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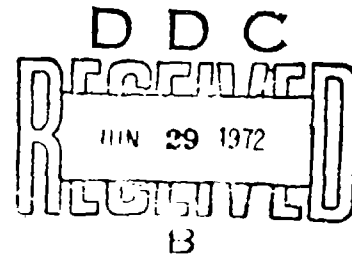
ENGINEERING PARAMETERS STUDY
OF
NITROGEN TETROXIDE FLOW DECAY
FINAL REPORT

R. C. Mitchell, J. V. Lecce, K. W. Fertig

Rocketdyne
A Division of North American Rockwell Corporation
Canoga Park, California

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June 1972



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FOREWORD

The research reported herein was sponsored by the Air Force Rocket Propulsion Laboratory, Director of Laboratories, Edwards Air Force Base, California, under Contract FO4611-71-C-0034. The monitoring agency was LKDP; the contract monitors were Capt. A. McPeak and Lt. J. J. Bon.

This program was conducted by members of Chemical and Material Sciences, Rocketdyne Advanced Programs Department. Dr. E. A. Lawton served as Program Manager, and Mr. M. T. Constantine and Dr. R. C. Mitchell served as Responsible Scientists. The technical efforts were performed by Dr. R. C. Mitchell, Messrs. J. V. Lecce and K. W. Fertig, Drs. R. I. Wagner and J. Hon, and Mr. M. Robertson.

This report contains no classified data abstracted from other reports. It has been assigned the Rocketdyne Report No. R-8950.

This report has been reviewed and is approved.

J. J. Bon, 1st Lt, USAF
Project Engineer

ABSTRACT

An experimental and analytical program was conducted as a step in a systematic engineering parametric study to establish the necessary engineering criteria for the prediction and prevention of flow decay in operational nitrogen tetroxide systems. Tests were made with both green and red-brown nitrogen tetroxide over ranges of seven other parameters: initial propellant temperature, temperature drop before reaching the test section, time during which the temperature drop is imposed, filter pore size, local velocity through the filter, total volume per unit filter area of propellant passing through the filter during a test, and iron saturation condition.

Flow decay was observed under some test conditions and was absent under other conditions. The rates of decay ranged up to 2.8 %/min, although the mean rate was about 0.5 %/min for all tests in which any significant flow decay occurred.

It was possible to deduce information about the effects of these eight major independent variables on flow decay. However, it was found that the effects of these parameters are generally not simple or independent of each other; they exhibit many interactions. In addition, there are often threshold effects for flow decay (i.e., an identifiable boundary between a range of variables for which no flow decay occurs and a range for which flow decay occurs at varying rates). These thresholds are not sharp, and further depend upon the interactions of the independent variables.

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NOMENCLATURE

A	Filter area
A_f	Free area of filter available for flow
C	Discharge coefficient (defined by Eq. 8)
D	Filter nominal pore size
H	Pressure drop across the filter, psi
H^*	Calibration value of H (i.e., for a clean filter), psi
k	Constant in Eq. 3
L	Flow decay parameter defined by Eq. 11, gal./sq in.
L_t	Flow decay parameter defined by Eq. 10, gal./sq in.
n	Constant in Eq. 3
Q	Flowrate, gal./min
Q^*	Calibration flowrate (i.e., for a clean filter), gal./min
Q'_2	Best estimate of the value of Q_2 (i.e., flowrate at time t_2) if $H_2 = H_1$
Re	Reynolds Number for filter, $DQ\rho/A\mu$
t	Time, min
T	Temperature, F
T_o	Initial propellant temperature, F
ΔT	Temperature drop (T_o minus temperature at test section during flow), F
V	V_{12}/A (total amount of propellant per unit filter area which has passed through the filter), gal./sq in.
V_{12}	Volume of N_2O_4 flowing through filter between t_1 and t_2 , gal.
W	$1 - Q/Q^*$, fractional drop in flowrate between the clean filter case and the case of interest
X	$1 - Q'_2/Q_1$, fractional flow decay at constant H
y	General random variable
Y	$X/(t_2 - t_1)$
Z	$(W_2 - W_1)/(t_2 - t_1)$

GREEK

ϵ	Random error term
μ	Viscosity
μ_i	Mean value of the i^{th} variable; true value of the outcome of the i^{th} experiment
ρ	Density
σ	Standard deviation

LITERAL

cov(a,b)	Covariance of a and b
E(y)	Expected value of y
GB	Two-level variable with assigned values of 1 when green N_2O_4 is used and -1 when red-brown N_2O_4 is used
RL	Two-level variable with assigned values of 1 for rapid cooldown and -1 for long cooldown
SAT	Two-level variable with assigned values of 1 for N_2O_4 which is doped with iron pentacarbonyl to ensure iron saturation, and -1 for N_2O_4 tested as received
var(a)	Variance of a

SUBSCRIPTS

0	Initial value, at $t = 0$ as with clean filter
1	Value at time t_1
2	Value at time t_2 ($t_2 > t_1$)

INTRODUCTION

The phenomenon of flow decay is defined as a spontaneous decrease in the flow-rate through a constant pressure flow system. Flow decay in nitrogen tetroxide systems is a function of the in situ formation of solid or gel-like materials that can obstruct the flow through valves, filters, orifices, or any other flow element with a constriction of small size. There are several ferric nitrate derivatives which can be deposited to produce flow decay, such as nitrosyl tetranitratoferrate, $\text{NOFe}(\text{NO}_3)_4$, and partially hydrated or hydrolyzed ferric nitrates, $\text{Fe}(\text{NO}_3)_{3-n}(\text{OH})_n \cdot x\text{H}_2\text{O}$. These materials are soluble in nitrogen tetroxide at levels of the order of a few parts per million (as iron). While there are many factors which can influence the corrosion processes that produce these compounds in solution, the extensive exposure of all nitrogen tetroxide to iron during the manufacturing and shipping processes can be expected to form these materials in approximately equilibrium amounts.

Rocketdyne has conducted a number of previous investigations of aspects of flow decay, beginning in 1964 (Ref. 1 through 4). Laboratory investigations and observations of flow decay in field systems have also been made by a number of other companies and agencies. A useful summary of past work is given in Ref. 5. The previous studies have provided some understanding of the underlying mechanisms and many of the important parameters affecting nitrogen tetroxide flow decay. However, in general, they have not provided information that could permit prediction of the occurrence or absence of flow decay. The fulfillment of this technology void would provide the basis for engineering control of this potential system failure mode through definition of required system design criteria and/or system management concepts.

This program was intended to be the initial step in a systematic engineering parametric study to establish the necessary engineering criteria for the prediction and prevention of flow decay in operational nitrogen tetroxide systems. Its goals were to establish experimental techniques and data analysis techniques to give statistically reproducible nitrogen tetroxide flow decay data, and to provide an interim guide to the gross effects of major parameters on N_2O_4 flow decay. A fundamental assumption underlying the program was that any commercial nitrogen tetroxide will have the potential of undergoing flow decay, if suitable conditions are present during flow. Therefore, the philosophy was to disengage corrosion studies (i.e., variables which primarily affect the formation of iron compounds in solution) from these investigations of deposition of flow decay material.

In this program, the first task (Phase I) was to develop a test plan to be used in performing flow decay tests. In the second task (Phase II), flow techniques and apparatus developed and used in previous Rocketdyne programs were modified and used to perform parametric tests, following the sequential experimental design outlined in Phase I. The third task (Phase III) comprised the analysis of test results to define sets of conditions under which flow decay will or will not occur in specific system components, and to develop a preliminary basis for establishing criteria to avoid this failure mode.

FLOW DECAY TESTS

EXPERIMENTAL SYSTEM

An experimental flow bench system was built and used for study of the flow decay phenomena under Contract AF04(611)-11620 (Ref. 2) and later refurbished and modified for use under Contract F04611-68-C-0070 (Ref. 4). For the current program, the flow bench was refurbished again and a number of changes were made to the system to satisfy current requirements. Changes included installation of larger propellant tanks, an agitator in the main propellant tank, and improved instrumentation.

A schematic diagram of the flow system is presented in Fig. 1. The main tank, or run tank, and the catch tanks comprise the end points of the N_2O_4 flow path. The main tank is a 10-gallon flanged spherical stainless-steel vessel contained within a temperature-conditioned, stirred-water bath. The catch tank indicated on the schematic is actually two 5-gallon stainless-steel cylinders connected in parallel; no temperature control was provided for these tanks. Both the run and catch tanks are connected to a pressurization and vent system which supplies gaseous nitrogen for pressurization. The pressure control system maintains both the tank being emptied and the tanks being filled at constant pressure during any flow process. The controls for setting the pressure levels are operated remotely.

All materials of construction in the flow bench are compatible with N_2O_4 . The tanks, valves, fittings, and fluid lines are fabricated of type 304, 316, 321, or 347 stainless steel. Valve seats and stem packings are made of either Teflon or Kel-F. Teflon tape is used as the thread lubricant on pipe fittings.

Two parallel test sections are provided. The flowrate is adjusted, in general, by selecting and setting the desired run and catch tank pressures. However, each flow path has a servo-operated, remote-control metering valve located downstream of the test section which can be used for additional control. For about 90 percent of the tests, this valve was kept full open. Between each test section and the main tank is a heat exchanger. The heat exchangers consist of a length of 1/4-inch stainless-steel tubing in an open water bath. Each heat exchanger bath is agitated and the temperature is held constant by operating an on-off valve that controls the flow of coolant water from a refrigeration bath. A standpipe returns the overflow from the heat exchanger bath to the refrigeration bath. Ball valves are provided to route the propellant flow through the heat exchangers or around them before entering the test sections. Also, ball valves are provided to select either the run tank standpipe outlet port or the bottom outlet port, depending on whether the run was a rapid cooldown test or a long or slow cooldown test, respectively.

After completing a run, propellant can be discharged to a waste storage tank or recycled to the main tank through a bypass line that can be filtered or not, as desired. In this program, the recycled propellant was never filtered. A 40-micron filter was installed in the system feed line to filter all new propellant coming into the flow bench from the storage cylinders (see Fig. 1).

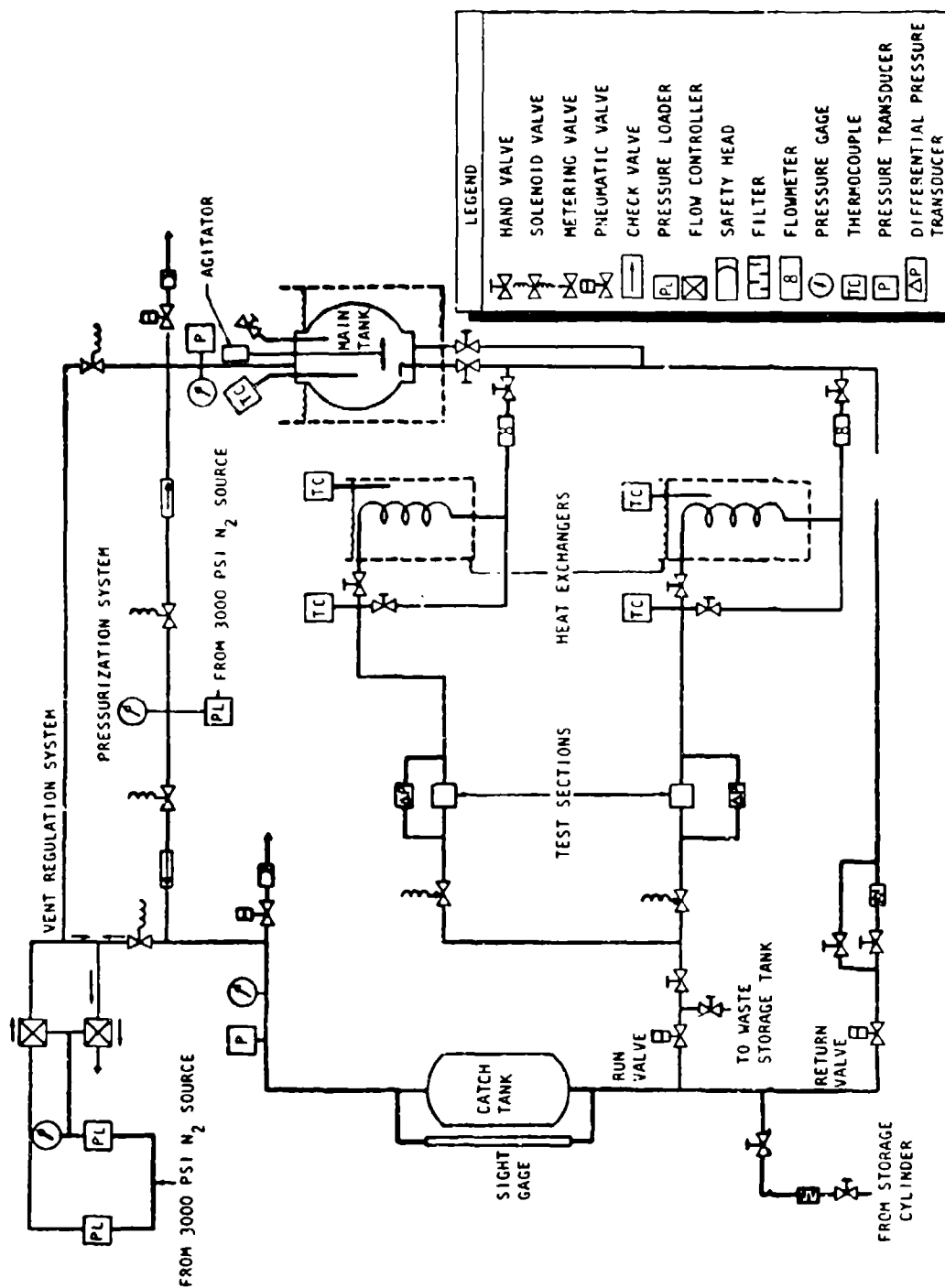


Figure 1. Schematic Diagram of Experimental Flow Bench System

The test sections consisted of small stainless filters of the woven-wire type. These filters are commercially available units obtained from Western Filter Company, Inc., Los Angeles (basic part number 19310). A special feature of this filter is that it can be added to or removed from the system with minor effort. Thus, it was particularly suited to the needs of this program. With the exception of one filter size (a 50-mesh wire screen), all the filters used in this program were in the micron range. The filter sizes used are listed below:

Size, microns	Micron Rating	
	Nominal (a)	Absolute (b)
2	2	10
5	5	15
10	10	25
40	40	60
50 mesh		280

(a) 95 to 98 percent of particles above this size are removed

(b) 100 percent of particles above this size are removed

INSTRUMENTATION

Nitrogen tetroxide flowrates were measured in each of the parallel test sections by Fischer-Porter, radio-frequency-type turbine flowmeters. Propellant temperatures were measured in the main tank and in the line between the heat exchanger outlets and the test sections (as shown in Fig. 1) by iron-constantan thermocouples and a Pace 150-degree reference junction. Also, thermocouples were installed in the main tank bath and both heat exchanger baths to assist in setting the desired test conditions. Pressures in the main and catch tanks were determined with Taber pressure transducers. Pressure drops across the test sections were measured with Data Sensor differential pressure transducers. These flowrates, temperatures, and pressures were recorded on five Hewlett-Packard Mosely dual-pen strip chart recorders. Through use of selector switches, heat exchanger bath temperatures could be read on the recorder used for indicating propellant line temperature, but were not recorded during the actual test runs.

TEST PLAN

A test plan was developed and approved by the Air Force Project Officer before the experimental work was started. It was designed as a sequential plan to: (1) incorporate features to minimize the required number of tests, (2) take into consideration the changeover time between subsequent tests, and (3) allow flexibility in investigating problem areas as they would be identified during the test program.

The major independent variables to be controlled and measured were: propellant composition, test section hardware, initial propellant temperature, temperature drop before reaching the test section, time during which the

temperature drop is imposed, initial flowrate, and saturation condition (i.e., whether the N_2O_4 was used as received, or doped with a small amount of iron pentacarbonyl to ensure iron saturation). A large matrix of potential tests was prepared with a preliminary selection of the combinations of test conditions and order in which test sets would be conducted. However, it was recognized at the outset that: (1) the conditions for the test sets to be made, (2) the number of tests within each test set that would be required to obtain the necessary information (including replications to help resolve complex and unusual behavior), and (3) the order of test sets would differ somewhat from those given in the matrix as a result of sequential decisions (based on information from earlier tests) which would be made during the actual test program. This preliminary test plan outlined many more potential tests than realistic estimates would predict could be performed during the program; best efforts were made to make as many of these tests as possible.

During the program, tests were made with variations of all seven of the major independent variables originally selected. These variables, and the levels or ranges of values employed are summarized in Table I.

TABLE I. INDEPENDENT VARIABLES IN EXPERIMENTAL TESTS

Variable	Number of Levels	Range of Values
N_2O_4 Composition	2	Green and red-brown
Test Section Hardware	7	2-micron through 50-mesh filters
Initial Propellant Temperature, F	3	50, 75, and 100
Temperature Drop, F	7 (approximate)	0 through 34
Time for Temperature Drop	2	Short (during flow) and long (approximately 2 days)
Initial Flowrate, gpm	5 (approximate)	0.14 to approximately 0.5
Saturation Condition	2	As received, or doped with a small amount of iron pentacarbonyl

OPERATING PROCEDURE

The run tank was charged with nitrogen tetroxide from the appropriate storage cylinder, through a 40-micron filter in the fill line.

For certain test series, a contractual requirement was to use propellant saturated with flow decay material. To ensure that saturated conditions existed, a small quantity (an amount corresponding to "one saturation dose" of iron using the approximate solubility data from Ref. 6) of iron pentacarbonyl was reacted with the nitrogen tetroxide in the run tank to form nitrosyl

tetranitratoferrate, the flow decay compound. The iron pentacarbonyl was placed in a microliter syringe with a 24-inch long needle and injected directly into the run tank. A septum and ball valve arrangement was designed and mounted on the top flange of the run tank for this purpose. The tank contents were agitated during this addition.

Both long and rapid cooldown tests were conducted in this program. In the "rapid" cooldown tests, the propellant was allowed to stand in the run tank for a minimum of 2 hours at a given initial temperature, T_0 , before a test was started. The main tank agitator was turned on periodically to help equalize the temperature. The heat exchanger baths were then adjusted to the desired temperature. Final prerun preparations consisted of setting the ball valves in the flow system to achieve the desired flow path. If the propellant was to be subjected to a temperature drop before entering the test section, it was flowed through the heat exchanger where it would undergo rapid cooldown. If the propellant was bypassed around the heat exchanger, i.e., no temperature drop was imposed, the run would be a zero temperature drop test but still a part of the rapid cooldown test series.

For the long (or slow) cooldown tests, new propellant was transferred from the storage cylinder to the flow bench and allowed to stand at a selected starting temperature, T_0 , for at least 2 hours. Then the propellant was cooled slowly over a period of about 48 hours to result in the desired temperature drop. The propellant was maintained at the final temperature for at least 2 hours to ensure that temperature equilibration was reached. The run was then conducted with the propellant undergoing no further temperature changes before entering the test section.

To begin a run, the main tank was pressurized to the selected level with gaseous nitrogen. The catch tank was then pressurized and the vent regulator was set to the proper pressure. Flow was started by activating the remote-operated ball valve at the catch tank inlet. Flowrates through the test sections were adjusted as necessary by making changes to the vent regulator pressure setting and/or the main tank pressure setting. With the exception of a few runs (i.e., runs with very low flowrates) the metering valves were wide open. In most cases, runs or a series of runs were carried to propellant depletion. At this point, the propellant was either returned to the main tank through the bypass line, or dumped in a waste storage container.

