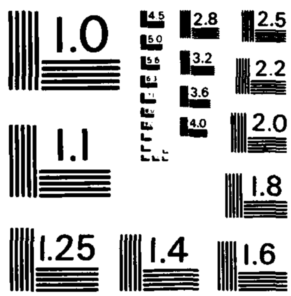
AD-A134 891 PROJECT DELUGE: A PROPOSED MATHEMATICAL MODEL FOR THE HOLLOMAN AFB TEST TRACK SIMULATED RAINFIELD(U) ARMAMENT DIV (AFSC) EGLIN AFB FL C B EVANS ET AL. 01 JUL 83 1/1

UNCLASSIFIED AD-TR-83-46 F/G 14/2 NL

END
DATE
FILMED
2 83



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

A134891

AD-TR- 83-46

FINAL REPORT

PROJECT DELUGE: A PROPOSED MATHEMATICAL MODEL FOR THE HOLLOMAN AFB TEST TRACK SIMULATED RAINFIELD

6585TH TEST GROUP
HOLLOMAN AIR FORCE BASE, NEW MEXICO

1 JULY 1983

APPROVED FOR PUBLIC RELEASE

DISTRIBUTION UNLIMITED

ARMAMENT DIVISION
AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE
EGLIN AIR FORCE BASE, FLORIDA 32542

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
AD-TR-83-46

2. GOVT ACCESSION NO.
A134891

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Project Deluge: A Proposed Mathematical Model for the Holloman AFB Test Track Simulated Rainfield

5. TYPE OF REPORT & PERIOD COVERED
Technical Report (TR)
May 82 - May 83

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Major Charles B. Evans
Mr Windell L. Gilliam

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
6585th Test Group (AFSC)
Test Track Division
Holloman AFB New Mexico 88330

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
JON: TKG04F01

11. CONTROLLING OFFICE NAME AND ADDRESS
6585th Test Group (AFSC) (TK)
Holloman AFB New Mexico 88330

12. REPORT DATE
1 July 1983

13. NUMBER OF PAGES
14

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
Same as item #11

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
Not Applicable

16. DISTRIBUTION STATEMENT (of this Report)
Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
Same as item #16

18. SUPPLEMENTARY NOTES
Reference Technical Report (TR) AD-TR-83-42, The Development of a Holloman High Speed Test Track Heavy Rainfield.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Rain Rate	Deluge
Simulated Rainfield	Math Model of a Rainfield
High Speed Test Track	Material Erosion
Mass Spectrometer	Spray Nozzle
Mass Median Diameter	Liquid Water Content (LWC)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report relates the characteristics of the Holloman High Speed Test Track's simulated rainfield to those of a natural rainfield as defined by mathematical models propogated by other experimenters. Data collected for heavy rain rates (25-30 in/hour) generated for Project Deluge in a controlled environment are analyzed and a tentative mathematical model relating the key parameters is provided. This report specifies the additional efforts required to finalize the model.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FOREWORD

The purpose of rain erosion testing on the High Speed Test Track (HSTT) at Holloman Air Force Base is to study the erosive effects of extended supersonic or hypersonic flight through rain clouds on material samples and components of aerospace systems.

The mechanism used to generate the simulated rain environment is a series of adjustable spray nozzles spaced along the side of the track adjusted to discharge over the flight path. The rain rate is controlled by the water pressure and drop size distribution is controlled by a combination of nozzle adjustments and pressure.

For the selection of materials to be effective, it is essential that the component designer understand the relationship of the simulated rainfield characteristics and those of natural rainfields. This report is the first attempt to quantify these relationships, and provide the designer with a tool to assess the differences.

PROJECT DELUGE: A PROPOSED MATHEMATICAL MODEL FOR THE HOLLOMAN AFB TEST TRACK SIMULATED RAINFIELD, VOLUME II

1.0 BACKGROUND

1.1 During the performance of Project Deluge it became apparent that a requirement existed for a means to define the Test Track's simulated rainfield capabilities to achieve the parameters most often used by prospective customers to identify their requirements, i.e. accumulated rain rate (ARR) and mass median diameter (MMD).

