	0.999783	0.095692	0.471907	25.26294
1.5	8	4	0.999711	0.043769	0.44631	24.0517
1.5	10	3	0.999938	0.095692	0.477734	25.53538
1.5	10	4	0.999917	0.043769	0.451801	24.3135
1.5	12	3	0.999978	0.095692	0.481024	25.68869
1.5	12	4	0.999971	0.043769	0.454908	24.46116
1.8	4	2	0.985622	0.076674	0.507976	26.92949
1.8	4	3	0.97851	0.021231	0.48233	25.74939
1.8	6	2	0.998148	0.076674	0.542855	28.49555
1.8	6	3	0.997223	0.021231	0.512532	27.13658
1.8	8	2	0.999605	0.076674	0.558379	29.17809
1.8	8	3	0.999407	0.021231	0.526843	27.7822
1.8	10	2	0.999885	0.076674	0.566265	29.52136
1.8	10	3	0.999827	0.021231	0.534216	28.11186
1.8	12	2	0.999959	0.076674	0.570764	29.71615
1.8	12	3	0.999938	0.021231	0.538442	28.2999

TABLE – 4: MINIMUM ANGLE GASP UNDER GAMMA DISTRIBUTION FOR r=9, c=2, δ=2

a	λ/λ_0	g	L (p_1)	L(p_2)	tanθ	θ
0.7	4	14	0.997199	0.097019	0.157932	8.974696
0.7	4	15	0.996999	0.082128	0.155396	8.832866
0.7	6	14	0.999714	0.097019	0.165622	9.404079
0.7	6	15	0.999694	0.082128	0.162938	9.254326
0.7	8	14	0.999945	0.097019	0.168555	9.567573
0.7	8	15	0.999942	0.082128	0.165821	9.415183
0.7	10	14	0.999985	0.097019	0.169958	9.645709
0.7	10	15	0.999984	0.082128	0.167201	9.492098
0.7	12	14	0.999995	0.097019	0.170734	9.688892
0.7	12	15	0.999995	0.082128	0.167964	9.534614
0.8	4	9	0.996248	0.085758	0.19076	10.79997
0.8	4	10	0.995832	0.065276	0.186646	10.57239
0.8	6	9	0.999607	0.085758	0.20033	11.32809
0.8	6	10	0.999564	0.065276	0.195947	11.08647
0.8	8	9	0.999924	0.085758	0.204043	11.53249
0.8	8	10	0.999916	0.065276	0.199573	11.28641
0.8	10	9	0.999979	0.000001	0.188178	10.65716
0.8	10	10	0.999977	0.065276	0.201319	11.38261
0.8	12	9	0.999993	0.085758	0.20682	11.68516
0.8	12	10	0.999992	0.065276	0.202288	11.43593
0.9	4	6	0.995267	0.085293	0.22605	12.73765
0.9	4	7	0.99448	0.056589	0.219322	12.37035
0.9	6	6	0.999491	0.085293	0.237729	13.37266
0.9	6	7	0.999407	0.056589	0.230513	12.98068
0.9	8	6	0.999901	0.085293	0.242339	13.62236
0.9	8	7	0.999884	0.000001	0.221671	12.49869
0.9	10	6	0.999972	0.085293	0.244569	13.74302
0.9	10	7	0.999968	0.056589	0.237129	13.3401
0.9	12	6	0.99999	0.085293	0.24581	13.81008
0.9	12	7	0.999989	0.056589	0.238331	13.40531
1.2	4	4	0.98576	0.018202	0.31051	17.2501
1.2	4	5	0.982231	0.006686	0.307968	17.11714
1.2	6	4	0.998331	0.018202	0.326334	18.07329
1.2	6	5	0.997914	0.006686	0.32268	17.88386
1.2	8	4	0.999661	0.018202	0.333368	18.43674
1.2	8	5	0.999576	0.006686	0.32953	18.23859

1.2	8	4	0.999661	0.018202	0.333368	18.43674
1.2	10	5	0.99988	0.006686	0.33299	18.41724
1.2	10	4	0.999904	0.018202	0.336888	18.61806
1.2	12	4	0.999966	0.018202	0.338874	18.72016
1.2	12	5	0.999958	0.006686	0.334947	18.51814
1.5	4	2	0.978393	0.025869	0.406496	22.12154
1.5	4	3	0.967766	0.004161	0.401822	21.89132
1.5	6	2	0.997229	0.025869	0.427931	23.1676
1.5	6	3	0.995847	0.004161	0.41916	22.7415
1.5	8	2	0.999414	0.025869	0.43824	23.66497
1.5	8	3	0.999121	0.00001	0.427026	23.12376
1.5	10	2	0.99983	0.025869	0.443538	23.91909
1.5	10	3	0.999746	0.004161	0.433904	23.45624
1.5	12	2	0.99994	0.025869	0.446563	24.06375
1.5	12	3	0.999909	0.004161	0.436841	23.59767
1.8	6	1	0.996421	0.058417	0.533289	28.0705
1.8	6	2	0.992854	0.003413	0.505565	26.81955
1.8	8	1	0.99921	0.058417	0.547778	28.71296
1.8	8	2	0.99842	0.003413	0.517931	27.38106
1.8	10	1	0.999766	0.058417	0.555354	29.04579
1.8	10	2	0.999532	0.003413	0.524819	27.69133
1.8	12	1	0.999915	0.058417	0.559722	29.2367
1.8	12	2	0.99983	0.003413	0.528872	27.8731

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