NITROGEN TETROXIDE COMPOSITIONS

Two types of nitrogen tetroxide, red-brown and green, were used in this program. A standard nitrogen tetroxide, 1-ton shipping container was emptied, cleaned, and sent to the Western Test Range (WTR) and another to the Eastern Test Range (ETR) to be filled with 100 gallons each of red-brown N_2O_4 and green N_2O_4 , respectively. A sampling system was designed, assembled, and used to take samples for chemical analysis from each of the two propellant supply tanks after they were returned. These samples were analyzed by Rocketdyne using conventional "wet" techniques (per specification MIL-P-26539C, and in some cases MIL-P-26539B) except for the water analyses, which utilized nuclear magnetic resonance (1H nmr) techniques with $N_2O_4-H_2O$ standards carefully prepared and sealed in precision nmr tubes during an earlier Rocketdyne program.

Information also was obtained from ETR and WTR on their chemical analyses of the propellant sources from which the propellants shipped to Rocketdyne were taken. Information from WTR showed that the N_2O_4 in the ready storage vehicle (RSV) used for the 2 June 1971 filling of Rocketdyne's supply tank was loaded on 20 and 21 August 1970. The WTR chemical analysis results were obtained for a sample taken from the RSV on 1 June 1971. Results of chemical analysis were received from ETR for a propellant sample taken from the RSV used to fill the supply tank used in this program. The ETR sample was taken on 19 April 1971, which is reasonably close to the time (17 June 1971) that the supply tank was filled. The results of these chemical analyses are summarized in Table II.

TABLE II. CHEMICAL ANALYSIS OF NITROGEN TETROXIDE USED FOR TESTS

Component	Red-Brown N_2O_4 , wt. %	Green N_2O_4 , wt. %
NO	--	0.54 ^(a) , 0.63 ^(c)
H ₂ O	0.048 ^(a) , 0.055 ^(b)	0.060 ^(a) , 0.10 ^(c)
N_2O_4 assay	99.9 ^(b)	99.4 ^(a) , 99.0 ^(c)
NOC1	--	0.03 ^(a) , 0.02 ^(c)

(a) Rocketdyne analyses; (b) WTR analyses; (c) ETR analyses

It can be seen that there is fairly good agreement between results of the various analyses.

There was some concern about the implications of the low NO concentration measured for the green N_2O_4 relative to the lower limit of the current MIL specification (0.60 wt. %). ETR obtained an NO content of 0.63 wt. % compared to 0.54 wt. % obtained by Rocketdyne. The two analyses were made within a short interval of time and therefore both can be considered applicable analyses. An average of the two points gives a value of 0.59 wt. % which is approximately equal to the lower limit of the current MIL specification. All of the other component concentrations are within the MIL-P-26539C limits.

EXPERIMENTAL RESULTS AND ANALYSIS

DERIVED FLOW DECAY PARAMETERS

The ideal experiment to measure flow decay would hold the driving force (pressure differential) across the test section exactly constant. Unfortunately, this would be extremely difficult. In this program, the main tank and catch tank pressures were controlled during a run at constant levels (as discussed in the Flow Decay Test section), within the operating band of the pressure regulators. The net effect on pressure drop across the test section (H), as the resistance across the test section increased (i.e., flow decay was occurring) could cause H to decrease, remain constant, or increase. This possible range in trend is a result of the complex interaction of several factors: the actual increase in resistance across the test section caused by deposition of flow decay material; changes in the pressure drop in the remainder of the flow system, as the flowrate changes; and fluctuations in main tank and catch tank pressures, within the normal operating bands.

These relationships are partly illustrated in Fig. 2. The lowest of the three curves is the calibration curve (corresponding to a completely clean filter) and was generally known from the calibration measurements at the beginning of a run. Points 1 and 2 represent values of Q and H measured at two times during a run. In this case, H_2 is shown as greater than H_1 , although this is not always true (as discussed in the previous paragraph). The two dashed curves through Points 1 and 2 represent the hydraulic characteristic curves for the filter with the degree of clogging present at each time but, since it is not possible to "freeze" the filter at a given point, it is not possible to determine these two curves experimentally.

Several methods and parameters were considered to reduce the basic experimental data to a common basis, in order to permit direct comparisons between runs and for use in correlation analyses. The final choice, and most meaningful parameters to characterize the amount and rate of flow decay are defined as

$$X = \frac{Q_1 - Q_2'}{Q_1} \quad (1)$$

$$Y = \frac{X}{t_2 - t_1} \quad (2)$$

where t_1 and t_2 are times corresponding to Points 1 and 2 during a run, Q_1 is the measured flowrate at time t_1 , and Q_2' is the best estimate of the value of Q_2 if H were held constant at the value H_1 (i.e., Point a in Fig. 2). Therefore, Y is the best estimate of the rate of fractional decrease in flow that would occur if the driving force across the test section remained exactly constant during a test.

Each filter test section, with the exception of those used on Runs 1 through 39 and 160 through 165, was flow calibrated with N_2O_4 to be used in that particular test series. These sets of calibration data points were fitted

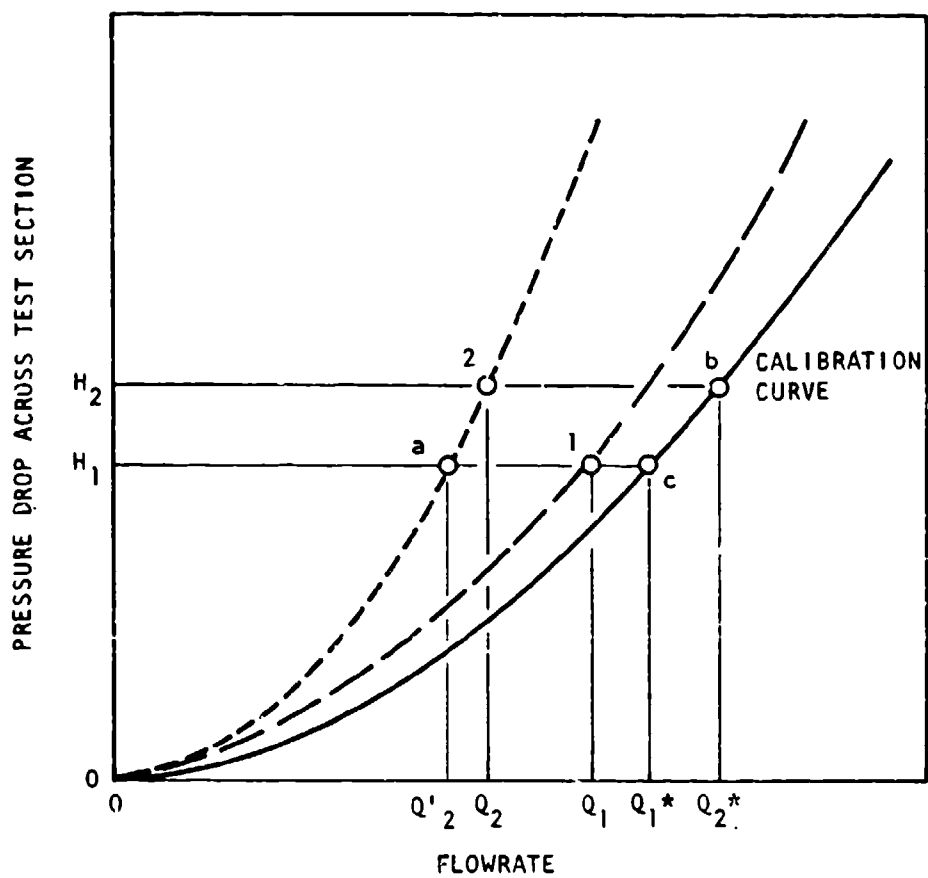


Figure 2. Typical Hydraulic Characteristics of Filters During Flow Decay Test

very well by the equation

$$H^* = k(Q^*)^n \quad (3)$$

where the value of n for various filters was very consistent and approximately equal to 2. The value of k did vary among the different filters. Typical pressure drop versus flowrate calibration curves for several different filter test sections are shown in Fig. 3. In Fig. 3, to distinguish between filters having the same nominal pore size but different filter areas, the letter "H" or "F" was added to the micron rating.

It is assumed that Eq. 3 also represents hydraulic characteristic curves for partly clogged filters, with n still equal to 2, but with different values of k . Equation 1 can then be written as

$$X = 1 - \frac{Q_2}{Q_1} \left(\frac{H_1}{H_2} \right)^{1/2} \quad (4)$$

This equation was used to reduce the experimental data to a common basis.

Another parameter that is of some value in analyzing flow decay data was defined as

$$W = \frac{Q^* - Q}{Q^*} \quad (5)$$

and represents the flowrate defect, or fractional drop in flowrate between the new filter case and the point of interest. Values of W at various stages in a filter's history can be compared, e.g.

$$Z = \frac{W_2 - W_1}{t_2 - t_1} \quad (6)$$

It can be shown that Y and Z are related approximately by the expression

$$Z \approx Y \frac{Q_1}{Q_1^*} \quad (7)$$

A third parameter was derived for use in examining the experimental flow decay data, as outlined below. The flowrate can be expressed in terms of a discharge coefficient, C , and the filter area, A , as

$$Q = CA \sqrt{\frac{H}{\rho}} \quad (8)$$

The discharge coefficient will increase as the filter becomes partly clogged, and is a function of many variables that influence the deposition of flow decay material, including a filter Reynolds Number, which can be defined as

$$Re = \frac{DQ\rho}{\mu} \quad (9)$$

If it is assumed that C is proportional to the free filter area, A_f , (i.e., total area of openings available for flow) at any time, and that the amount of effective free filter area that is clogged by flow decay material (if at all) is proportional to the quantity of N_2O_4 per unit filter area that has

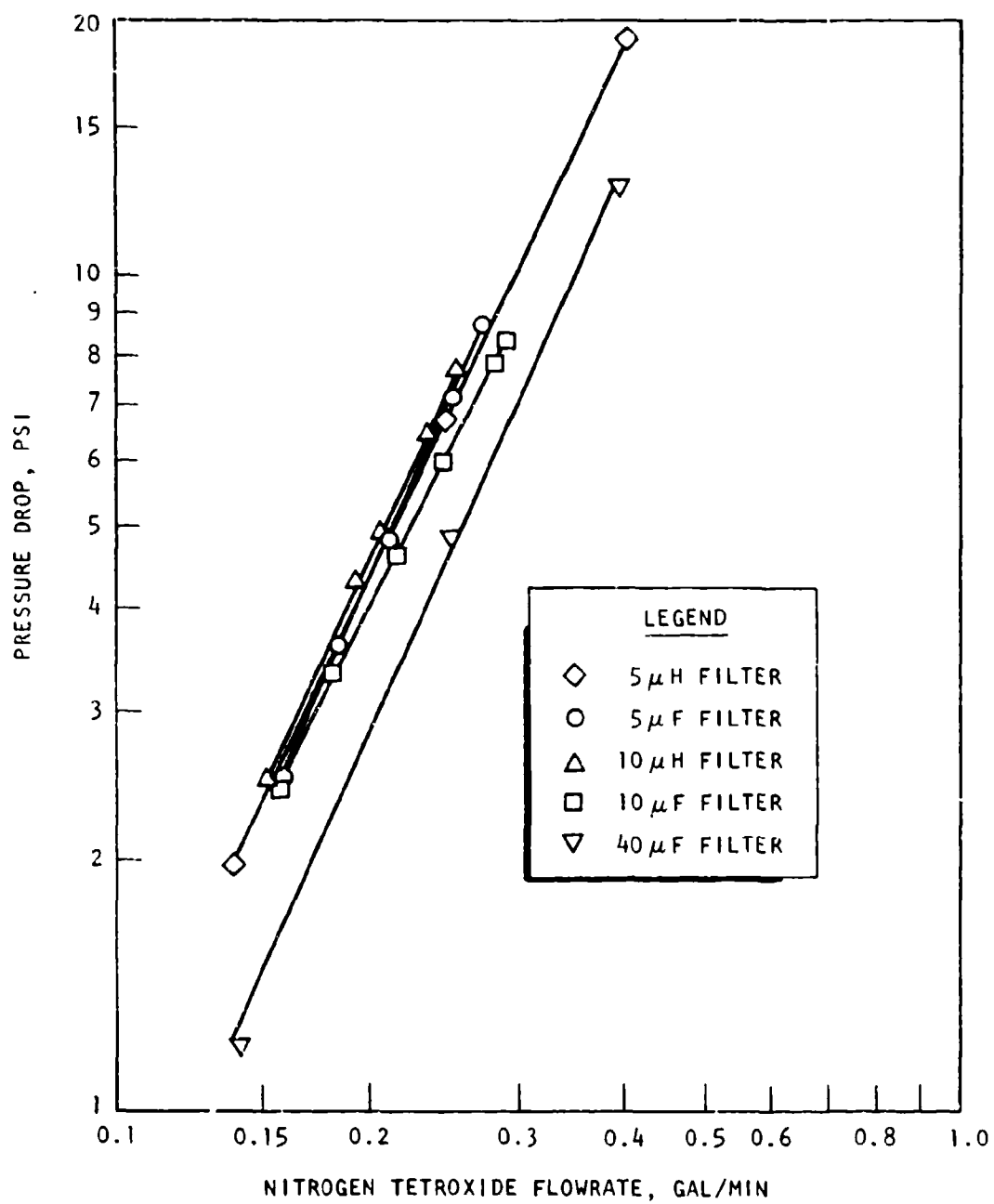


Figure 3. Typical Hydraulic Calibration Curves for Filter Test Sections

flowed through the filter, then the following equations can be developed

$$1 - \frac{C}{C_0} = \frac{L}{A} \int_0^t Q(t) dt \quad (10)$$

$$\frac{C_1 - C_2}{C_0} = \frac{L}{A} \int_{t_1}^{t_2} Q(t) dt \quad (11)$$

$$L = \frac{A}{V_{12}} \left(\frac{C_1 - C_2}{C_0} \right) \quad (12)$$

where Eq. 11 and 12 apply for constant H (i.e., C_0 is the same for both t_1 and t_2) and V_{12} is the total volume of N_2O_4 passing through the filter between time t_1 and time t_2 . Combining Eq. 8 and 12, plus defining Q_0 as the new filter (i.e., calibration) flowrate results in

$$L = \frac{A}{V_{12}} \frac{Q_1 - Q_2'}{Q^*} \quad (13)$$

It can be shown that X and L are related approximately by the expression

$$L = \frac{2AX}{Q^*(t_2 - t_1)(2 - X)} \quad (14)$$

ANALYSIS OF EXPERIMENTAL ERROR

Only a small amount of flow decay occurs with the type of filters and conditions being used in these tests; therefore, a number of experimental error analyses were made to provide guidance in the data reduction work. After considering both the precision of various experimental measurements and the precision associated with each of several techniques for extracting numbers from the recorder charts, it was possible to choose a convenient technique giving an acceptable precision in the final data values (i.e., flowrate and pressure drop across the test section plus corresponding values from the filter calibration curves at various times during a run). The error analysis techniques and results are outlined in the following paragraphs.

A group of n experiments is considered in which μ_i represents the true value of the outcome of the i^{th} experiment. It is recognized that there is experimental error at each step and thus the observed values correspond to a random variable y_i such that

$$y_i = \mu_i + \epsilon_i$$

in which ϵ_i is the random error term. It is assumed that the ϵ_i are all independent and have expected value zero. If it is further assumed that they

are normally distributed, then a 95 percent confidence interval on μ_i is

$$y_i \pm 1.96 \sigma_i \quad (15)$$

where σ_i is the standard deviation of y_i (and hence of ϵ_i), i.e.,

$$\begin{aligned} \sigma_i^2 &= \text{var}(y_i) = E(y_i - E(y))^2 \\ &= E(\epsilon_i^2) \end{aligned}$$

Thus, knowing the variance of y_i allows establishment of error bounds on the experimental outcome.

In the current situation, y_i is a function of several independent variables. Dropping the subscript i for convenience, this can be written as

$$y = f(v_1, \dots, v_m)$$

where v_1, \dots, v_m are the values of the independent variables (recorder chart readings, for example), and which are subject to experimental errors. In general, the moments of y (mean and variance) are functions of the moments of the v_j . Computing these moments can be a very arduous task unless f is extremely simple. In many cases, this can not be done in closed form; therefore, it may be necessary to resort to numerical integration or possibly the use of Monte-Carlo techniques.

However, if the variances of the v_j are small, approximate moments of y can be computed by expanding f in a generalized Taylor's series about the means of the v_j . Thus, a first-order approximation to y is given by

$$y = f(\mu_1, \dots, \mu_m) + \sum_{j=1}^m \frac{\partial f}{\partial v_j} (x_j - \mu_j)$$

where the μ_j are the means of v_j

$$E(v_j) = \mu_j$$

It follows that

$$\begin{aligned} E(y) &= f(\mu_1, \dots, \mu_m) + \sum_{j=1}^m \frac{\partial f}{\partial v_j} E(v_j - \mu_j) \\ &= f(\mu_1, \dots, \mu_m) \end{aligned} \quad (16)$$

$$\begin{aligned} \text{var}(y) &= E(y - E(y))^2 \\ &= E \left[\sum_{j=1}^m \left(\frac{\partial f}{\partial v_j} \right) (v_j - \mu_j) \right]^2 \\ &= \sum_{\ell=1}^m \sum_{j=1}^m \frac{\partial f}{\partial v_\ell} \frac{\partial f}{\partial v_j} E(v_\ell - \mu_\ell)(v_j - \mu_j) \end{aligned} \quad (17)$$

If it is assumed that v_j is independent from v_l , then,

$$E(v_l - \mu_l)(v_j - \mu_j) = \begin{cases} \sigma_j^2 & l = j \\ 0 & l \neq j \end{cases}$$

Therefore, the final result is

$$\text{var}(y) = \sum_{j=1}^m \left(\frac{\partial f}{\partial v_j} \right)^2 \sigma_j^2 \quad (18)$$

Comparing Eq. 18 with Eq. 15, it can be seen that the problem of determining a confidence interval for the experimental outcome has been reduced to estimating the variances of the independent variables.

Equation 18 was evaluated with X as the dependent variable (i.e., $y = X$) and using the expression in Eq. 4 to define f . The final evaluation of this equation was made with the following values for the means and variances of the experimental variables.

Independent Variable (v_j)	Nominal Mean Value	Estimated Variance (σ_j^2)
Q_1 and Q_2	0.25 gpm	$2.5 \times 10^{-7} \text{ gpm}^2$
H_1 and H_2	7 psia	$4 \times 10^{-4} \text{ psia}^2$
$t_1 - t_2$	10 minutes	--
t_1 and t_2	--	$1 \times 10^{-4} \text{ min}^2$

The estimated maximum experimental error (95% level) in each case is two times the square root of the estimated variance. With these values, and using Eq. 18, the estimated standard deviation of X is 0.0035 (i.e., a change of 0.35% in flow). This estimated value is essentially independent of the time interval ($t_2 - t_1$) because of the small experimental error in measuring time. This value was then used in various statistical tests applied to the data to determine whether flow decay occurred or not. For example, experimental runs for which the values of X are greater than $1.282 \sigma_X$ (i.e., 0.0045) can be said to represent cases of flow decay ($X > 0$) at the 90 percent confidence level. This value of $1.282 \sigma_X$ is the deviation from the mean corresponding to a confidence level of 90 percent for a one-sided test (normal distribution).