1.2 Prior research of natural rain has demonstrated that the drop size distribution of raindrops in a rainfield can be defined by an exponential expression of the form (Ref 1)

N_d = No EXP $(-\Lambda D)$

where:

N_d = number of drops of unit size range per unit volume (N/m^3)

N_o = Value of N_d when $D=0$

D = Drop diamter (mm)

Λ = Variable which is dependent upon rain rate or intensity of precipitation

The relationship of Λ with rain rate is defined by the expression:

$\Lambda = aR^b$ (mm^{-1})

where: a and b are constants

R = rain rate (mm/hr)

1.3 The following methods were used by past experimenters to derive the relationships noted above:

a. Rain rate was determined by rain gauge measurements

b. Drop size distributions were determined by using flour beds to catch rain and calculating the size from sieves or,

c. Measuring the impressions of drops on blotting paper

1.4 A parallel methodology has been employed to formulate the equations for the Test Track simulated rainfield. The major difference is the use of a mass spectrometer to count and catalog the raindrops by unit size. The substitution of the spectrometer for flour/blotting paper will enhance the accuracy in determining the statistics for the drop size distribution and the resulting equations.

2.0 DATA BASE The data used in this report was accumulated as part of Project Deluge during November 1981. The mass spectrometer used to measure and count the drop sizes was the Illinois Institute of Technology Research Institute (IITRI) Counter specifically designed and constructed for use in the Test Track's simulated rainfield. The use of this counter is discussed in Volume 1, along with the test conditions, raw data formating and data output from the counter. (Reference AD-TR-83-42, The Development of a Holloman High Speed Test Track Heavy Rainfield)

2.1 The basic parameters measured during the experiment were:

a. Rain rate - using standard rain accumulation type gauges (ARR)(in/hr).

b. Drop size and number of each - IITRI Counter. Drop size interval width of 0.6mm, centered around diameters of 0.6, 1.2, 1.8, 2.4, 3.0, 3.6, 4.2, and 4.8mm.

2.2 Data parameters calculated and provided by Project Deluge are:

a. Number of drops per unit size per cubic meter (N/m^3)

b. Mass Median Diameter (MMD or Do), (mm).

c. Liquid Water Content (LWC), ($grams/m^3$).

d. Equivalent Rain Rate (ERR), (in/hr).

3.0 DATA ANALYSIS AND EVALUATION

3.1 The data of paragraph 2.0 above was subjected to regression analysis to determine the best fit relationships between the different variables. The computer program selected for this function provides the capability of evaluating seven regression models simultaneously for each set of data. The resulting equations providing statistically significant relationships are provided below with the result of previous experimenters.

3.2 The matrix format provides a means of comparing previous experimenters results with natural rainfall and the results obtained with Project Deluge.

TABLE 1

Source	Type of Precipitation	N_o $(mm^{-1}m^{-3})$	Λ (mm^{-1})	D_o (mm)	$\sum LWC$ (g/m^{-3})
Marshall-Palmer	Ottawa - Summer	8000	$4.1R^{-0.21}$	$0.9R^{0.21}$	$0.072R^{0.88}$ (a)
Jones (1956)	Thunderstorm	$389R^{1.02}$	$2.5R^{-0.05}$	$1.48R^{0.05}$	$0.052R^{0.97}$ (b)
Joss et al (1970)	Thunderstorm	1400	$3.0R^{-0.21}$	$1.22R^{0.21}$	- - -
Project Deluge (1981) (c)	Simulated Rainfield	$R/(0.117+2.29X10^{-5}R)$	$3.346R^{-0.125}$	$0.916R^{0.154}$	$0.0789R^{0.868}$

NOTES: Rain Rate (R) is in units of mm/hr for all cases.

(a) Marshall-Palmer as reported by Atlas.(Ref 2)

(b) Sissenwine developed this relationship by integrating the Jones' equation over volume. (Ref 1)

(c) The mean rain rate measured by gauges over all positions within the simulated rainfield was 29.1 inches per hour.

3.3 Other Established Relationship:

Dyer (Ref 1) $Do = 3.67\,\Lambda^{-1.00}$

Project Deluge $Do = 3.6779\,\Lambda^{-0.996}$

Coefficient of Determination = 0.875

3.3.1 Assessment of Statistical Parameters:

Coefficient of Correlation - The hypothesis

H_0: $\rho = 0$

H_1: $\rho > 0$

was tested using the student's t test, where the test value is defined by:

$$t^* = \frac{r\sqrt{N-2}}{\sqrt{1-r^2}}$$

with acceptance criterion

$$t^* < t_{\alpha, N-2}$$

and with rejection criterion

$$t^* > t_{\alpha, N-2}$$

By manipulating the equation for t^*, it can be shown that for a sample size of 81, the following minimum values of r is required for rejection of H_0: at the levels of significant (α) indicated.