DATA REDUCTION AND DERIVED RESULTS

Values of Q and H were taken from the recorded traces for each run at several times: (1) as near to the beginning of the run as practical, (2) at the end of the run, and (3) at one or more intermediate times, especially including any inflection points within a run. Generally, the slopes of the Q and H

traces were fairly constant for at least several minutes at a time. A computer program was written and used to calculate values of various parameters (X , Y , Z_1 , Z_2 , W , V , L , Re) for each significant time interval within each run. A complete set of this computer output is given in the Appendix. These derived results were then used with a variety of techniques to organize, generalize, and correlate the data.

One of the first efforts in organizing the derived results was to develop a large matrix showing a brief indication of the results of each experimental run. A summary of results for all the flow decay tests conducted in this program is given in Tables III, IV, and V. The test conditions for the runs are given along the side and top of each table and are for the most part self-explanatory. To differentiate between filters having the same pore size but different filter areas, the letter "H" or "F" is added to the pore size rating. The temperatures listed are nominal values; the actual values for each run are given in Appendix A.

Each box in these tables contains information about the tests that were run under the conditions represented by the values of the seven independent variables corresponding to that particular box. The first number (or group of numbers) in each box is the test run number(s). The second entry is a simplified indication of whether or not that particular run produced flow decay. The word "yes" indicates that the values of X and Y were high enough to indicate that flow decay occurred (i.e., to reject the hypothesis that X and Y are equal to zero) at the 90 percent level of confidence. The error analysis and estimated standard deviation of X and Y as outlined in the Analysis of Experimental Error section were used to establish the acceptance region for the above test at the 90 percent level of confidence. The word "no" is given as the second entry in a box if the value of Y is low enough to indicate that no significant flow decay occurred (for this purpose, the minimum level of significant flow decay was defined to be $Y = 0.05$ %/min) at the 90 percent level of confidence. The abbreviation "Unr" is given if the values of X and Y do not permit placing the result in one of the first two categories. The third entry in each box is the value (or range of values) of Y , in %/min. In some instances, where two or more runs were made under a given set of test conditions, some runs did and other runs did not exhibit flow decay. In these instances, the table box is divided into two or three sections and the appropriate information is given for each group of tests in the format described above.

There are many observations that can be made and conclusions that can be drawn from Tables III, IV, and V. Many of these are incorporated in the conclusions and discussions of the effects of the independent variables, which are given in the remaining sections of this report. However, several results should be noted at this point, including the following. There were no cases of validated flow decay with filters as coarse as 40-micron. (This was also true for 50-mesh.) There were five runs (numbers 1, 3, 4, 10, and 167) in which the results, considered without the other experimental results, would indicate valid flow decay. However, in each of these cases, there are other, more compelling reasons to conclude that true flow decay will not occur under those conditions. For each of these five anomalous runs, there are much larger numbers of data points at the same conditions (and others with, e.g., higher temperature drops and, smaller filter pore

TABLE III. SUMMARY OF FLOW DECAY TESTS USING IRON-SATURATED N₂O₄

Filter Size	Initial Propellant Temperature, F										
	Nominal Temperature Drop, F										
	0	5	10	15	0	5	10	15	20	30	0
Brown N ₂ O ₄ Saturated, Rapid Cooldown	63(a), Yes (b), 0.22(c)	65; Yes; 0.60	67; Yes; 0.87	69; Yes; 1.34 to 2.74	59, 41; Yes; 0.07 to 0.11	43, 47; Yes; 0.35 to 0.56	45, 49; Yes; 0.70 to 0.96	60; Yes; 0.30 to 0.45	61, 62; Yes; 0.30 to 0.45	51, No; 0.13	55-58; Yes; 0.06 to 0.41
Green N ₂ O ₄ Saturated, Rapid Cooldown	64; No; 0.11	66; Yes; 0.10	68; Yes; 0.25	70; Yes; 0.28 to 0.33	40, 42; Yes; 0.16 to 0.20	44, 48; Yes; 0.25 to 0.38	46, 50; Yes; 0.70 to 0.74	54; Unr; 0.03	55; Yes; 0.13	59; Yes; 0.07	106; No; -0.07
	120; No; 0.0	129; Unr; 0.06	131-134; Yes; 0.17 to 0.53	135-138; Yes; 0.17 to 0.53	83; Yes; 1.36	85; Yes; 1.32	88; Yes; 0.94	91; Yes; 1.35	94, 95; Yes; 0.55 to 0.61	107; No; -0.03	112; Unr; 0.02
	121-125; Yes; 0.11 to 0.49	126-128; Yes; 0.21 to 0.51			84; Yes; 0.21	86, 87; Yes; 0.22	89; Yes; 0.06	92, 93; Yes; 0.10 to 0.36	94, 95; Yes; 0.55 to 0.61	109; No; -0.07	110, 115; Yes; 0.13 to 2.57
					97; No; -0.10		99; No; 0	101; Yes; 0.05	103-105; Yes; 0.10 to 0.15	108; Yes; 0.07	117; Yes; 0.06
10LF					96; Unr; 0.04		98; No; -0.03	100; No; -0.02	102; Unr; 0.04		

- NOTES: (a) In each box, the first number(s) is the test run number.
 (b) The second entry in each box is one of three words: (1) Yes, if the values of X and Y are high enough to indicate flow decay (X and Y > 0) at the 90 percent level of confidence; (2) No, if the value of Y is low enough to indicate no significant flow decay (Y < 0.05) at the 90 percent level of confidence; and (3) Unr (for unresolved), if the values of X and Y do not permit placing it in one of the first two categories.
 (c) The third entry in each box is the value (or range of values) of Y, in 1/min.
 (d) These are very early tests of doubtful validity.

TABLE IV. SUMMARY OF FLOW DECAY TEST RESULTS USING BROWN AS-RECEIVED N_2O_4

Filter Size	Initial Propellant Temperature = 75 F			
	Nominal Temperature Drop, F			
	0	15	20	32
Brown N_2O_4 As-Received Rapid Cooldown	2 μ F 162(a); No ^(b) ; -0.02(c) 161,165; Unr; 0.01 to 0.04	160,163; No; -0.01 to 0.0 164; Yes; 0.05		
	5 μ F		20, 22, 24, 26, 28 30, 32, 34, 36, 38; Yes; 0.05 to 0.68	18, 19, 21, 23, 25, 27, 29, 31, 33, 35, 37; Yes; 0.15 to 2.13
	40 μ F	5, 7, 11; No; -0.14 to -0.03 9; Unr; 0.10 1(d), 3(d); Yes; 0.16	13; No; -0.06	15, 17; No; -0.06 to -0.02
	50 Mesh-F	2, 6, 8, 12; No; -0.17 to 0.05 4(d), 10; Yes; 0.05 to 0.14	14; No; -0.07	16; No; -0.06
Brown N_2O_4 As-Received Slow Cooldown	5 μ H		170-172; Yes; 0.07 to 0.25 173; No; -0.08	
	40 μ F		159, 166, 169; No; -0.19 to 0.0 157, 158, 168; Unr; 0.01 to 0.05 167; Yes; 0.12	

See Table I for Notes (a), (b), (c), and (d)

TABLE V. SUMMARY OF FLOW DECAY TEST RESULTS USING GREEN AS-RECEIVED N_2O_4

Filter Size	Initial Propellant Temperature, F					
	75					
	Nominal Temperature Drop, F					
	0	5	10	20	25	100
5 μ H	73, 79, 143-145 ^(a) ; Yes ^(b) ; 0.13 to 0.88 ^(c)	81, 146, 147; Yes; 0.06 to 1.07	75; Yes; 0.49	77; Yes; 0.56		
5 μ F	74; Yes; 0.06 60; Unr; 0.02	82; Yes; 0.06	76; Unr; 0.01	78; Yes; 0.11		
40 μ F			149-150; No; -0.09 to -0.01 148; Unr; 0.06	151, 152; No; -0.09 to 0.0		
5 μ H				140-142; Yes; 0.13 to 0.32	153; Yes; 020 154-156; Unr; 0.02 to 0.06	
40 μ F				135-137; Unr; 0 to 0.04 138-139; No; -0.13 to -0.12		

Green N_2O_4
As-Received
Rapid Cooldown

Green N_2O_4
As-Received
Slow Cooldown

See Table I for Notes (a), (b), and (c)

sizes) for which flow decay was not present. Therefore, it is judged valid to conclude that flow decay will not occur under any of the conditions tested with filters of nominal pore size at least as large as 40 microns.

There are other trends that can be observed merely from examination of these tables. The incidence of flow decay (and the rate of decay) is increased by increasing the temperature drop and by decreasing the filter pore size. Although some additional trends may be suspected from examination of these tables, caution should be exercised since the situation is more complex than it may appear at first. There are other independent variables that are not explicitly listed in Tables III through V. These include initial flowrate (which was measured, but is not shown in these tables) and the "history parameter," V , which expresses the total amount of propellant per unit filter area which has passed through the filter. Another complexity arises because there appear to be many interactions among the various independent variables.

Part of the project was devoted to going beyond the yes-no level of information about the incidence of flow decay, and to perform correlations to establish at least a preliminary basis for representing the amount of flow decay that occurred under various experimental conditions. Because of the large number of independent variables and complexity of the flow decay phenomenon, it was necessary to rely on other statistical plus multiple regression analyses. These are described in the next section.

MULTIPLE REGRESSION ANALYSIS

Multiple regression techniques were used to analyze the data. This type of analysis provides a convenient tool to determine if various independent variables have a significant effect on the outcome of a test. This technique is also valuable in detecting cross effects or interactions between the independent variables. In particular, a step-wise multiple regression was performed, in which various combinations of the independent variables were allowed in the regression, and selections were made to delete variables that were of low value in the regression and to add (or retain) variables that were of high value (i.e., contributed significantly to reducing the residual sum of squares).

To provide some guidance for the regression analyses, theoretical analyses were made of the physical processes that may be occurring during flow decay. However, since the actual complex mechanisms of flow decay are only partly understood, and are generally not very amenable to analysis, it was necessary to perform most of the regression efforts in an empirical manner. Approximately 100 sets of step-wise multiple regression analyses were made; each case comprised a series of approximately 5 to 50 steps in which various combinations of the independent variables were permitted.

The nine primary independent variables considered in the regressions were: Reynolds number (Re); nominal filter pore size (D); temperature drop (ΔT); initial temperature (T_0); the average flowrate per unit filter area (Q/A); the history parameter (V), which expresses the total volume of propellant per unit filter area that passed through the filter during the run; and three 2-level parameters. The 2-level parameters were: (1) the type of

N₂O₄ (green or red-brown), (2) whether or not the propellant was doped with a small amount of iron pentacarbonyl to ensure saturation or was tested as-received, and (3) whether the temperature drop was imposed rapidly (during flow) or slowly (over approximately 2 days). The two possible levels for each of these three parameters were assigned values +1 and -1, respectively, for use in the regression analyses. In addition to these nine primary independent variables, a large number of combinations of these variables were also allowed as possible independent variables.

Regression analyses were made for the total set of test data and for many partitioned subsets of the data. There are over 1,000,000 combinations of the nine primary variables with the nominal number of levels tested for each during this program. Therefore, it can be readily seen that it was important to examine the data, where possible, for subsets in which there are fewer independent variables and hence, fewer possible combinations of conditions. The subsets included such groupings as: all runs for which there was significant flow decay; all runs with green N₂O₄ for which there was significant flow decay; all runs with green N₂O₄, tested as-received, subjected to a rapid temperature drop; etc. The multiple regression results for the subsets were more useful than those for the total set of data in deducing effects and interactions of the independent variables.

To demonstrate the ability of multiple regression analysis techniques to extract information from complex data, the following simple example from the multiple regression analyses performed during this project is discussed in some detail. Several analyses were performed for a partitioned subset of the test data consisting of Runs 120 through 128 and 130 through 134. For these runs, the filter pore size and initial temperature were held constant at 5μ and 50 F, respectively. Moreover, the propellant for all runs was red-brown N₂O₄, saturated with respect to iron, and was cooled rapidly. The only parameters that were allowed to vary were ΔT, V, Q/A, and T₀. It had been found from previous analyses that inclusion of Re did not improve the regression as compared with the use of Q/A and D alone. For these particular runs, V and Q/A were highly correlated and therefore V was also dropped as an independent variable. It then follows that the rate of flow decay, Y, is some function of only ΔT and Q/A plus experimental error. Typically in a regression analysis, it is assumed that the dependent variable (or some transformation of it) is normally distributed with constant variance but with mean depending on the independent variables, i.e.,

$$E(Y) = f(\Delta T, Q/A) \quad \text{var}(Y) = \sigma^2 \quad (19)$$

where E = expectation and var = variance. Assuming that f is reasonably well behaved, it can be approximated by an expansion about nominal values of ΔT and Q/A. In this case, the expansion to be considered is

$$f(\Delta T, Q/A) = a_1 + a_2 \Delta T + a_3 (Q/A - 1.5) + a_4 \Delta T (Q/A - 1.5) \quad (20)$$

The a_i are the unknown regression coefficients and are to be estimated using the standard least squares criterion. Under the model assumptions given, these estimates will be optimum in the sense that they have minimum mean squared error loss among all possible invariant estimates (those estimates invariant under change of scale or location of origin). They are also minimum variance estimates among all unbiased ones.

Equation 20 can be used for several purposes. First of all, the hypothesis

$$H_0: a_i = 0$$

can easily be tested against the alternatives

$$H_1: a_i \neq 0, H_2: a_i > 0, H_3: a_i < 0$$

using the standard F-statistic. The confidence at which this hypothesis can be rejected gives a measure of the confidence with which it can be concluded that the parameter for which a_i is a coefficient has an effect upon flow decay. The sign of the estimate of a_i gives the indication of the direction of this effect.

From the regression analysis, the estimates of the coefficients a_1, a_2, a_3, a_4 are 0.12, 0.025, 0.093, and -0.003 respectively. The coefficient a_2 is considered to represent the main effect of the variable ΔT (defined here as the slope of the regression curve at the nominal values of ΔT and Q/A). Since $a_2 > 0$, the regression equation predicts that a temperature drop will tend to enhance flow decay. The standard deviation of this estimate is given as 0.013. Thus, it can be said that this effect is real, with a high degree of confidence; in fact, the hypothesis that $a_2 = 0$ can be rejected at a 92 percent confidence level. Similarly, the value of a_3 as 0.093 indicates that (for $\Delta T = 0$) the effect of Q/A is to enhance flow decay. The confidence with which $a_3 = 0$ can be rejected is again quite high (93 percent).

In this example, a cross effect between ΔT and Q/A was allowed through inclusion of the term $a_4 \Delta T(Q/A - 1.5)$. The value of -0.003 for a_4 indicates that the effect of ΔT is decreased as Q/A is increased. This follows from the fact that

$$\begin{aligned} \frac{\partial Y}{\partial \Delta T} &= a_2 + a_4 (Q/A - 1.5) \\ &= 0.025 - 0.003 (Q/A - 1.5) \end{aligned} \quad (21)$$

Similarly, the effect of Q/A is decreased as ΔT is increased. The standard deviation of a_4 is 0.008. The hypothesis that $a_4 = 0$ can be rejected only at a 28 percent level of confidence. This is quite low; therefore, caution should be exercised in drawing any general conclusions concerning the existence of the negative cross effect between ΔT and Q/A .

A plot of the data points and regression curve predictions for this case is given in Fig. 4. The positive Q/A effect for any given ΔT is seen by noting that the family of curves all have a positive slope. The positive ΔT effect is seen by noting that each curve in the family has a higher ΔT indexing it than the one immediately below it. Finally, the small cross effect between ΔT and the Q/A variable is evidenced by the changing slope of the three curves plotted.

Results of several of the more useful multiple regression analysis cases for partitioned subsets of the data are given in Tables VI and VII. The case numbers given in these tables do not mean that these were the first eight analysis cases that were run.

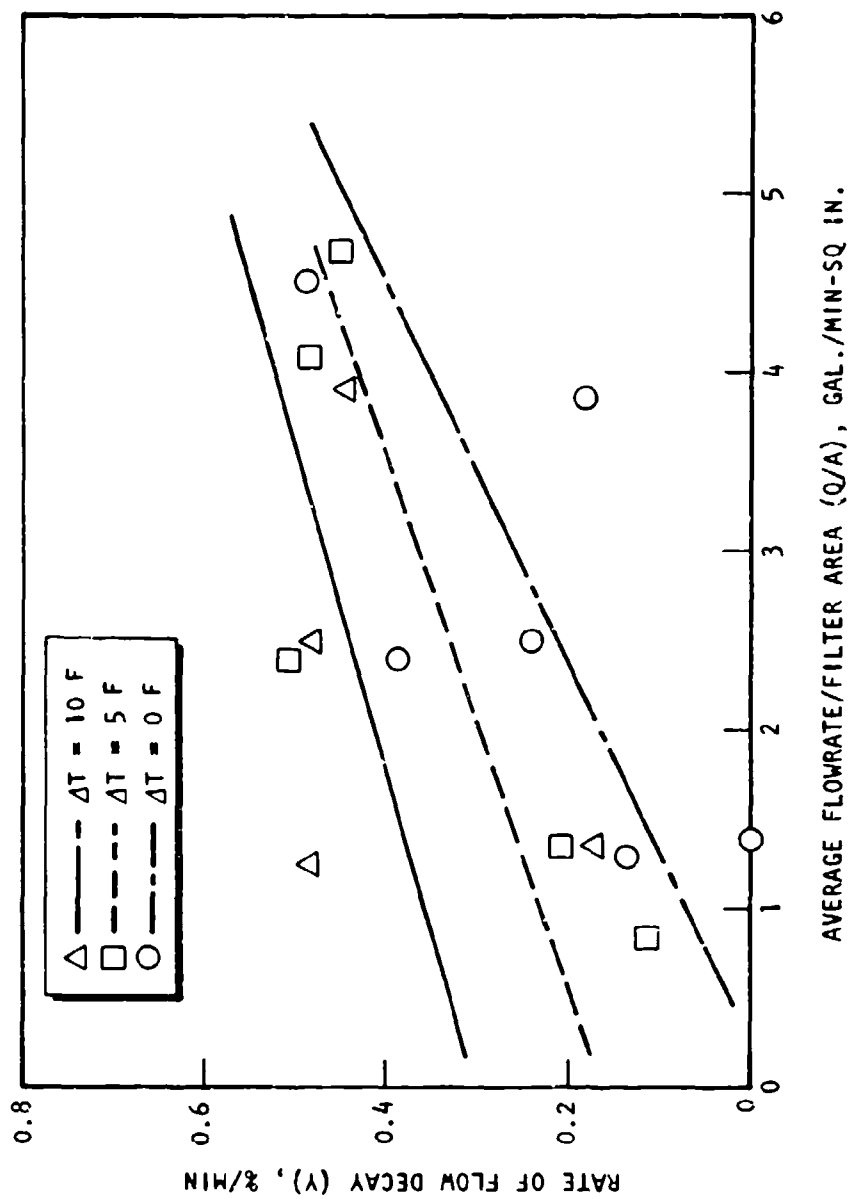


Figure 4. Regression Equation Predictions and Data Points (Regression Case 2 in Table VI)

TABLE VI. RESULTS OF MULTIPLE REGRESSION ANALYSES FOR SELECTED DATA SUBSETS

Independent Variable	Constant Term	D	ΔT	T_0	Green or Brown (GB)	Saturated or ASIS (SAT)	Rapid or Long Cooldown (RL)	V	λ/A
Case 1 13 data points 8 degrees of freedom $s = 0.15$	0.81 0.29 0.98	5	20	75	B	ASIS	0.003 0.16 0.07	0.076 0.031 0.96	0.19 +0.69 RL 0.33 0.34
Case 2 15 data points 11 degrees of freedom $s = 0.15$	0.12 0.08 0.83	5	0.025 0.013 0.32	50	G	S	R	$V_1 \sim 0/A$ for this data set.	0.093* 0.046* 0.93*
Case 3 29 data points 20 degrees of freedom $s = 0.31$	0.39 0.10 0.999	5	-0.001 0.008 0.15	0.005 0.006 0.53	G	S	R	-0.044 0.016 0.99	0.35 0.15 0.97
Case 4 16 data points 7 degrees of freedom $s = 0.11$	0.085 0.16 0.38	10	0.014 0.015 0.62	-0.0026 0.0039 0.47	B	S	R	-0.0016 0.0065 0.21	-0.29 0.37 0.55
Case 5 26 data points 12 degrees of freedom $s = 0.10$	0.39 0.07 0.9999	-0.061 -0.063 GB 0.022 0.98	0 0.029 -0.008 GB 0.006 0.99	75	0.41 0.07 0.999	S	R	-0.025 0.005 0.99	0.44 +1.09 GB 0.13 0.99
Case 6 28 data points 16 degrees of freedom $s = 0.31$	0.38 0.34	5	0.002 +0.011 SAT 0.018	75	G	0.40 0.29 0.87	0.12 0.39	-0.034 0.025 0.84	0.55 0.16 0.99
Case 7 30 data points 18 degrees of freedom $s = 0.34$	0.72 0.10 1.00	-0.046 0.032 0.83	0.040 0.010 0.999	-0.019 0.005 0.999	B	S	R	0.06 0.01 0.13	0.62 0.23 0.99
Case 8 39 data points 25 degrees of freedom $s = 0.56$	0.45 0.19 0.98	-0.023 0.064 0.28	-0.0008 0.01 0.09	0.013 0.012 0.71	G	S	R	-0.021 0.022 0.67	0.31 0.35 0.60

*for $\Delta T = 0$ instead of $\Delta T = 15$

TABLE VII. FINAL REGRESSION EQUATIONS FOR SELECTED DATA SUBSETS

<u>Case 1</u>	$Y = 0.81 + 0.076 (V - 15) + 0.19 (Q/A - 1.5) + 0.003 RL + 0.69 RL (Q/A - 1.5)$
<u>Case 2</u>	
<u>Case 3</u>	$Y = 0.12 + 0.024 \Delta T + 0.093 (Q/A - 1.5) - 0.003 \Delta T (Q/A - 1.5)$
<u>Case 4</u>	$Y = 0.39 - 0.001 (\Delta T - 15) + 0.005 (T_o - 75) - 0.044 (V - 15) + 0.35 (Q/A - 1.5) + (\Delta T - 15) [-0.0003 (T_o - 75) - 0.0061 (V - 15) + 0.028 (Q/A - 1.5) + 0.0014 (\Delta T - 15)]$
<u>Case 5</u>	$Y = 0.085 + 0.014 (\Delta T - 15) - 0.0026 (T_o - 75) - 0.0016 (V - 15) - 0.29 (Q/A - 1.5) + (\Delta T - 15) [-0.0010 (T_o - 75) + 0.0004 (V - 15) + 0.0048 (Q/A - 1.5)]$
<u>Case 6</u>	$Y = 0.39 - 0.061 (D - 7) + 0.010 (\Delta T - 15) + 0.41 GB - 0.025 (V - 15) + 0.44 (Q/A - 1.5) - 0.063 GB (D - 7) + 1.088 GB (Q/A - 1.5) + (\Delta T - 15) [-0.0035 (D - 7) + 0.0008 (\Delta T - 15) - 0.0079 GB - 0.001 (V - 15) + 0.018 (Q/A - 1.5) - 0.002 GB (D - 7)]$
<u>Case 7</u>	$Y = 0.38 + 0.002 (\Delta T - 15) + 0.40 SAT + 0.12 RL - 0.034 (V - 15) + 0.53 (Q/A - 1.5) + (\Delta T - 15) [0.0006 (\Delta T - 15) + 0.011 SAT - 0.002 (V - 15) + 0.051 (Q/A - 1.5) - 0.038 SAT (Q/A - 1.5)]$
<u>Case 8</u>	$Y = 0.72 - 0.046 (D - 7) + 0.040 (\Delta T - 15) - 0.019 (T_o - 75) + 0.62 (Q/A - 1.5) - 0.026 (T_o - 75) (Q/A - 1.5) + (\Delta T - 15) [-0.002 (D - 7) - 0.0015 (T_o - 75) + 0.001 (V - 15) + 0.026 (Q/A - 1.5) - 0.0024 (T_o - 75) (Q/A - 1.5) - 0.00002 (\Delta T - 15) (T_o - 75)]$
	$Y = 0.45 - 0.023 (D - 7) - 0.0008 (\Delta T - 15) + 0.013 (T_o - 75) - 0.021 (V - 15) + 0.31 (Q/A - 1.5) - 0.0042 (T_o - 75) (Q/A - 1.5) + (\Delta T - 15) [-0.0031 (D - 7) + 0.0003 (\Delta T - 15) - 0.0007 (T_o - 75) + 0.0006 (V - 15) - 0.0013 (T_o - 75) (Q/A - 1.5) - 0.0001 (\Delta T - 15) (T_o - 75)]$

For a given case, a single entry in a column of Table VI indicates that the variable in that column was held fixed at the value shown for all tests included in that subset. (Conversely, all test data for the specified conditions were included in the subset.) If three numbers are given, this indicates that the variable was included in the set of independent variables. The top entry is the estimate of the regression coefficient, the second is the estimate of its standard deviation, and the third is the level of confidence at which the hypothesis can be rejected that the regression coefficient is zero. For example, in Case 5, the estimate of the regression coefficient for the variable GB is 0.41, its standard deviation is 0.07, and there is 99.9 percent confidence that this coefficient is not zero.

The value of a given coefficient can be interpreted as the effect of the independent variable which it represents. More precisely, the effect is the slope of the regression curve evaluated at the nominal values $D = 7$ microns, $\Delta T = 15$ F, $T_0 = 75$ F, $GB = 0$, $SAT = 0$, $RL = 0$, $V = 15$ gal/sq in., and $Q/A = 1.5$ gal/min-sq in. (except for Case 2 for which the nominal ΔT value used was zero). In some instances, there is an extra term added to the coefficient. For example, the coefficient for ΔT , Case 5, is given as $0.020 - 0.008 GB$. This is to be interpreted as $(0.020 - 0.008) = 0.012$ for green N_2O_4 and $(0.020 + 0.008) = 0.028$ for brown N_2O_4 . The estimate of the standard deviation and confidence level apply to the 0.020 portion only. Evaluation of the standard deviation corresponding to the values 0.012 and 0.028 would involve an expression requiring the variances and covariances of the ΔT and $\Delta T \cdot GB$ terms, that is

$$\sigma_{a_2}^2 = \sigma_{a_1}^2 + \sigma_{a_3}^2 + 2\text{cov}(a_1, a_3) \quad (22)$$

where a_1 is the coefficient of ΔT , a_2 is the coefficient of ΔT for $GB = 1$, and a_3 is the coefficient of $\Delta T \cdot GB$. These computations were not performed, in general.

The conclusions that were drawn from all of the regression analyses are discussed in the final subsection, Effects of Independent Variables, which follows the considerations of threshold effects.

THRESHOLD EFFECTS

It has been observed that there often appears to be a "threshold" effect for flow decay i.e., an identifiable boundary between a range of the variables for which no flow decay occurs and a range for which flow decay occurs in varying amounts. Such thresholds are probably not sharp, and certainly depend on the interactions of the independent variables. Investigations of threshold effects were made during this program. Descriptions of general threshold behavior, techniques for deducing threshold values from the experimental data, and examples of threshold effects are described in this subsection.

The experimental model assumed in Eq. 19 is capable of describing a broad range of real situations. Its application, however, depends upon the ability to characterize the functional form of $E(Y)$ in terms of parameters

(regression coefficients), which can be estimated from the data. In the present situation, however, very little is known from physical grounds concerning the behavior of flow decay as a function of the various independent variables that have been defined. In the example presented in the Multiple Regression Analyses subsection, it was assumed that f is an analytic function of its variables and hence can be approximated by a truncation of a generalized Taylor's series expansion about the nominal values of those independent variables. This expansion was assumed to be valid only in a region where there was positive flow decay. The reason for this restriction is due to the possible threshold effect for flow decay. If Y is used as the dependent variable denoting flow decay, $\bar{v} = (v_1, \dots, v_n)$ denotes the vector of test conditions and c denotes the region of n -space for which there is positive flow decay, then the threshold that is being discussed is the boundary of c . In particular, the expectation of Y , called f in Eq. 19, can be written as

$$f(\bar{v}) = \begin{cases} 0 & \bar{v} \in c' \\ g(\bar{v}) & \bar{v} \in c \end{cases} \quad (23)$$

in which g is a positive function and c' is the complement of c . The test data appear to bear out the existence of the region c' (region of no flow decay) and hence Eq. 23 is probably an accurate description. Clearly, f cannot be approximated by a series expansion for all \bar{v} because it is not analytic. However, it is assumed to be continuous. This continuity assumption makes it possible to estimate the boundary of c from estimates of g by finding those \bar{v} such that $g(\bar{v}) = 0$, thus the boundary of c , ∂c , is given by

$$\partial c = \{\bar{v} | g(\bar{v}) = 0\} \quad (24)$$

It is actually the function g that is being approximated by a truncated series expansion. The coefficients of this expansion are estimated in the regression analysis previously discussed. Since g is only defined on c , those points not in c must be deleted from the regression analysis. The problem here, however, is that the boundary of c is not known a priori; therefore, it is difficult to decide on the basis of the value of a particular \bar{v} whether or not that data point should be deleted from the regression analysis. The problem is circumvented by using only those points for which there is probable true flow decay (i.e., $Y > 0$ at a specified level of confidence) and hence it is probable that $\bar{v} \in c$ (i.e., \bar{v} is a member of the set c).

Two examples of this threshold phenomenon are described. The first is Case 5 in Table VI. For this case, the initial propellant temperature was held fixed at 75 F; the N_2O_4 was saturated and cooled rapidly. These restrictions leave 14 of the original 26 data points in this case. Of these, 2 had a filter diameter of 10 microns; the remainder had a 5-micron filter. It therefore seems useful to analyze the case for $D = 5$ microns because this is where the highest confidence in the estimated regression curve can be placed. The following variables are left to vary: temperature drop (ΔT), history parameter (V), and average flow per filter area (Q/A).

The regression equation for Case 5 thus reduces to

$$Y = 9.035 + 0.0228 (\Delta T - 15) + 0.0008 (\Delta T - 15)^2 - 0.0250 (V - 15) + 1.526 (Q/A - 1.5) - 0.0010 (\Delta T - 15) (V - 15) + 0.0176 (\Delta T - 15) (Q/A - 1.5)^2 \quad (25)$$

where D is set equal to 5 microns and GB is set equal to 1 (i.e., green N_2O_4). Those values of ΔT , V, and Q/A for which Y in Eq. 25 is zero will thus approximate a portion of the boundary of c when the variables take on the previously prescribed values.

In practice, however, this approximation is only valid when Eq. 25 represents a reasonably good fit of the data. Further, since the values of ΔT , V, and Q/A for which Y is zero will lie outside the region for which data was used to estimate the coefficients of Eq. 25, then extrapolation errors may be introduced. These will be minimized for those cases in which the data used are "close" to the threshold. This appears to be the case for the present example.

Figure 5 is a plot of those data points used to estimate the regression curve for which the N_2O_4 was green and the filter diameter was 5 microns. Further, only those points for which ΔT was less than or equal to 20 F are displayed. Also shown are representatives of the regression equations. To avoid constructing a four-dimensional graph ($Y = f(\Delta T, V, Q/A)$), the following mechanism was used to plot Y:

1. The vertical axis is the rate of flow decay, Y
2. The horizontal axis is the average flow per filter area, Q/A
3. The family of curves is indexed by the temperature drop, ΔT
4. The history parameter was mapped onto the Q/A coordinate through linear or quadratic mappings

Step 4 may require further comment. The line for $\Delta T = 0$, e.g., is the regression line which would ideally pass through both $\Delta T = 0$ data points (triangles) in the case of a perfect curve fit. The lower $\Delta T = 0$ point has associated with it a V of 10.0 and a Q/A of 0.88. The upper point has a value of V = 26.5 and a value of Q/A = 2.01. The straight line in the V, Q/A plane given by

$$V = 10.0 + 14.6 (Q/A - 0.88)$$

passes through these two points. The straight line labeled $\Delta T = 0$ in Fig. 5 is then obtained by substituting Eq. 26 into Eq. 25 as well as setting $\Delta T = 0$ in Eq. 25. The result is a linear relationship between Y and Q/A. Equivalently, the $\Delta T = 0$ curve in Fig. 5 may be thought of as a projection onto the Y, Q/A plane of a line on the regression surface in the three-dimensional space (Y, V, Q/A) (see Fig. 6). This line on the regression surface (line AC in Fig. 6) connects the two points which are given by the regression estimates of the lower and upper $\Delta T = 0$ points (points a and b in Fig. 6). In general, there are an infinite number of lines connecting these two points and which lie on the regression surface. The one

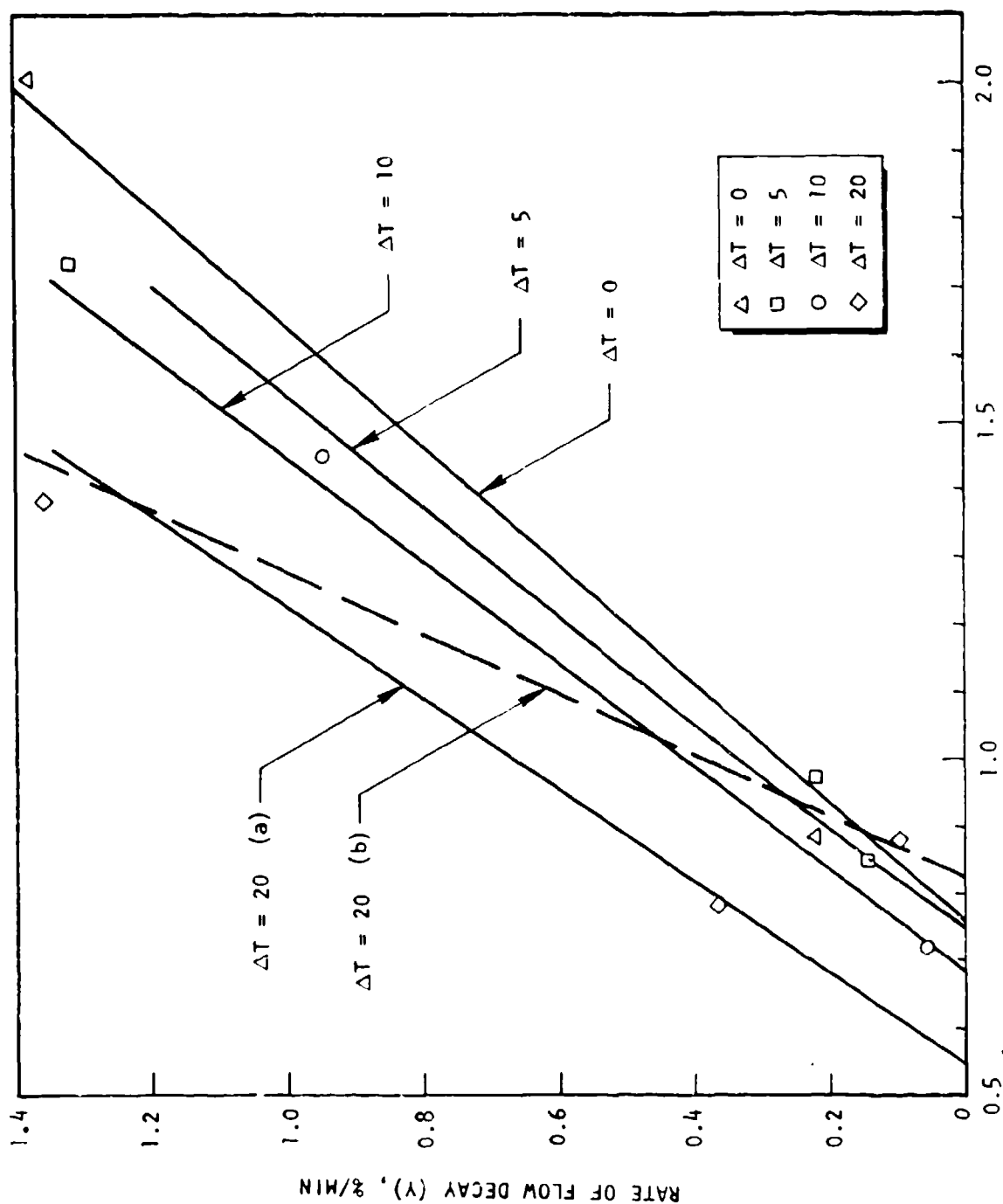


Figure 5. Threshold Effects (Regression Case 5)

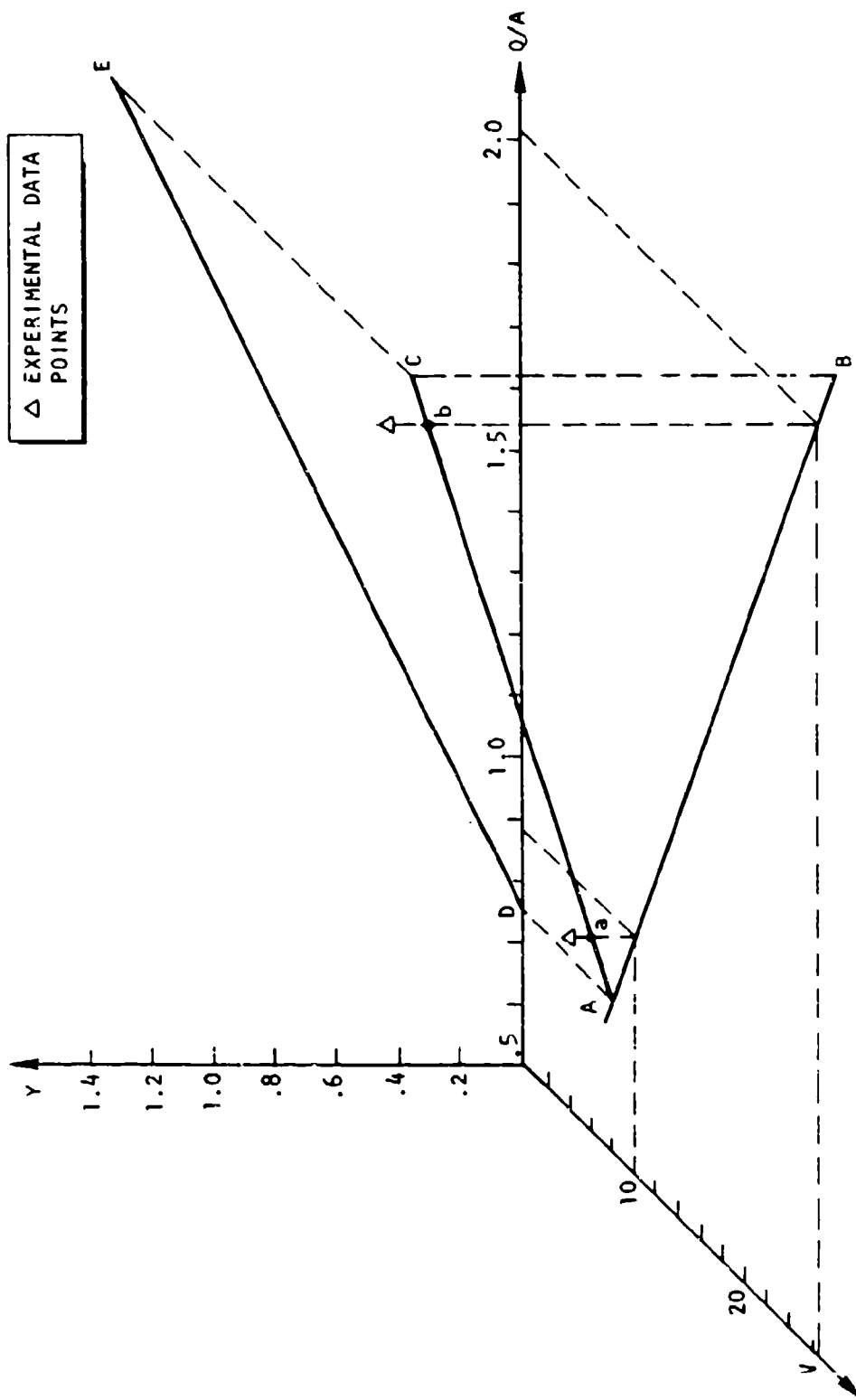


Figure 6. Projection Construction of Figure 5

chosen here is that which projects as a straight line onto the V, Q/A plane (line AB in Fig. 6).