α	0.10	0.05	0.02	0.01
ρ	0.1820	0.2153	0.2532	0.2783

Based on this test, all equations selected have coefficients of correlation significantly different from zero, i.e. H_0: $\rho = 0$ is rejected implying the relationship between the variables is not a chance occurrence.

3.3.2 Regression Coefficients: The alternate hypothesis

H_0: $a_1 = 0$ H1: $a_1 \neq 0$

or H_0: $b_1 = 0$ H1: $b_1 \neq 0$

was tested using the Student's t test, where the test value is defined by either:

$$t^* = \frac{a_1 - A_1}{Syx/Sx}\sqrt{N-2} \qquad \text{where } A_1 = 0$$

or:

$$t^* = \frac{b_1 - B_1}{Syx/Sx}\sqrt{N-2} \qquad \text{where } B_1 = 0$$

For both cases, the acceptance criterion is

$$t^* < t_{\alpha,\, n-2}$$

and the rejection criterion is

$$t^* > t_{\alpha,\, n-2}$$

Based on this test, the regression coefficients for all selected equations are significantly different from zero at all levels of significance.

4.0 COMPARISON OF SIMULATED RAINFIELD MODEL (TENTATIVE) TO KNOWN NATURAL RAINFIELD MODELS.

4.1 vs Marshall-Palmer Model: This model was postulated from observations of summer rains in Ottawa, Canada. Evaluation of each parameter provides the following:

(a) N_0 ($mm^{-1}m^{-3}$) - Defined as the number of drops per unit size per unit volume when droplet diameter is zero. Mathematically,

$$\lim_{D \to 0} N_D = N_0$$

For the Marshall-Palmer model this is defined to be a constant value of 8000. The best relationship derived from the simulated rainfield is:

$$N_0 = R \left[0.117 + 2.288X10^{-5} R \right]^{-1} .$$

This equation implies that as rain rate (R) goes from zero to infinity. N_0 goes from zero to 43706.3. Mathematically given by:

(1) $$\lim_{R \to 0} N_0 = \lim_{R \to 0} \frac{R}{0.117 + 2.288X\ 10^{-5}\ R}$$

$$= \frac{0}{0.117 + 2.288X\ 10^{-5}\ (0)}$$

$$\lim_{R \to 0} N_0 = 0$$

(2) $$\lim_{R \to \infty} N_0 = \lim_{R \to \infty} \frac{R}{0.117 + 2.288X\ 10^{-5}\ R}$$

$$= \lim_{R \to \infty} \frac{1}{\frac{0.117}{R} + 2.288X10^{-5}}$$

$$= \frac{1}{0 + 2.288X10^{-5}}$$

$$\lim_{R \to \infty} N_0 = 43706.3$$

Conclusion: There is a significant difference in both the value and characteristics of N_0 between the two models.

(b) LAMDA, (Λ , mm^{-1}), A variable which is dependent upon rain rate Generally stated mathematically as:

$$\Lambda = a R^{b}$$

For the Marshall-Palmer model the values of a and b are 4.1 and -0.21, respectively. The calculated values of a and b for the simulated rainfield are 3.346 and -0.125 with standard error of estimates of 1.146 and 0.021, respectively. Using these values the indicated confidence limits were calculated to be:

$(1-\alpha)$ %	a = 3.346	b = -0.125
99.00	$0.389 \leq a \leq 6.302$	$-0.1794 \leq b \leq -0.0711$
95.00	$1.100 \leq a \leq 5.592$	$-0.1664 \leq b \leq -0.0841$
90.00	$1.461 \leq a \leq 5.231$	$-0.1598 \leq b \leq -0.0907$
Z_c	0.658	4.04

Conclusions: The mathematical relationship between Λ and R is confirmed to be a power function. While there is no statistically significant difference in the scaling parameter (a) values, there is a very significant statistical difference in the shaping parameter's (b) values.