The line plotted in the V, Q/A plane (line DE in Fig. 6) can be seen to intercept $Y = 0$ for Q/A near 0.75. This intercept is the threshold value of Q/A predicted by the regression surface for $V = 7.7$. It can thus be seen that the plotting procedure used for Fig. 5 will depict thresholds for Q/A. The information not represented in Fig. 5 is the value of V at which these Q/A thresholds lie.

The $\Delta T = 5$ curve has three data points associated with it. These three points determine a quadratic relationship between V and Q/A. The $\Delta T = 10$ curve again uses a linear transformation. For $\Delta T = 20$, there are three points and hence a quadratic function would suffice. However, it was easier to picture the regression curves by using two separate linear mappings. The (a) curve is meant to approximate the $\Delta T = 20$ points (diamonds) at $Y = 0.36$ and $Y = 1.35$, while the (b) curve approximates those at $Y = 0.10$ and $Y = 1.35$.

Admittedly, this procedure of graphing the data and regression curves in two-dimensions is somewhat artificial. However, it does serve two extremely important functions. First, it shows that the data are reasonably well fit by the multiple regression equation (Eq. 25). Secondly, it provides a visual check on how well an extrapolation of the regression curve to zero might truly represent the thresholds of the independent variables.

Figure 7 represents the functional relationships between ΔT , V, and Q/A at the threshold. These are found by setting $Y = 0$ in Eq. 25. It can be seen that, for each given V, Q/A is nearly a monotonically decreasing function of ΔT . Conversely, for each V, ΔT is a decreasing function of Q/A. That is, as the flow per filter area is increased, it is necessary to go to smaller temperature drops to avoid flow decay. The lack of pure monotonicity may be due to a modelling error in not defining the exact types of interactions possible. Nevertheless, the goodness of fit depicted in Fig. 5 indicates that the thresholds presented in Fig. 7 are reasonable approximations.

Case 1 in Table VI is considered for a second example of the threshold phenomenon for N_2O_4 flow decay, as predicted by a regression curve. Attention is restricted to that subset of the data used in Case 1 that employed a rapid cooldown for the temperature drop. Figure 8 is a graph of these data as well as the regression surface given in Table VII, and evaluated for rapid cooldown.

Plane ABCD is a three-dimensional representation of this regression equation, giving flow decay Y, as a function of V and Q/A. In the group of runs used for this case, the following variables did not vary: $\Delta T = 20$ F, $T_0 = 75$ F, $D = 5$ micron, and use of as-received (ASIS) brown N_2O_4 . Line BC lies in the plane of the V and Q/A axes and represents the intersection of the regression plane with the $Y = 0$ plane. Similarly, lines AD and CD lie in the planes formed by the V and Y axes and the Q/A and Y axes, respectively, and represent the intersections of the regression plane with these planes. Although the plane formed by the regression curve is shown in Fig. 8 as ABCD, the plane extends beyond AD.

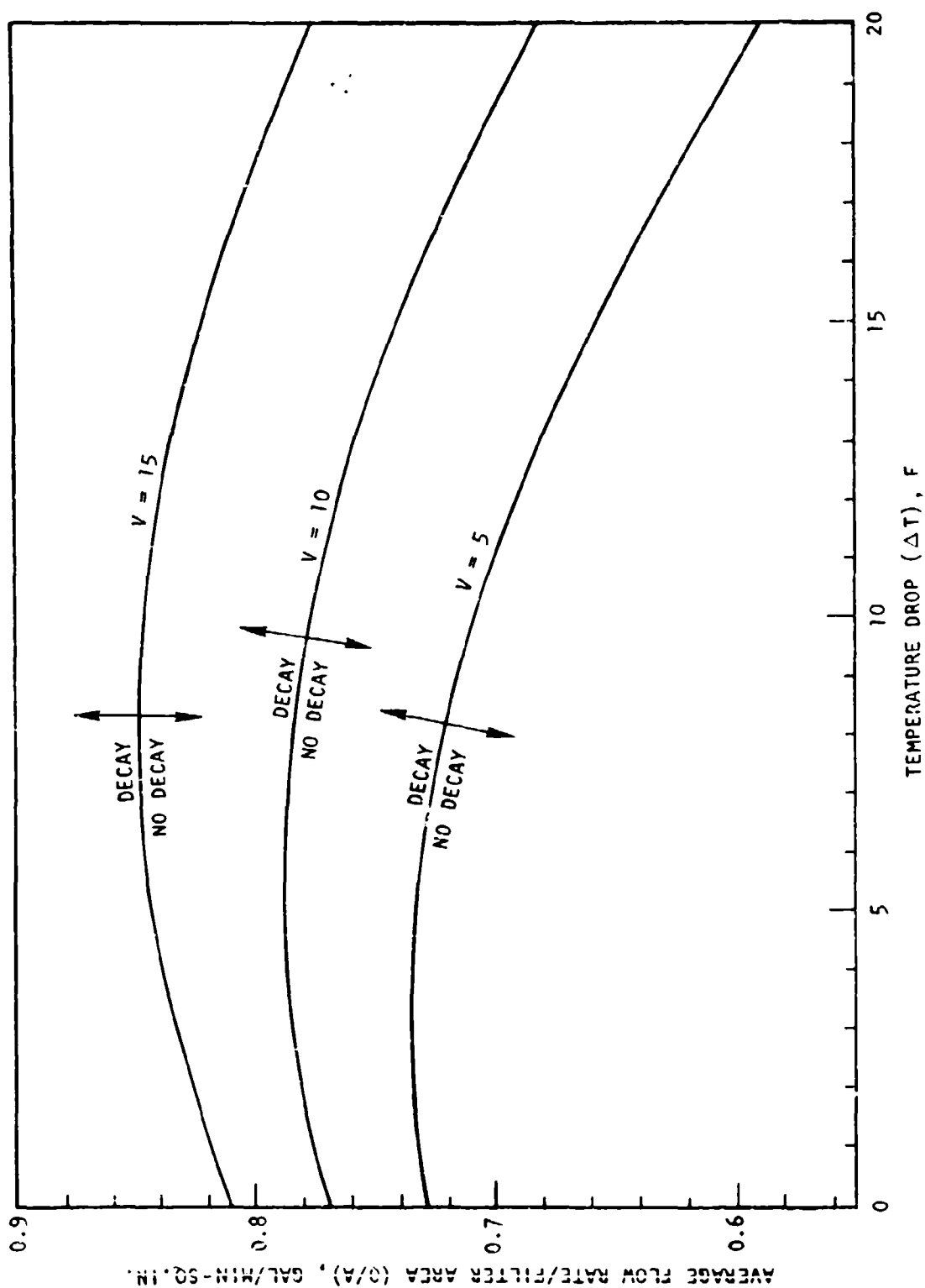


Figure 7. Functional Relationships at the Threshold (Regression Case 5)

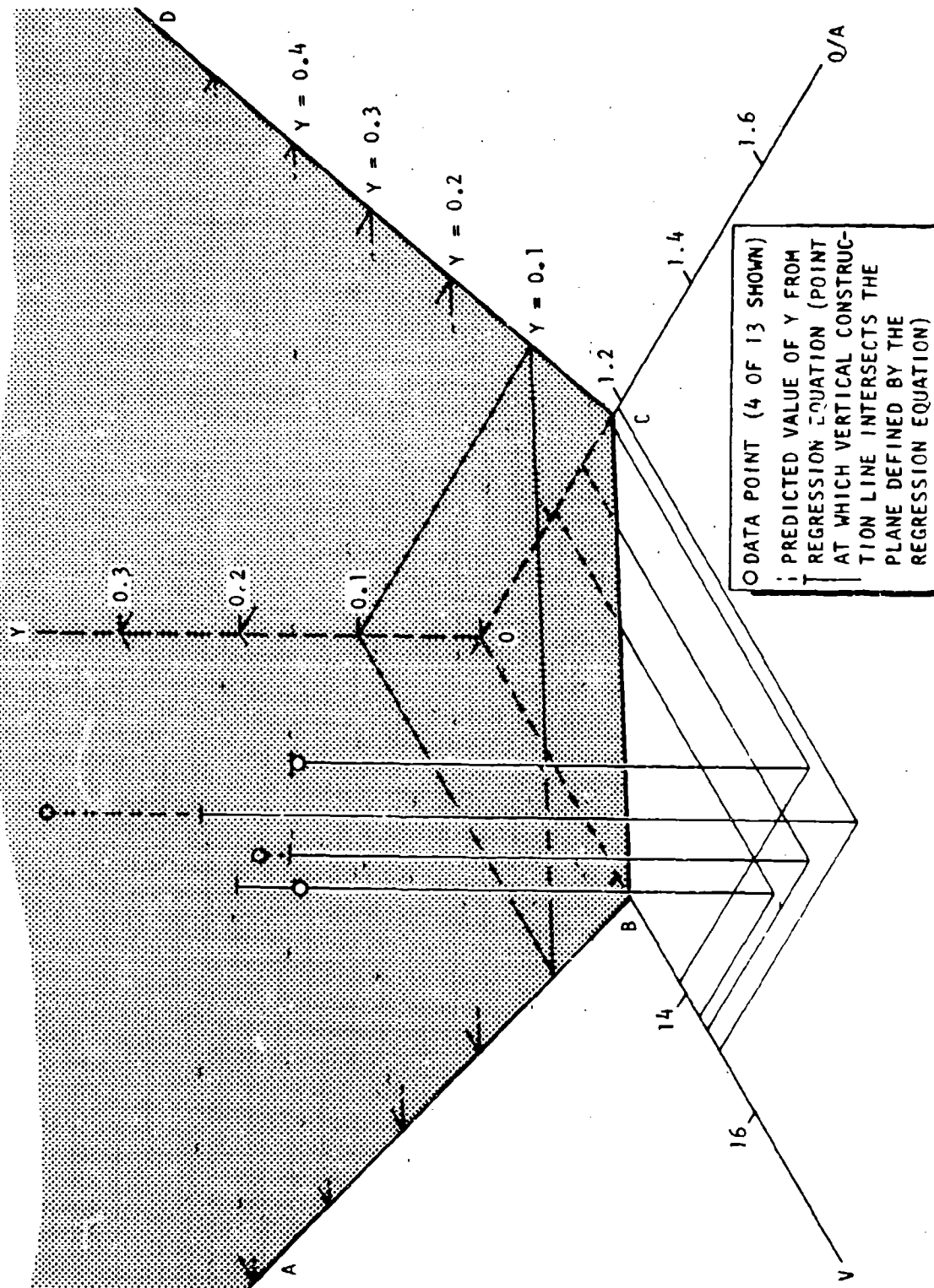


Figure 8. Example of Regression Plane and Threshold Effects (Regression Case 1)

The regression equation predicts that no flow decay will occur if the data point has V, Q/A coordinates that fall between line BC and the origin of the axes. These values of V, Q/A are below the threshold where the regression curve predicts flow decay. All other positive values of V and Q/A are at or above the threshold values and therefore flow decay would be expected.

EFFECTS OF INDEPENDENT VARIABLES

There are a number of trends and effects of the independent variables (all of which represent or are derived directly from the test conditions) which can be deduced from the test data and the results of the regression analyses performed on the data. The major effects are discussed in this subsection. The reader should continually keep in mind that extreme caution must be taken in extrapolating any effects and trends to different flow situations and conditions. The flow decay phenomenon is very complex and is affected by a large number of independent variables. The complexity is increased by the substantial interaction effects between the variables.

It is readily apparent that the effect of the parameter ΔT is, in general, positive. That is, flow decay is increased as the temperature drop is increased. This conclusion follows, e.g., from regression Cases 2, 5, and 7 (Table VII) for which the estimate of the ΔT coefficient is more than two standard deviations from zero. Case 4 also lends credence to this conjecture of a positive ΔT effect although the confidence level is only 0.62. The negative coefficients for Cases 3 and 8 are not significant because they fall well within the range of estimated errors. Case 6 is a little more subtle. The data indicate that the slope is positive ($0.002 + 0.011 = 0.013$) for saturated conditions, while negative ($0.002 - 0.011 = -0.009$) for unsaturated conditions. If the standard deviation of the -0.009 estimate is computed, however, it is found to be 0.01. Thus, again, the negative coefficient could be attributed to data scatter. Conversely, the positive coefficients of Cases 2, 5, and 7 cannot be attributed to data scatter and hence the conjecture of a positive ΔT effect is upheld.

The filter pore size effect on the other hand is generally negative, meaning that flow decay is decreased as the pore size of the filter is increased. This conclusion follows from Cases 5, 7, and 8 for which the hypothesis that the diameter coefficient is zero can be rejected with 0.98, 0.83, and 0.28 levels of confidence, respectively. Admittedly, the 0.28 level is very low but the trend is still apparent.

A possible anomaly in the effect of D may appear from close examination of Case 5. The estimate of the diameter effect for green N_2O_4 is $-0.061 - 0.063 = -0.124$, while for brown N_2O_4 it is $-0.061 + 0.063 = 0.002$. The standard deviations of these estimates are 0.04 and 0.016, respectively. Cases 7 and 8 on the other hand give estimates of -0.046 and -0.023 for the D coefficient for brown and green N_2O_4 , respectively. It is possible that the differences between these cases could be attributed to chance. However, it is more probable that the apparent anomaly is due to a modelling error. For example, there may be some cross effects due to the initial temperature; Cases 7 and 8 were analyzed assuming that there were none.

This could account for a difference since $T_0 = 75$ F for Case 5 while Cases 7 and 8 included data with various initial temperatures. Moreover, this argument is not limited to temperature although this is the only parameter that was held constant in Case 5 and allowed to vary in Cases 7 and 8. Cross effects between D and V or D and Q/A could also be present, causing biases to be introduced since the values for V and Q/A varied over somewhat different ranges among the different cases.

When the N_2O_4 is green, the data indicate that the effect of the filter history parameter, V, is generally negative (i.e., the rate of flow decay decreases as the total amount of propellant which has passed through the filter is increased). In particular, Cases 3 and 6 show this effect with high confidence levels (0.99 and 0.84, respectively). Case 8 lends supporting evidence with a 0.67 level of confidence. Case 5 also indicates a negative V effect when no-cross effects between V and GB are assumed. However, it is apparent from studying the brown N_2O_4 runs that there is a cross effect. In fact, Cases 4 and 7 indicate that the effect of parameter may be zero; both compute V coefficients well within $\sigma/4$ of zero. Case 1, on the other hand, indicates a significant positive effect for V when the N_2O_4 is brown and tested as received. This case must be considered cautiously, since it is based on a small number of data points and small errors in model assumptions can have a large effect.

In general, however, the investigations concerning the effect of V show that there is a definite change in the behavior of flow decay depending on whether green or brown N_2O_4 is being considered. Case 5 indicates that green N_2O_4 enhances flow decay because the GB coefficient is positive. However, this result must be scrutinized more carefully. It should be recalled that all the slopes were computed at specified nominal values (the mean values for the entire set of test data) of ΔT , Q/A, V, etc. This normalizing was done to make it possible to compare the different cases directly. The problem is that although these are nominal values for the entire data set, they may be atypical for a particular subset. The result is that when cross effects between the variables are assumed, the main effects become essentially an extrapolation of the data from its own nominal value to that of the prespecified ones. This may not cause any problems if the cross effects are small, but if they are large, erroneous results might be computed. This may be the situation for Case 5. A large cross effect is computed between GB and Q/A; the coefficient of GB (Q/A - 1.5) is 1.09. For this particular data set, the average value of Q/A is 1.1 and not 1.5 (the mean value for the total data set). Therefore, at the average Q/A, the effect of GB is $0.41 + 1.09(1.1 - 1.5) = -0.025$. The large coefficient for GB at Q/A = 1.5 may be the result of an extrapolation error in going from Q/A = 1.1 to Q/A = 1.5. The general trend at the nominal value of this data set is really negative. This negative effect means that green N_2O_4 experienced less flow decay than brown N_2O_4 . This conclusion is further substantiated by direct comparisons between sets of test data for which the only difference in the nine basic independent variables considered was between green and red-brown N_2O_4 .

In any case, it is certainly apparent that the GB variable has a large effect on the other variables. In essence, this means that the flow decay phenomenon behaves differently depending on whether green or brown N_2O_4 is used.

As another example, the effect of the temperature parameter also appears to be mixed depending upon whether or not green or brown N_2O_4 is used. For green N_2O_4 , Case 3 indicates a positive T_0 effect (with an estimated value of 0.005 for the coefficient and 0.53 confidence level of a non-zero coefficient). For brown N_2O_4 , Case 4 predicts a negative effect with a -0.0026 estimate and a 0.47 confidence level. Because of these relatively low confidence levels, these trends should be considered with caution. Cases 7 and 8, on the other hand, predict the same trends for the T_0 parameter but at higher confidence levels (-0.019 at 0.999 for brown N_2O_4 and +0.013 at 0.71 for green N_2O_4).

The iron saturation parameter appears to have a positive effect on flow decay for green N_2O_4 . Case 6 substantiates this by estimating 0.40 for the coefficient of SAT and giving a 0.87 confidence level that this coefficient is not zero. For brown N_2O_4 , it is only possible to make indirect comparisons between as-received and doped propellant. Regression Case 1 (brown N_2O_4 tested as received) gives a constant term of 0.81. This term is the flow decay predicted by the regression curve at the nominal values of $V = 15$, $Q/A = 1.5$, and $RL = 0$ (i.e., representing an average of the +1 and -1 values assigned to green and brown N_2O_4 , respectively).

Case 7 considers brown, saturated N_2O_4 . The regression curve predicts a value of $Y = 1.01$, when evaluated at the nominal parameter values specified by Case 1 (i.e., $D = 5$ microns, $\Delta T = 20$ F, $T_0 = 75$ F, $V = 15$ gal./sq in., $Q/A = 1.5$ gal./min-sq in.). Thus, there appears to be a net positive effect for the saturation parameter for brown N_2O_4 as well as green N_2O_4 . Case 4 might also be used to get a further estimate of the saturation parameter for brown N_2O_4 . The problem here is that Case 4 holds the diameter fixed at 10 microns, while Case 1 holds it fixed at 5 microns, and there is no direct estimate of the effect of this diameter difference for these two cases.

The regression curves indicate that the cooling rate parameter enhances flow decay. However, this effect is predicted only at very low confidence levels (Case 1 predicts a 0.003 coefficient and a 0.07 confidence level; Case 4 predicts a 0.12 coefficient and a 0.39 confidence level). These low levels are at least partly due to the fact that most of the runs with long cooldowns did not exhibit any significant flow decay; very few long cooldown runs with significant rates of flow decay were available for use in the regression analyses.

The last main independent variable that remains to be considered is the flow parameter Q/A . The effect of this parameter is generally positive (i.e., increasing Q/A increases flow decay). For green N_2O_4 , Cases 2, 3, 5, and 6 predict this effect with the very high confidence levels of 0.93, 0.97, 0.999, and 0.99, respectively. Case 8 predicts the same effect at a 0.60 level. For brown N_2O_4 , the data are more mixed. Case 1 predicts a positive effect for rapidly cooled N_2O_4 . This estimate is 0.88 with a standard deviation of 0.65. The estimate when a long cooldown is used is -0.50 with a standard deviation of 0.45. However, the results for this case are quite tenuous because of the small number of long cooldown tests for which flow decay was observed (only three points) and because of the large $RL \times Q/A$ cross effect.

A deviation of just one of the long cooldown points could have a very large effect on the predicted equation. Thus, modelling errors, e.g., not being able to identify all of the independent variables, could have a disastrous effect in this particular case.

Case 4 predicts a negative Q/A effect for brown N_2O_4 . Again, this is only at a relatively low level of confidence (0.55). The only high confidence level for the Q/A coefficient for brown N_2O_4 is given in Case 7. Here the estimate of the coefficient is 0.62 with a level of confidence that it is not zero of 0.99.

CONCLUSIONS AND RECOMMENDATIONS

Flow decay is a very complex phenomenon. There are many independent variables that affect the incidence and amount of flow decay. The effects of these parameters are generally not simple or independent of each other; they exhibit many interactions. In addition, there are often threshold effects for flow decay (i.e., an identifiable boundary between a range of variables for which no flow decay occurs and a range for which flow decay occurs in varying amounts). These thresholds are not sharp, and further depend upon the interactions of the independent variables.

A number of major effects of parameters on flow decay are outlined in the following paragraphs. The reader should keep in mind the complex nature of flow decay, and that these are only intended to be interim conclusions. Extreme caution must be taken in extrapolating effects and trends to different flow situations and conditions.

Increasing the filter pore size has a significant effect in preventing or reducing flow decay. It appears that flow decay will not occur, under the conditions tested during this program, with filters with nominal pore size at least as large as 40 microns. There were a few tests that might appear to be exceptions to this generalization, however, they are judged to be outliers. Decreasing the filter pore size, below its threshold, increases the rate of flow decay.

Keeping the temperature drop (from the initial propellant temperature) as small as possible is another important factor in preventing or minimizing flow decay. However, some cases of flow decay were observed with no temperature drop. There is often a non-zero temperature drop threshold below which no flow decay occurs. The amount or rate of flow decay increases as the temperature drop is increased above its threshold value. In some ranges of conditions, there is approximately a linear relationship between rate of flow decay and the temperature drop.

Decreasing the local velocity through the screen decreases the amount of flow decay, at least over the range tested during this program. The actual velocity-related parameter considered was Q/A , for which the range of values was about 0.7 to 4.7 gal/min-sq in. There appear to be strong interactions between Q/A and many of the other independent variables. Use of a filter Reynolds Number was not particularly advantageous in the data correlation efforts.

Comparisons between green and red-brown N_2O_4 were not without complications. There appeared to be a number of sizable differences in the effects of other variables between the two types of propellant, especially in the effects of Q/A , initial temperature, and the history parameter V . However, direct comparisons between sets of test data for matched conditions (i.e., sets for which the only difference in the nine basic independent variables considered was between green or red-brown N_2O_4) indicate that the green N_2O_4 tested exhibited somewhat lower rates of flow decay than did the red-brown N_2O_4 tested.

Rapid temperature drops (during flow) seem to cause somewhat more flow decay than occurs with the same temperature drop imposed slowly over a period of approximately 2 days. However, this effect was less important than the effects of such variables as T , D , and Q/A (all symbols are defined in the Nomenclature section).

The effect of initial temperature was less consistent between differing types of N_2O_4 when the propellants were doped with iron pentacarbonyl to ensure saturation. With green N_2O_4 , increasing T_0 increased flow decay, while the opposite trend was observed with red-brown N_2O_4 .

There was some difference between the amount of flow decay for the as-received propellants and for the propellants doped with a small amount (one saturation dose) of iron pentacarbonyl to ensure iron saturation. The differences seemed to be regular and more a matter of degree than substantive differences in type of flow decay behavior. Therefore, the data for doped N_2O_4 represent slightly conservative results as applied to the particular nitrogen tetroxide propellants that were used in the testing.

In addition to these general effects of the test conditions, more detailed information is contained in the body of this report which will be of value to individuals evaluating the potential of flow decay in operational nitrogen tetroxide systems. The following portions of the report should be particularly examined for this purpose: Tables III through VII and Fig. 4 through 8, the text accompanying these tables and figures, and Appendix A. For example, a user could select from these test results those which match closely the conditions for a system being considered; then, use the results and trends for those data to help in evaluating the flow decay potential for the application of interest.

This program was intended to be the initial step in a systematic engineering parametric study to establish the necessary engineering criteria for predicting flow decay in operational N_2O_4 systems. Although many complexities were encountered in this initial step, it was possible to develop experimental techniques and data analysis techniques to give statistically reproducible N_2O_4 flow decay data, and to deduce from the data the gross effects of major parameters. It is recommended that these efforts be continued to complete the systematic engineering parametric study. Subsequent efforts would build upon the results of this program and culminate in a design guide for predicting the occurrence or absence of flow decay and establishing design and system management criteria to avoid this problem.

The tests during this program were intended to investigate gross effects of those parameters that were expected to have the greatest influence on N_2O_4 flow decay. The recommended future tests would extend the work to delimit more precisely the ranges of these operating and design parameters under which flow decay will and will not occur, determine the effects of additional parameters (e.g., concentrations of NO , H_2O , and other impurities in the N_2O_4 , plus other types of flow constrictions), and investigate more thoroughly the interactions between various parameters. Completion of this systematic engineering study would form the basis for engineering control of this potential system failure mode by defining required system design criteria and/or system management concepts to avoid flow decay.

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6. Interim Final Report D180-12741-1, Application of Radioactive Tracer Techniques to Flow Decay Problems, The Boeing Company, Seattle, Washington, for the Jet Propulsion Laboratory, NASA Contract NAS7-779, December 1970.

APPENDIX: COMPUTER PRINTOUTS OF DERIVED RESULTS

The computer output given in this appendix lists for each test run values of several derived parameters for each of the possible pairings of the data points taken from the recorder traces. The particular data points are indicated by the two time values shown in the second column. The third and fourth columns list values of X and Y (defined, with other symbols, in the text and in the Nomenclature section). The fifth column lists values of W for each of the time values given in the second column. The abbreviated labels near the right side of the table give, in this order: (1) type of N_2O_4 ("B" for red-brown and "G" for green), (2) saturated ("S") with iron or tested as received (left blank), (3) cooled rapidly ("R") or over a long time ("L"), (4) the filter size (normal pore size in microns, followed by "F" or "H" to distinguish different filter areas; generally, the filters marked "H" had roughly one-half the area of filters marked "F", although actual areas were used in all calculations), (5) the initial temperature, and (6) the temperature drop. For Runs 1-38 and 160-165 calibration tests were not made for the clean filters. Consequently, w_1 , w_2 , Z, and $1/L$ are not defined. This fact is indicated by the abbreviation "N/A" in the appropriate locations in the tables.

RUN NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100w1/100w2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE NTG. CO/L. FILTER	TO (F)	DT (F)	
1	1.3/ 5.2	0.310	0.27	N/A / N/A	N/A	7	N/A	22.2	B	R 40F 74	0
1	1.3/11.0	1.577	0.153	N/A / N/A	N/A	15	N/A	21.9			
1	1.2/11.5	0.635	0.123	N/A / N/A	N/A	5	N/A	21.6			
2	2.3/ 7.2	1.121	0.223	N/A / N/A	N/A	-	N/A	114.5	B	R 50MF 74	0
2	2.3/11.5	0.449	0.043	N/A /	N/A	11	N/A	117.3			
2	1.2/11.5	-0.679	-0.153	N/A / N/A	N/A	5	N/A	116.2			
3	3.0/ 5.0	1.436	0.435	N/A / N/A	N/A	5	N/A	24.0	B	R 40F 74	0
3	3.0/ 3.0	0.370	0.102	N/A / N/A	N/A	10	N/A	23.6			
3	3.0/ 1.0	-0.524	-0.175	N/A / N/A	N/A	5	N/A	23.5			
4	2.1/ 5.1	-0.213	-0.073	N/A / N/A	N/A	4	N/A	130.0	B	R 50MF 74	0
4	2.1/ 3.1	0.744	0.124	N/A / N/A	N/A	3	N/A	127.3			
4	3.1/ 3.1	0.353	0.320	N/A / N/A	N/A	4	N/A	126.9			
5	1.0/ 5.4	-0.231	-0.064	N/A / N/A	N/A	3	N/A	24.2	B	R 40F 75	0
5	1.0/ 3.1	-0.210	-0.030	N/A / N/A	N/A	12	N/A	24.0			
5	3.4/ 3.1	0.071	0.125	N/A / N/A	N/A	5	N/A	23.7			
6	1.0/ 5.0	0.209	0.052	N/A / N/A	N/A	5	N/A	123.6	B	R 50MF 75	0
6	1.0/ 9.4	-1.065	-0.127	N/A / N/A	N/A	11	N/A	123.7			
6	5.0/ 9.4	-1.277	-0.290	N/A / N/A	N/A	6	N/A	126.7			
7	1.0/11.0	-1.436	-0.143	N/A / N/A	N/A	15	N/A	20.9	B	R 40F 74	0
8	1.0/11.0	-1.744	-0.174	N/A / N/A	N/A	12	N/A	112.9	B	R 50MF 74	0
9	1.4/ 4.2	0.123	0.044	N/A / N/A	N/A	4	N/A	19.4	B	R 40F 74	0
9	1.4/ 7.6	0.629	0.101	N/A / N/A	N/A	9	N/A	19.3			
9	4.2/ 7.6	0.507	0.143	N/A / N/A	N/A	5	N/A	19.1			
10	1.0/ 4.2	-0.524	-0.164	N/A / N/A	N/A	4	N/A	111.1	B	R 50MF 74	0
10	1.0/ 7.3	0.983	0.145	N/A / N/A	N/A	8	N/A	109.5			
10	4.2/ 7.3	1.439	0.417	N/A / N/A	N/A	4	N/A	108.8			
11	1.2/ 3.4	-0.019	-0.009	N/A / N/A	N/A	2	N/A	14.9	B	R 40F 74	0
11	1.2/ 6.2	-0.403	-0.081	N/A / N/A	N/A	5	N/A	14.8			
11	3.4/ 6.2	-0.383	-0.137	N/A / N/A	N/A	3	N/A	14.7			
12	1.2/ 3.4	-0.279	-0.127	N/A / N/A	N/A	2	N/A	94.1	B	R 50MF 74	0
12	1.2/ 6.6	-2.297	-0.425	N/A / N/A	N/A	5	N/A	93.9			
12	3.4/ 6.6	-2.012	-0.629	N/A / N/A	N/A	3	N/A	93.5			
13	2.2/ 9.6	-0.033	-0.005	N/A / N/A	N/A	8	N/A	13.3	B	R 40F 74	20
13	2.2/16.6	-0.345	-0.059	N/A / N/A	N/A	15	N/A	13.2			
13	9.6/16.6	-0.786	-0.112	N/A / N/A	N/A	7	N/A	13.0			

RUN NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE	WTC	COZL. FILTER	70 (F)	DT (F)
14	2.3/10.0	-0.627	-0.037	N/A / N/A	N/A	7	N/A	81.0	R	R 50MF	74	20
14	2.3/17.4	-1.002	-0.069	N/A / N/A	N/A	13	N/A	79.3				
14	10.0/17.4	-0.373	-0.050	N/A / N/A	N/A	7	N/A	79.9				
15	1.4/ 3.3	-0.270	-0.036	N/A / N/A	N/A	3	N/A	13.1	B	P 40F	74	32
15	1.4/16.4	-0.374	-0.053	N/A / N/A	N/A	17	N/A	12.9				
15	3.3/16.4	-0.502	-0.079	N/A / N/A	N/A	3	N/A	12.7				
16	4.2/11.2	0.161	0.023	N/A / N/A	N/A	7	N/A	90.0	R	R 50MF	74	32
16	4.2/16.2	-0.754	-0.063	N/A / N/A	N/A	12	N/A	79.5				
16	11.2/16.2	-0.916	-0.133	N/A / N/A	N/A	5	N/A	79.2				
17	7.2/15.3	-0.314	-0.037	N/A / N/A	N/A	3	N/A	12.6	R	P 40F	74	31
17	7.2/23.3	-0.304	-0.013	N/A / N/A	N/A	19	N/A	12.5				
17	7.2/31.0	-0.527	-0.022	N/A / N/A	N/A	25	N/A	12.3				
17	15.3/23.3	0.011	0.001	N/A / N/A	N/A	8	N/A	12.3				
17	15.3/31.0	-0.212	-0.014	N/A / N/A	N/A	16	N/A	12.2				
17	23.3/31.0	-0.222	-0.031	N/A / N/A	N/A	7	N/A	12.1				
18	3.0/12.2	1.449	0.157	N/A / N/A	N/A	9	N/A	1.5	R	R 5F	74	32
18	3.0/11.6	3.224	0.207	N/A / N/A	N/A	16	N/A	1.5				
18	3.0/32.2	7.700	0.254	N/A / N/A	N/A	29	N/A	1.4				
18	12.2/13.0	1.302	0.232	N/A / N/A	N/A	6	N/A	1.5				
18	12.2/32.2	6.363	0.317	N/A / N/A	N/A	20	N/A	1.4				
18	18.6/32.2	1.75	0.340	N/A / N/A	N/A	11	N/A	1.4				
19	1.3/ 4.4	0.777	0.237	N/A / N/A	N/A	3	N/A	1.5	B	P 5F	74	32
19	1.3/15.2	16.243	1.212	N/A / N/A	N/A	13	N/A	1.4				
19	1.3/22.3	29.335	1.423	N/A / N/A	N/A	19	N/A	1.3				
19	1.3/30.0	50.643	1.706	N/A / N/A	N/A	23	N/A	1.2				
19	4.4/15.2	15.531	1.444	N/A / N/A	N/A	11	N/A	1.4				
19	4.4/22.3	29.339	1.595	N/A / N/A	N/A	17	N/A	1.3				
19	4.4/30.0	50.264	1.963	N/A / N/A	N/A	21	N/A	1.2				
19	15.2/22.3	16.787	2.143	N/A / N/A	N/A	7	N/A	1.3				
19	15.2/30.0	41.077	2.775	N/A / N/A	N/A	12	N/A	1.1				
19	22.3/30.0	29.613	2.113	N/A / N/A	N/A	6	N/A	1.1				
20	2.6/ 3.2	0.393	0.177	N/A / N/A	N/A	6	N/A	1.8	B	P 5F	74	21
20	2.6/13.0	0.479	0.046	N/A / N/A	N/A	12	N/A	1.9				
20	3.2/13.0	-0.519	-0.103	N/A / N/A	N/A	5	N/A	1.7				
21	2.0/ 6.0	0.323	0.206	N/A / N/A	N/A	4	N/A	1.6	R	R 5F	74	31
21	2.0/12.2	1.433	0.146	N/A / N/A	N/A	11	N/A	1.6				
21	6.0/12.2	0.671	0.103	N/A / N/A	N/A	7	N/A	1.6				
22	1.0/ 7.3	1.524	0.224	N/A / N/A	N/A	3	N/A	1.8	B	R 5F	74	19
22	1.0/13.0	2.275	0.190	N/A / N/A	N/A	13	N/A	1.9				
22	7.3/13.0	0.763	0.147	N/A / N/A	N/A	6	N/A	1.7				

RUN No	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100M1/100M2 (%)	100Z (%/MIN)	V (GAL/TM2)	1/L (GAL/TM2)	RE FILTER	MTG COOL.	TO (F)	DT (F)
23	1.6/ 7.0	2.534	0.469	N/A / N/A	N/A	6	N/A	1.6	B	R 5F	74 32
23	1.6/14.2	3.430	0.203	N/A / N/A	N/A	14	N/A	1.6			
23	7.0/14.2	0.398	0.121	N/A / N/A	N/A	1	N/A	1.6			
24	0.3/ 4.4	3.377	0.330	N/A / N/A	N/A	4	N/A	1.3	B	R 5F	74 19
24	0.3/ 3.4	4.273	0.437	N/A / N/A	N/A	15	N/A	1.3			
24	0.3/13.4	3.479	0.455	N/A / N/A	N/A	14	N/A	1.7			
24	4.0/ 3.4	1.336	0.247	N/A / N/A	N/A	6	N/A	1.7			
24	4.0/13.4	2.579	0.274	N/A / N/A	N/A	10	N/A	1.7			
24	3.4/13.4	1.253	0.315	N/A / N/A	N/A	4	N/A	1.7			
25	1.4/ 3.0	3.065	0.730	N/A / N/A	N/A	5	N/A	1.6	B	R 5F	74 32
25	1.4/13.0	3.311	0.637	N/A / N/A	N/A	5	N/A	1.6			
25	1.4/14.4	3.051	0.619	N/A / N/A	N/A	14	N/A	1.6			
25	5.0/10.0	2.336	0.667	N/A / N/A	N/A	5	N/A	1.6			
25	5.0/14.4	3.144	0.584	N/A / N/A	N/A	9	N/A	1.5			
25	10.0/14.4	2.274	0.517	N/A / N/A	N/A	5	N/A	1.5			
26	0.6/ 4.4	1.979	0.521	N/A / N/A	N/A	4	N/A	1.3	B	R 5F	74 19
26	0.6/ 3.4	3.603	0.410	N/A / N/A	N/A	10	N/A	1.3			
26	0.6/13.4	3.042	0.394	N/A / N/A	N/A	14	N/A	1.3			
26	4.4/ 3.4	1.662	0.332	N/A / N/A	N/A	6	N/A	1.3			
26	4.4/13.4	3.126	0.347	N/A / N/A	N/A	10	N/A	1.7			
26	3.4/13.4	1.487	0.372	N/A / N/A	N/A	4	N/A	1.7			
27	2.2/ 6.6	1.920	0.436	N/A / N/A	N/A	5	N/A	1.6	B	R 5F	74 33
27	2.2/10.6	3.226	0.384	N/A / N/A	N/A	9	N/A	1.6			
27	2.2/13.6	6.176	0.512	N/A / N/A	N/A	12	N/A	1.6			
27	5.0/10.6	1.331	0.333	N/A / N/A	N/A	4	N/A	1.6			
27	6.6/13.6	4.339	0.620	N/A / N/A	N/A	3	N/A	1.6			
27	10.6/13.6	3.043	1.016	N/A / N/A	N/A	3	N/A	1.5			
28	0.3/ 5.6	1.720	0.353	N/A / N/A	N/A	5	N/A	1.3	B	R 5F	74 19
28	0.3/10.6	4.693	0.489	N/A / N/A	N/A	11	N/A	1.7			
28	0.3/13.2	6.167	0.460	N/A / N/A	N/A	15	N/A	1.7			
28	5.6/10.6	3.025	0.630	N/A / N/A	N/A	5	N/A	1.7			
28	5.6/13.2	4.525	0.526	N/A / N/A	N/A	9	N/A	1.7			
28	10.6/13.2	1.547	0.407	N/A / N/A	N/A	4	N/A	1.7			
29	1.6/ .2	2.326	0.640	N/A / N/A	N/A	4	N/A	1.6	B	R 5F	74 34
29	1.6/10.4	6.577	0.747	N/A / N/A	N/A	9	N/A	1.5			
29	1.6/14.0	9.014	0.727	N/A / N/A	N/A	13	N/A	1.5			
29	5.2/10.4	4.352	0.337	N/A / N/A	N/A	6	N/A	1.5			
29	5.2/14.0	6.347	0.773	N/A / N/A	N/A	9	N/A	1.5			
29	10.4/14.0	2.609	0.725	N/A / N/A	N/A	4	N/A	1.5			
30	2.0/ 4.6	1.132	0.453	N/A / N/A	N/A	3	N/A	1.9	B	R 5F	74 19
30	2.0/ 3.3	3.089	0.451	N/A / N/A	N/A	3	N/A	1.9			
30	2.0/13.3	5.036	0.427	N/A / N/A	N/A	14	N/A	1.9			
30	4.6/ 3.3	1.900	0.452	N/A / N/A	N/A	5	N/A	1.8			
30	4.6/13.3	3.391	0.423	N/A / N/A	N/A	11	N/A	1.9			
30	3.3/13.3	2.030	0.406	N/A / N/A	N/A	6	N/A	1.8			