(c) Mass Median Diameter--Do(mm), defined as the droplet - diameter which divides the Liquid Water Content (LWC) into two parts. Generally defined mathematically by the equation:

$$D_o = a_1 R^{+b}$$

For the Marshall-Palmer model, the values of a_1 and b are 0.90 and 0.21, respectively. The calculated values of a_1 and b (simulated rainfield) are 0.916 and 0.154 with standard error of estimates of 1.143 and 0.0206, respectively.

Again the indicated confidence limits are:

$(1-\alpha)\%$	$a_1 = 0.916$	$b = 0.154$
99.0	$-2.033 \leq a_1 \leq 3.8659$	$0.100 \leq b \leq 0207$
95.0	$-1.324 \leq a_1 \leq 3.157$	$0.1132 \leq b \leq 0.194$
90.0	$-0.9643 \leq a_1 \leq 2.797$	$0.120 \leq b \leq 0.1875$
Z_c	0.0143	2.734

Conclusions: Again, the basic relationship between the variables is confirmed. Also, there is no statistically significant difference in the values of a_1, but there is a statistically significant difference in the b values. However, note that the critical Z value is less than 3.0, i.e. the Marshall-Palmer's specified b value is less than 3 σ from the value determined for the simulated rainfield.

(d) Overall conclusions: The expected relationships for both Λ and D_0 as a function of rain rate were verified. The significant differences in the regression coefficients and the form of N_0, simply implies that the simulated rainfield as configured does not duplicate the droplet diameter distribution of an Ottawa summer rain.

4.2 Vs Jones (1956) Model: This model was postulated from observations of thunderstorms. Definitions of the parameters are the same as previously provided. Comparing the simulated rainfields to Jones' provides the following information:

(a) N_0 $(mm^{-1}m^{-3})$. Jones values is $N_0 = 3.89R^{1.02}vs$

$$N_0 = R\left[0.117 + 2.288X10^{-5}R\right]^{-1}$$

For both situations $N_0 = f(R)$, with only the form of the relationship differing. If the simulated rainfield data is fitted to a power function to place it into the same form as the Jones' observation, the following equation results:

$$N_0 = 1925.73R^{0.3959}$$

The confidence limits for the regression coefficients for the the power function are:

$(1-\alpha)\%$	$a_1 = 1925.73$	$b = 0.3959$
99.0	$1816.35 \leq a \leq 2035.11$	$0.2024 \leq b \leq 0.5893$
95.0	$1842.64 \leq a \leq 2008.82$	$0.2489 \leq b \leq 0.5428$
90.0	$185.99 \leq a \leq 1995.47$	$0.2725 \leq b \leq 0.5192$
Z_c	36.2	8.3

Conclusions: Both of the regression coefficients are statistically significantly different from those identified by Jones. Also, although both situations identify N_0 as a f(R), the forms of the relations are different.

(b) Λ (mm^{-1}). The Jones' determined relationship is $\Lambda = 2.5R^{-0.05}$ vs Track's $3.346R^{-0.125}$. The table of confidence limits provided in 4.1(b) above is applicable with the same conclusions. The critical Z scores for a and b, are 0.74 and 3.6, respectively.

(c) D_0(mm). Jones $1.48R^{0.05}$ vs Track $0.916R^{0.154}$

The Table of Confidence Limits provided in 4.1(c) above is applicable and the conclusions are the same. The critical Z scores are 0.493 and 5.05 for a and b respectively.

(d) Liquid Water Content, $\sum LWC$ (g/m^3). Defines the liquid water content of the rainfield per unit volume. Using the Jones' equations Dyer defined the following relationship for LWC as a function of rain rate:

(1) $\sum LWC = 0.052R^{0.97}$

Independently, Atlas, using the Marshall-Palmer equations derived this relationship:

(2) $\sum LWC = 0.072R^{0.88}$

The relationship between these two variables observed during DELUGE is:

(3) $\sum LWC = 0.07889R^{0.868}$ (Regressing R on $\sum LWC$)

The confidence limits for the derived Deluge values are:

$(1-\alpha)\%$	$a = 0.07889$	$b = 0.868$
99.0	$-4.458 \leq a \leq 4.616$	$0.644 \leq b \leq 1.0926$
95.0	$-3.368 \leq a \leq 3.526$	$0.698 \leq b \leq 1.0387$
90.0	$-2.814 \leq a \leq 2.972$	$0.725 \leq b \leq 1.0114$
Z Critical	0.004 0.015	0.138 (Atlas) 1.169 (Dyer)

Conclusion: There are no statistically significant differences between the coefficients for the relationships described by the equation:

$\sum LWC = aR^b$

As determined by either Atlas or Dyer and those experimentally determined by Track.