RUN NO.	T1/T2 (H:MM)	100X (%)	100Y (%/MIN)	100w1/100w2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE MTG. COOL. FILTER	TO DT (F) (F)
31	5.0/ 6.2	1.300	0.750	N/A / N/A	N/A	3	N/A	1.6 B R SF	74 34
31	5.0/10.0	5.706	0.331	N/A / N/A	N/A	7	N/A	1.6	
31	5.0/14.0	3.000	0.166	N/A / N/A	N/A	11	N/A	1.6	
31	5.0/18.0	3.314	1.074	N/A / N/A	N/A	4	N/A	1.6	
31	5.2/14.0	7.130	0.921	N/A / N/A	N/A	9	N/A	1.6	
31	10.0/14.0	3.000	0.375	N/A / N/A	N/A	4	N/A	1.5	
32	2.0/ 5.4	1.034	0.532	N/A / N/A	N/A	4	N/A	1.3 B R SF	74 19
32	2.0/ 9.6	2.523	0.333	N/A / N/A	N/A	9	N/A	1.3	
32	2.0/13.4	4.321	0.423	N/A / N/A	N/A	13	N/A	1.7	
32	5.0/ 9.6	0.304	0.146	N/A / N/A	N/A	4	N/A	1.3	
32	5.3/13.4	2.834	0.331	N/A / N/A	N/A	9	N/A	1.7	
32	9.6/13.4	2.303	0.613	N/A / N/A	N/A	4	N/A	1.7	
33	1.0/ 5.0	4.304	1.210	N/A / N/A	N/A	4	N/A	1.5 B R SF	74 33
33	1.0/ 9.2	0.130	1.116	N/A / N/A	N/A	3	N/A	1.5	
33	1.0/13.6	13.142	1.073	N/A / N/A	N/A	13	N/A	1.5	
33	5.0/ 9.2	4.504	1.072	N/A / N/A	N/A	4	N/A	1.5	
33	5.0/13.6	3.701	1.012	N/A / N/A	N/A	9	N/A	1.5	
33	3.2/13.6	4.336	0.333	N/A / N/A	N/A	4	N/A	1.4	
34	1.0/ 5.0	3.510	0.373	N/A / N/A	N/A	5	N/A	1.9 B R SF	74 19
34	1.0/ 9.4	6.114	0.723	N/A / N/A	N/A	10	N/A	1.9	
34	1.0/13.6	3.562	0.630	N/A / N/A	N/A	15	N/A	1.9	
34	5.0/ 9.4	2.633	0.613	N/A / N/A	N/A	5	N/A	1.9	
34	5.0/13.6	5.230	0.600	N/A / N/A	N/A	10	N/A	1.3	
34	3.2/13.6	2.607	0.021	N/A / N/A	N/A	5	N/A	1.8	
35	0.4/ 4.2	7.317	1.925	N/A / N/A	N/A	4	N/A	1.6 B R SF	74 33
35	0.4/ 3.6	14.746	1.793	N/A / N/A	N/A	9	N/A	1.6	
35	0.4/13.0	21.936	1.741	N/A / N/A	N/A	13	N/A	1.5	
35	5.2/ 3.6	3.016	1.622	N/A / N/A	N/A	5	N/A	1.5	
35	4.2/13.0	15.773	1.732	N/A / N/A	N/A	9	N/A	1.5	
35	3.6/13.0	3.433	1.917	N/A / N/A	N/A	4	N/A	1.4	
36	1.0/ 5.4	3.323	0.756	N/A / N/A	N/A	5	N/A	1.6 B R SF	75 20
36	1.0/10.4	6.539	0.702	N/A / N/A	N/A	10	N/A	1.6	
36	1.0/14.2	9.336	0.631	N/A / N/A	N/A	16	N/A	1.6	
36	3.4/10.4	3.333	0.677	N/A / N/A	N/A	5	N/A	1.6	
36	5.4/16.2	6.473	0.593	N/A / N/A	N/A	11	N/A	1.6	
36	10.4/16.2	3.133	0.551	N/A / N/A	N/A	6	N/A	1.6	
37	1.0/ 5.4	12.327	2.371	N/A / N/A	N/A	5	N/A	1.2 B R SF	75 34
37	1.0/11.0	22.023	2.217	N/A / N/A	N/A	3	N/A	1.2	
37	1.0/15.0	31.361	2.166	N/A / N/A	N/A	12	N/A	1.1	
37	5.0/11.0	11.334	2.301	N/A / N/A	N/A	4	N/A	1.1	
37	5.4/16.0	21.325	2.273	N/A / N/A	N/A	7	N/A	1.1	
37	11.0/16.0	12.104	2.421	N/A / N/A	N/A	4	N/A	1.0	
38	1.6/ 3.0	5.020	0.673	N/A / N/A	N/A	7	N/A	1.5 B R SF	74 19
38	1.6/10.0	3.539	0.593	N/A / N/A	N/A	14	N/A	1.5	
38	1.6/22.0	11.675	0.572	N/A / N/A	N/A	19	N/A	1.5	
38	3.0/10.0	3.705	0.329	N/A / N/A	N/A	7	N/A	1.5	
38	3.0/22.0	7.007	0.539	N/A / N/A	N/A	12	N/A	1.5	
38	16.0/22.0	3.429	0.371	N/A / N/A	N/A	6	N/A	1.4	

RUN NO.	T1/T2 MIN	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE MTC	COOL. FILTER	TO (F)	DT (F)
39	0.6/ 3.4	-0.148	-0.053	-0.40/ -0.41	-0.002	3	999999	2.0	BS R 5F	75	0
39	0.6/ 6.2	0.408	0.073	-0.40/ 0.00	0.072	6	1513	1.9			
39	3.4/ 6.2	0.556	0.198	-0.41/ 0.00	0.147	3	562	1.9			
40	0.8/ 3.4	1.333	0.513	-0.39/ 0.79	0.456	3	224	4.1	BS R 10F	75	0
40	0.8/ 6.2	1.075	0.199	-0.39/ 0.40	0.148	6	571	4.0			
40	3.4/ 6.2	-0.261	-0.093	0.79/ 0.40	-0.138	3	999999	4.0			
41	0.6/ 2.6	0.300	0.150	0.37/ 0.74	0.135	2	320	2.2	BS R 5F	75	0
41	0.6/ 6.6	0.636	0.106	0.37/ 1.12	0.126	7	1151	2.1			
41	2.6/ 6.6	0.337	0.034	0.74/ 1.12	0.095	5	1443	2.1			
42	1.4/ 4.4	0.322	0.174	0.00/ 0.55	0.120	4	726	4.4	BS R 10F	75	0
42	1.4/ 7.0	0.313	0.163	0.00/ 1.09	0.195	7	770	4.4			
42	4.4/ 7.0	0.392	0.151	0.55/ 1.09	0.281	3	325	4.4			
43	2.4/ 7.2	1.391	0.230	2.53/ 4.06	0.308	6	422	1.9	BS R 5F	75	21
43	2.4/13.6	3.879	0.346	2.53/ 6.67	0.365	13	348	1.8			
43	7.2/13.6	2.523	0.394	4.06/ 6.67	0.407	7	303	1.8			
44	0.2/ 5.0	1.735	0.299	1.11/ 2.95	0.319	7	406	3.7	BS R 10F	75	21
44	0.2/14.0	3.510	0.254	1.11/ 4.51	0.246	16	471	3.7			
44	5.0/14.0	1.306	0.226	2.95/ 4.51	0.194	9	525	3.7			
45	1.0/ 7.2	4.739	0.772	9.32/ 14.08	0.337	7	159	1.6	BS R 5F	74	33
45	1.0/14.3	13.310	0.964	9.32/ 21.55	0.350	15	123	1.5			
45	7.2/14.3	3.350	1.178	14.08/ 21.55	0.384	3	38	1.5			
46	1.0/ 6.0	2.390	0.478	4.92/ 7.20	0.455	6	248	3.3	BS R 10F	74	33
46	1.0/12.2	6.656	0.594	4.92/ 11.23	0.567	12	196	3.2			
46	1.0/13.0	11.931	0.702	4.92/ 16.30	0.689	18	162	3.1			
46	6.0/12.2	4.369	0.705	7.20/ 11.23	0.658	7	163	3.2			
46	6.0/13.0	9.774	0.315	7.20/ 16.30	0.758	13	138	3.1			
46	12.2/13.0	5.652	0.374	11.23/ 16.30	0.365	6	113	3.0			
47	1.4/ 3.4	4.331	0.690	25.53/ 29.13	0.506	6	163	1.3	BS R 5F	74	21
47	1.4/17.0	9.060	0.521	25.53/ 32.23	0.429	13	190	1.3			
47	1.4/24.2	12.657	0.566	25.53/ 34.66	0.388	18	194	1.2			
47	3.4/17.0	4.444	0.517	29.13/ 32.23	0.566	7	208	1.2			
47	3.4/24.2	3.223	0.520	29.13/ 34.66	0.360	12	202	1.2			
47	17.0/24.2	3.355	0.549	32.23/ 34.66	0.330	5	137	1.2			
48	2.2/ 3.2	3.074	0.512	15.32/ 17.95	0.438	5	205	2.8	BS R 10F	74	21
48	2.2/16.2	6.175	0.441	15.32/ 20.60	0.377	12	234	2.7			
48	2.2/24.2	8.449	0.394	15.32/ 22.17	0.312	19	264	2.7			
48	3.2/16.2	3.199	0.400	17.95/ 20.60	0.332	7	253	2.7			
48	3.2/24.2	5.545	0.347	17.95/ 22.17	0.264	13	237	2.6			
48	16.2/24.2	2.424	0.303	20.60/ 22.17	0.197	7	322	2.6			

HM NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE	MTG. COOL. FILTER	TO (F)	DT (F)
49	1.4/ 9.2	3.809	1.104	35.32/ 41.39	0.714	6	107	1.1	BS R 5F	74	33
49	1.4/16.4	15.263	1.013	35.32/ 45.65	0.655	11	112	1.1			
49	1.4/24.0	21.670	0.959	35.32/ 49.64	0.611	16	115	1.0			
49	9.2/16.4	7.231	1.011	41.39/ 45.65	0.592	5	109	1.0			
49	9.2/24.0	14.291	0.966	41.39/ 49.64	0.557	10	110	1.0			
49	16.4/24.0	7.561	0.995	45.65/ 49.64	0.525	5	103	1.0			
50	1.0/ 7.6	5.003	0.759	22.45/ 26.32	0.546	6	144	2.4	BS R 10F	74	33
50	1.0/16.0	10.330	0.725	22.45/ 30.30	0.557	12	147	2.4			
50	1.0/23.4	16.456	0.736	22.45/ 36.13	0.563	13	141	2.3			
50	7.6/16.0	6.132	0.736	26.32/ 30.30	0.534	7	141	2.3			
50	7.6/23.4	12.051	0.763	26.32/ 36.13	0.561	12	133	2.3			
50	16.0/23.4	6.256	0.345	30.30/ 36.13	0.592	6	117	2.2			
51	1.6/ 3.4	0.399	0.222	-1.00/ -0.50	0.276	2	408	3.3	BS R 10F	100	19
51	1.6/ 7.4	-0.739	-0.127	-1.00/ -1.54	-0.093	5	999999	3.3			
51	3.4/ 7.4	-1.142	-0.286	-0.50/ -1.54	-0.259	4	999999	3.3			
52	2.2/ 4.2	-0.391	-0.196	-1.53/ -2.06	-0.266	2	999999	3.6	BS R 10F	100	10
52	2.2/ 7.4	-0.001	-0.000	-1.53/ -1.57	-0.008	5	999999	3.4			
52	4.2/ 7.4	0.389	0.121	-2.06/ -1.57	0.153	3	723	3.4			
53	1.0/ 4.0	0.274	0.091	-0.69/ -0.35	0.114	4	1432	4.8	BS R 10F	100	19
53	1.0/ 8.0	0.475	0.063	-0.69/-14.52	-1.975	9	1915	4.8			
53	4.0/ 8.0	0.202	0.050	-0.35/-14.52	-3.542	5	2562	4.7			
54	1.3/ 4.4	0.131	0.070	0.63/ 1.03	0.134	3	1299	5.1	BS R 10F	100	10
54	1.3/ 3.4	0.199	0.030	0.63/ 1.04	0.054	9	4363	5.0			
54	4.4/ 3.4	0.013	0.004	1.03/ 1.04	0.003	5	23471	5.0			
55	1.3/ 3.0	0.216	0.180	-0.36/ 0.00	0.303	2	633	4.3	BS R 10F	100	30
55	1.3/ 6.4	0.353	0.077	-0.36/ 0.37	0.159	6	1616	4.2			
55	1.3/ 9.5	0.634	0.032	-0.36/ 0.74	0.143	10	1496	4.2			
55	1.3/13.2	0.670	0.059	-0.36/ 1.12	0.130	14	2079	4.2			
55	3.0/ 6.4	0.137	0.040	0.00/ 0.37	0.103	4	3060	4.2			
55	3.0/ 9.5	0.419	0.065	0.00/ 0.74	0.114	3	1903	4.2			
55	3.0/13.2	0.456	0.045	0.00/ 1.12	0.110	12	2727	4.2			
55	6.4/ 9.5	0.233	0.091	0.37/ 0.74	0.120	4	1339	4.2			
55	6.4/13.2	0.319	0.047	0.37/ 1.12	0.111	3	2533	4.2			
55	9.5/13.2	0.036	0.010	0.74/ 1.12	0.103	4	12214	4.1			
56	1.2/ 7.2	0.430	0.072	0.72/ 1.46	0.123	7	1744	4.1	BS R 10F	100	36
56	1.2/12.6	0.343	0.074	0.72/ 1.36	0.100	14	1672	4.0			
56	7.2/12.6	0.415	0.077	1.46/ 1.36	0.074	7	1592	4.0			

RUN NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE	NTC, CO2L, FILTER	TU DT (F) (P)
57	2.1/ 9.2	0.204	0.118	3.15/ 3.95	0.118	8	971	3.7	BS R 10F	100 36
57	2.4/17.6	2.224	0.146	3.15/ 5.55	0.158	17	776	3.6		
57	2.4/21.4	2.194	0.115	3.15/ 5.24	0.110	21	977	3.6		
57	2.4/31.4	4.170	0.144	3.15/ 7.26	0.142	31	777	3.6		
57	9.2/17.6	1.352	0.170	3.95/ 5.55	0.191	9	632	3.6		
57	9.2/21.4	1.402	0.115	3.95/ 5.24	0.106	13	976	3.6		
57	9.2/31.4	3.304	0.153	3.95/ 7.26	0.149	24	726	3.5		
57	17.6/21.4	-0.030	-0.008	5.55/ 5.24	-0.083	4	999999	3.5		
57	17.6/31.4	1.991	0.144	5.55/ 7.26	0.123	15	761	3.5		
57	21.4/31.4	2.020	0.202	5.24/ 7.26	0.202	11	540	3.5		
58	3.8/11.0	3.125	0.434	9.82/ 12.85	0.420	8	296	3.8	BS R 10F	99 35
58	3.8/16.2	5.441	0.439	9.82/ 14.93	0.412	14	298	3.8		
58	3.8/21.4	8.182	0.465	9.82/ 17.24	0.421	10	289	3.7		
58	3.8/26.6	10.095	0.443	9.82/ 18.97	0.401	25	290	3.7		
58	11.0/16.2	2.390	0.460	12.85/ 14.93	0.401	6	272	3.7		
58	11.0/21.4	5.220	0.502	12.85/ 17.24	0.423	12	247	3.7		
58	11.0/26.6	7.194	0.461	12.85/ 18.97	0.392	17	266	3.6		
58	16.2/21.4	2.898	0.587	14.93/ 17.24	0.444	6	219	3.6		
58	16.2/26.6	4.921	0.473	14.93/ 18.97	0.398	11	256	3.6		
58	21.4/26.6	2.083	0.401	17.24/ 18.97	0.332	6	299	3.6		
59	0.4/ 7.4	2.012	0.287	18.24/ 19.55	0.187	8	485	4.4	BS R 10F	100 10
59	0.4/18.2	4.418	0.243	18.24/ 21.47	0.182	20	565	4.3		
59	0.4/27.2	3.124	0.117	18.24/ 20.65	0.090	30	1185	4.3		
59	0.4/29.0	3.836	0.134	18.24/ 20.90	0.093	32	1030	4.3		
59	7.4/18.2	2.455	0.227	19.55/ 21.47	0.178	12	607	4.3		
59	7.4/27.2	1.135	0.057	19.55/ 20.65	0.055	22	2410	4.3		
59	7.4/29.0	1.862	0.086	19.55/ 20.90	0.062	24	1603	4.3		
59	18.2/27.2	-1.354	-0.150	21.47/ 20.65	-0.092	10	999999	4.3		
59	18.2/29.0	-0.609	-0.056	21.47/ 20.90	-0.053	12	999999	4.3		
59	27.2/29.0	0.735	0.408	20.65/ 20.90	0.142	2	335	4.3		
60	3.0/ 7.5	0.349	0.211	1.41/ 2.49	0.241	12	1332	5.6	BS R 5H	100 1
60	3.0/12.0	1.243	0.138	1.41/ 2.87	0.162	25	2023	5.6		
60	3.0/16.5	2.021	0.150	1.41/ 3.62	0.164	37	1849	5.5		
60	3.0/20.7	3.245	0.183	1.41/ 5.09	0.208	48	1497	5.5		
60	7.5/12.0	0.297	0.066	2.49/ 2.87	0.084	12	4195	5.5		
60	7.5/16.5	1.082	0.120	2.49/ 3.62	0.126	24	2278	5.5		
60	7.5/20.7	2.317	0.176	2.49/ 5.09	0.197	35	1546	5.4		
60	12.0/16.5	0.788	0.175	2.87/ 3.62	0.168	12	1565	5.4		
60	12.0/20.7	2.027	0.233	2.87/ 5.09	0.256	23	1158	5.4		
60	16.5/20.7	1.249	0.237	3.62/ 5.09	0.349	11	399	5.3		