(e) Overall Conclusions: The expected relationships for all of the parameters were verified. The differences in the coefficients are most probably attributable to differences in the rain rates observed. Deluge rain rates of 29 inches per hour would be observed only on rare occasion in nature.

4.3 Vs Joss et al (1970). This model is based on thunderstorm observations and is very similar to the Marshall-Palmer model. The differences between the two models (Joss vs Marshall) are the values cited for N_0 (both constants) and values for scaling parameters for both Λ and D_0 as $f(R)$. The comments and conclusions drawn for the comparison of Marshall-Palmer vs Track are applicable.

4.4 Vs Dyer. In her investigation of the other experimenters' work Dyer developed the following relationship between Λ and D_0, i.e.:

$$D_0 \Lambda = 3.67$$

or $$D_0 = 3.67 \Lambda^{-1}$$

This relationship appears to be consistent regardless of either the characteristics of the rainfall, i.e., thunderstorm, summer shower, etc. or the investigator. This relationship also holds for the simulated rainfield. The values derived via regressions are:

$$D_0 = 3.6779 \Lambda^{-0.996}$$

It can be readily shown that no statistical difference exists between the equations.

4.5 Proposed Model for Mini-Rainfield. The following equations are tentatively suggested for use in describing the mini-rainfield when it is configured as specified in the *Project Deluge* report:

General Equation: $N_0 = N_0 \text{ EXP } (-\Lambda D)$

$$N_0 = R\left[0.117 + 2.288\text{X}10^{-5}R\right]^{-1}$$

$$D_0 = 0.916R^{0.154}$$

$$D_0 = 3.6779\Lambda^{-1}$$

Rain rate (R) is the measured value for rain rate in mm/hr.

NOTE: (1) An alternate equation for N_0 is: $N_0 \;\; 1925.7R^{0.3959}$

(2) $\sum$LWC may be estimated using this equation:

$$\sum \text{LWC} = 0.07889R^{0.868} \quad (\text{g/m}^3)$$

RECOMMENDATIONS FOR ADDITIONAL TESTS:

In some instances where statistically significant differences exist, most can be attributed to the fact that the rain rates produced for Deluge, i.e. 25-30 inches per hour are almost never found in nature.

While it has been shown by the experimenters referenced,that the parameters of interest are dependent upon rain rate for the rain rate intensities observed, the sensitivity of the indicated parametric relationships to changes in rain rate has not been identified.

The simulated rainfield at Test Track has the capability to produce a wide spectrum of rain rate intensities to allow such a sensitivity analysis.

The following additional tests are planned:

(1) To extend the applicability of the proposed model from a "specific condition" of the mini-rainfield to a general statement of the mini-rainfield capabilities, additional measurements are required with the water pressure values set at values incrementally spaced between the maximum and minimum allowed.

(2) Because the Knollenberg Probe has the inherent capability to provide better resolution of droplets diameter, that it be used to acquire future data or the data for each set-up be acquired with both the Probe and the Counter.

(3) All of the above tests will be repeated on the Track so that the effects of out-of-door conditions can be incorporated into the final model equations.

The selection of the final model for the Test Track simulated rainfield facility will be delayed until after a comparison is made between the two counters and the above planned tests are completed.

REFERENCE DOCUMENTS:

1. Extremes of Hydrometers at Altitude for MIL-STD-210B, Supplement Drop Size Distributions, AFCRL-TR-73-0008, 9 Jan 73.

2. Shorter Contribution (Optical Extinction by Rainfall), Atlas, David, Journal of Meteorology, Vol 10, Dec 1953.

DISTRIBUTION

Defense Technical Information Center/TCA Cameron Station Alexandria VA 22314	12
HQ AD/TE Eglin AFB FL 32542	1
HQ USAF/RDPV Washington D C 20301	1
AUK/LSE Maxwell AFB AL 36112	1
6585TESTG/TKO Holloman AFB NM 88330	1
6585TESTG/TKI Holloman AFB NM 88330	3
6585TESTG/TKA Holloman AFB NM 88330	1
6585TESTG/TSL Holloman AFB NM 88330	1

DATE
FILMED

2 8