RUN NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE NT% COOL. MLTER	TO BT (F)(F)
61	1.0/ 3.6	0.921	0.354	7.81/ 8.42	0.238	5	762	4.8 BS R 5H	100 10
61	1.0/10.6	3.056	0.313	7.81/ 10.13	0.247	24	843	4.8	
61	1.0/13.8	5.304	0.326	7.81/ 12.73	0.276	43	812	4.7	
61	1.0/23.6	8.197	0.297	7.81/ 14.96	0.259	66	878	4.6	
61	3.6/10.6	2.155	0.303	8.42/ 10.13	0.251	17	876	4.8	
61	3.6/13.8	4.323	0.324	8.42/ 12.73	0.283	37	820	4.7	
61	3.6/23.6	7.343	0.294	8.42/ 14.96	0.262	60	892	4.6	
61	10.6/13.8	2.334	0.346	10.13/ 12.73	0.310	20	764	4.7	
61	10.6/23.6	5.303	0.295	10.13/ 14.96	0.266	43	884	4.6	
61	13.8/23.6	2.541	0.259	12.73/ 14.96	0.223	23	939	4.5	
62	1.3/ 5.2	1.774	0.522	16.43/ 17.77	0.393	8	545	4.6 BS R 5H	100 10
62	1.3/10.6	4.355	0.495	16.43/ 19.79	0.332	21	563	4.5	
62	1.3/13.4	5.259	0.453	16.43/ 20.42	0.343	27	619	4.5	
62	5.2/10.6	2.627	0.437	17.77/ 19.79	0.374	13	574	4.5	
62	5.2/13.4	3.548	0.433	17.77/ 20.42	0.323	19	644	4.5	
62	10.6/13.4	0.945	0.333	19.79/ 20.42	0.223	6	317	4.4	
63	1.0/ 4.6	1.080	0.300	2.60/ 3.51	0.253	8	761	3.4 BS R 5H	50 0
63	1.0/ 7.4	1.432	0.224	2.60/ 3.56	0.150	14	1014	3.4	
63	4.6/ 7.4	0.355	0.127	3.51/ 3.56	0.017	6	1767	3.3	
64	1.2/ 4.8	-1.093	-0.304	0.53/ -0.54	-0.296	3	999999	2.6 BS R 10F	50 0
64	1.2/ 7.8	-0.761	-0.115	0.53/ -0.56	-0.163	6	999999	2.6	
64	4.8/ 7.8	0.328	0.109	-0.54/ -0.55	-0.003	3	776	2.6	
65	1.0/ 5.2	2.872	0.634	6.50/ 9.27	0.660	4	162	1.5 BS R 5F	50 5
65	1.0/10.3	5.831	0.595	6.50/ 12.00	0.561	10	134	1.5	
65	5.2/10.3	3.046	0.544	9.27/ 12.00	0.487	6	199	1.5	
66	1.3/ 6.8	0.369	0.074	0.93/ 1.43	0.099	5	1249	2.7 BS R 10F	50 5
66	1.3/11.6	0.929	0.095	0.93/ 1.93	0.102	9	969	2.7	
66	6.8/11.6	0.561	0.117	1.43/ 1.93	0.103	4	781	2.7	
67	1.6/ 3.4	6.419	0.944	15.57/ 20.97	0.793	14	252	2.9 BS R 5H	50 10
67	1.6/14.2	11.015	0.874	15.57/ 24.70	0.724	25	263	2.3	
67	3.4/14.2	4.911	0.847	20.97/ 24.70	0.644	11	269	2.3	
68	1.3/ 3.4	1.233	0.188	2.59/ 4.17	0.239	6	463	2.4 BS R 10F	50 10
68	1.3/14.2	3.102	0.250	2.59/ 5.79	0.253	10	342	2.4	
68	3.4/14.2	1.887	0.325	4.17/ 5.79	0.280	5	260	2.4	
69	2.0/ 6.0	6.177	1.544	30.66/ 34.89	1.059	7	173	2.6 BS R 5H	50 16
69	2.0/10.3	12.527	1.423	30.66/ 39.22	0.973	16	133	2.5	
69	2.0/15.0	17.976	1.333	30.66/ 43.01	0.950	23	184	2.4	
69	6.0/10.3	6.763	1.410	34.89/ 39.22	0.902	8	181	2.4	
69	6.0/15.0	12.578	1.307	34.89/ 43.01	0.902	15	173	2.4	
69	10.3/15.0	6.230	1.483	39.22/ 43.01	0.901	7	163	2.3	

RUN NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100u1/100u2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE	MTG. COOL. FILTER	10 DT (I) (F)
70	2.6/ 6.0	1.192	0.351	4.33/ 6.47	0.439	3	233	2.4	BS R 10F	50 16
70	2.6/11.6	2.202	0.245	4.33/ 7.50	0.231	3	367	2.4		
70	2.6/15.0	3.411	0.275	4.33/ 8.54	0.233	11	328	2.3		
70	3.0/11.6	1.022	0.133	5.47/ 7.50	0.134	5	439	2.3		
70	6.0/15.0	2.246	0.250	5.47/ 8.54	0.231	3	356	2.3		
70	11.3/15.0	1.236	0.364	7.50/ 8.54	0.307	3	241	2.3		
71	1.3/ 5.6	11.153	2.935	0.00/ 0.00	0.000	7	0	2.6	BS R 5H	50 16
71	1.3/10.2	24.276	2.890	0.00/ 0.00	0.000	15	0	2.5		
71	1.3/12.2	28.553	2.745	0.00/ 0.00	0.000	18	0	2.4		
71	5.6/10.2	14.770	3.211	0.00/ 0.00	0.000	8	0	2.3		
71	5.6/12.2	19.534	2.967	0.00/ 0.00	0.000	11	0	2.3		
71	10.2/12.2	5.343	2.824	0.00/ 0.00	0.000	3	0	2.1		
72	2.4/ 5.0	1.376	0.529	6.54/ 7.66	0.432	3	222	3.0	BS R 10F	50 16
72	2.4/ 9.0	2.603	0.394	6.54/ 8.81	0.345	7	297	3.0		
72	2.4/12.2	3.242	0.351	6.54/ 9.58	0.310	11	352	3.0		
72	5.0/ 9.0	1.255	0.311	7.66/ 8.81	0.287	4	374	3.0		
72	5.0/12.2	1.993	0.263	7.66/ 9.58	0.266	8	441	3.0		
72	9.0/12.2	0.656	0.205	8.81/ 9.58	0.279	3	562	3.0		
73	1.4/ 4.4	2.321	0.772	8.55/ 10.62	0.753	7	350	4.3	G R 5H	75 1
73	1.4/ 3.2	3.621	0.532	8.55/ 11.35	0.513	17	502	4.3		
73	4.4/ 3.2	1.330	0.350	10.62/ 11.35	0.323	9	751	4.2		
74	0.3/ 5.2	0.073	0.017	1.31/ 1.85	0.009	5	7500	2.2	G R 5F	75 0
74	0.3/ 9.3	0.509	0.057	1.31/ 2.26	0.050	11	2179	2.1		
74	5.2/ 9.3	0.436	0.035	1.85/ 2.26	0.039	5	1235	2.1		
75	3.2/10.0	4.177	0.614	10.64/ 14.16	0.513	14	373	3.4	G R 5H	75 10
75	3.2/14.3	5.877	0.489	10.64/ 15.52	0.421	24	464	3.4		
75	10.0/14.3	1.566	0.326	14.16/ 15.52	0.232	10	679	3.3		
76	1.8/ 8.0	-0.027	-0.004	2.21/ 2.26	0.008	6	999.999	1.6	G R 5F	75 10
76	1.3/14.0	0.155	0.013	2.21/ 2.75	0.044	12	7901	1.6		
76	8.0/14.0	0.132	0.030	2.26/ 2.75	0.032	6	3277	1.6		
77	1.4/ 5.4	3.237	0.309	14.57/ 16.36	0.574	9	310	3.4	G R 5H	75 20
77	1.4/10.0	5.336	0.579	14.57/ 19.22	0.541	18	366	3.3		
77	1.4/16.2	3.363	0.565	14.57/ 21.66	0.479	31	431	3.3		
77	5.4/10.0	2.683	0.534	16.36/ 19.22	0.512	10	419	3.3		
77	5.4/16.2	5.293	0.481	16.36/ 21.66	0.444	22	490	3.2		
77	10.0/16.2	2.682	0.433	19.22/ 21.66	0.393	13	543	3.2		
78	1.4/ 4.3	0.025	0.007	2.92/ 2.93	0.004	3	32256	3.6	G R 5H	75 20
78	1.4/ 9.6	1.170	0.143	2.92/ 4.22	0.159	19	1660	3.6		
78	1.4/16.4	1.615	0.108	2.92/ 4.33	0.094	34	2171	3.6		
78	4.3/ 3.6	1.145	0.279	2.93/ 4.22	0.269	11	991	3.6		
78	4.3/16.4	1.591	0.137	2.93/ 4.33	0.121	26	1701	3.5		
78	9.6/16.4	0.450	0.066	4.22/ 4.33	0.016	15	3483	3.5		

RUN NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE MTC. COOL. FILTER	TO (F)	DT (F)
79	2.0/ 6.2	3.799	0.904	26.94/ 29.74	0.667	8	293	3.4 G R SH	75	0
79	2.0/10.4	7.405	0.882	26.94/ 32.33	0.642	16	293	3.3		
79	6.2/10.4	3.749	0.893	29.74/ 32.33	0.617	8	293	3.2		
80	2.4/ 5.8	0.109	0.032	8.39/ 8.49	0.027	4	3877	2.0 G R SF	75	0
80	2.4/10.8	0.130	0.016	8.39/ 8.30	-0.011	9	7889	2.0		
80	5.8/10.8	0.022	0.004	8.49/ 8.30	-0.037	6	27748	2.0		
81	0.8/ 5.2	4.907	1.115	27.64/ 31.27	0.826	9	240	3.3 G R SH	75	5
81	0.8/ 8.2	7.926	1.071	27.64/ 33.45	0.786	14	246	3.3		
81	5.2/ 9.2	3.175	1.058	31.27/ 33.45	0.727	6	243	3.2		
82	1.6/ 8.8	0.571	0.079	9.49/ 10.20	0.100	7	1422	1.7 G R SF	75	5
82	1.6/11.6	0.446	0.045	9.49/ 10.20	0.071	10	2579	1.8		
82	1.6/19.8	1.046	0.057	9.49/ 10.57	0.060	19	1962	1.7		
82	8.8/11.6	-0.126	-0.045	10.20/ 10.20	-0.003	3	999999	1.7		
82	8.8/19.8	0.477	0.043	10.20/ 10.57	0.033	11	2546	1.7		
82	11.6/19.8	0.602	0.073	10.20/ 10.57	0.045	8	1535	1.7		
83	1.0/ 7.6	9.626	1.459	2.20/ 11.50	1.409	14	148	3.7 GS R SH	75	0
83	1.0/14.2	18.276	1.335	2.20/ 20.00	1.348	27	148	3.5		
83	7.6/14.2	9.571	1.450	11.50/ 20.00	1.287	13	134	3.3		
84	2.4/ 7.2	1.192	0.248	1.96/ 3.00	0.217	4	388	1.6 GS R SF	75	0
84	2.4/13.8	2.436	0.214	1.96/ 4.10	0.188	10	420	1.5		
84	7.2/13.8	1.259	0.191	3.00/ 4.10	0.167	6	463	1.5		
85	2.4/ 6.2	4.883	1.235	27.31/ 30.62	0.836	7	190	3.0 GS R SH	75	5
85	2.4/ 9.8	9.757	1.318	27.31/ 34.39	0.957	13	181	3.0		
85	6.2/ 9.8	5.124	1.423	30.62/ 34.39	1.031	6	164	2.9		
86	1.2/ 5.4	0.596	0.142	5.94/ 6.47	0.125	4	643	1.5 GS R SF	75	5
86	1.2/ 9.4	1.188	0.145	5.94/ 7.50	0.190	7	625	1.5		
86	5.4/ 9.4	0.595	0.149	6.47/ 7.50	0.258	3	606	1.4		
87	1.8/ 4.4	0.926	0.356	6.90/ 7.76	0.532	3	295	1.7 GS R SF	75	5
87	1.8/ 7.6	1.275	0.220	6.90/ 8.19	0.223	6	476	1.7		
87	4.4/ 7.6	0.352	0.110	7.76/ 8.19	0.135	3	946	1.7		
88	1.4/ 5.4	3.978	0.995	35.34/ 37.77	0.606	6	229	2.4 GS R SH	75	11
88	1.4/ 8.4	6.584	0.941	35.34/ 39.32	0.567	10	240	2.4		
88	5.4/ 8.4	2.713	0.904	37.77/ 39.32	0.516	4	245	2.4		
89	1.6/ 5.6	0.377	0.094	11.11/ 11.73	0.155	3	862	1.2 GS R SF	75	11
89	1.6/ 8.4	0.377	0.056	11.11/ 11.73	0.091	5	1465	1.2		
89	5.6/ 8.4	0.000	0.000	11.73/ 11.73	0.000	2	999999	1.2		

RUN NO.	T1/2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE NTG. COXL. FILTER	10 DT (F) (F)
90	2.2/ 9.6	-1.443	-0.195	13.22/ 12.17	-0.163	7	999999	1.5 GS R 5F	75 11
90	2.2/19.4	-0.761	-0.047	13.42/ 12.72	-0.043	15	999999	1.5	
90	9.5/13.4	0.372	0.075	13.17/ 12.72	0.062	8	1379	1.5	
91	3.2/ 4.0	2.227	1.237	45.31/ 45.31	0.677	5	204	2.2 GS R 5H	75 20
91	2.2/ 7.0	5.433	1.332	45.13/ 47.47	0.703	7	13.5	2.2	
91	4.0/ 7.0	4.359	1.455	45.51/ 47.47	0.719	4	169	2.2	
92	1.3/ 4.4	1.396	0.537	11.73/ 13.20	0.563	2	165	1.2 GS R 5F	75 20
92	1.3/ 7.0	1.393	0.534	11.73/ 13.71	0.579	4	243	1.2	
92	4.4/ 7.0	0.504	0.194	13.20/ 13.71	0.195	2	453	1.2	
93	1.4/ 7.2	1.793	0.509	13.00/ 14.73	0.293	5	325	1.4 GS R 5F	75 20
93	1.4/12.0	3.032	0.236	13.00/ 15.70	0.236	10	375	1.4	
93	1.4/20.0	1.793	0.093	13.00/ 14.73	0.093	16	1043	1.4	
93	7.2/12.8	1.262	0.225	14.73/ 15.70	0.172	5	430	1.3	
93	7.2/20.0	0.000	0.000	14.73/ 14.73	0.000	11	999999	1.4	
93	12.8/20.0	-1.278	-0.177	15.70/ 14.73	-0.134	6	999999	1.3	
94	2.0/ 8.2	3.780	0.610	14.16/ 17.51	0.541	5	159	1.2 GS R 5F	75 30
94	2.0/12.4	5.953	0.572	14.16/ 19.27	0.491	9	169	1.2	
94	2.0/13.2	8.320	0.551	14.16/ 22.02	0.485	13	172	1.2	
94	3.2/12.4	2.259	0.535	17.51/ 19.27	0.413	3	175	1.2	
94	3.2/13.2	5.342	0.534	17.51/ 22.02	0.451	8	173	1.2	
94	12.4/13.2	3.154	0.541	19.27/ 22.02	0.475	5	163	1.2	
95	1.0/ 6.4	3.579	0.663	0.00/ 0.00	0.000	5	0	1.5 GS R 5F	75 30
95	1.0/10.0	5.493	0.610	0.00/ 0.00	0.000	9	0	1.5	
95	1.0/13.2	7.428	0.614	0.00/ 0.00	0.000	12	0	1.5	
95	6.4/10.0	1.985	0.551	0.00/ 0.00	0.000	4	0	1.5	
95	6.4/13.2	4.054	0.595	0.00/ 0.00	0.000	7	0	1.5	
95	10.0/13.2	2.111	0.660	0.00/ 0.00	0.000	3	0	1.4	
96	0.6/ 3.8	0.458	0.143	-0.85/ -0.43	0.129	3	739	3.8 GS R 10F	75 0
96	0.6/ 8.6	0.348	0.043	-0.85/ -0.45	0.050	8	2391	3.7	
96	3.8/ 8.6	-0.111	-0.023	-0.43/ -0.45	-0.003	5	999999	3.6	
97	1.0/ 5.2	-0.047	-0.011	0.00/ 0.00	0.000	6	999999	4.8 GS R 10H	75 0
97	1.0/ 9.0	-0.785	-0.098	0.00/ -0.55	-0.068	11	999999	4.7	
97	5.2/ 9.0	-0.739	-0.194	0.00/ -0.55	-0.144	5	999999	4.7	
98	2.2/ 6.4	-0.006	-0.002	-0.92/ -0.93	-0.003	4	999999	3.3 GS R 10F	75 11
98	2.2/10.0	-0.213	-0.027	-0.92/ -0.94	-0.003	8	999999	3.3	
98	2.2/14.0	-0.345	-0.029	-0.92/ -0.97	-0.005	11	999999	3.2	
98	6.4/10.0	-0.207	-0.057	-0.93/ -0.94	-0.004	4	999999	3.2	
98	6.4/14.0	-0.338	-0.045	-0.93/ -0.97	-0.005	7	999999	3.2	
98	10.0/14.0	-0.131	-0.033	-0.94/ -0.97	-0.007	4	999999	3.2	

RUN NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE FILTER	NTC COOL.	TO (F)(F)	DT
99	2.6/ 5.4	-0.191	-0.068	-0.52/ -0.53	-0.001	4	999999	4.5	GS R 10H	75	11
99	2.6/ 9.2	0.059	0.009	-0.52/ 0.00	0.079	9	15024	4.5			
99	2.6/12.4	0.002	0.000	-0.52/ -0.55	-0.003	13	601618	4.4			
99	5.4/ 9.2	0.249	0.066	-0.53/ 0.00	0.139	5	2051	4.5			
99	5.4/12.4	0.192	0.027	-0.53/ -0.55	-0.004	9	4822	4.4			
99	9.2/12.4	-0.057	-0.018	0.00/ -0.55	-0.173	4	999999	4.4			
100	4.2/ 9.8	0.032	0.006	-0.92/ -0.94	-0.004	6	16820	3.1	GS R 10F	75	20
100	4.2/13.2	-0.381	-0.042	-0.92/ -0.96	-0.004	9	999999	3.1			
100	4.2/15.6	-0.265	-0.023	-0.92/ -0.98	-0.005	11	999999	3.0			
100	9.8/13.2	-0.414	-0.122	-0.94/ -0.96	-0.004	3	999999	3.0			
100	9.8/15.6	-0.297	-0.051	-0.94/ -0.98	-0.006	6	999999	3.0			
100	13.2/15.6	0.116	0.048	-0.96/ -0.98	-0.010	2	1937	3.0			
101	2.2/ 8.0	-0.058	-0.010	0.00/ 0.00	0.000	8	999999	4.3	GS R 10H	75	20
101	2.2/13.2	0.087	0.008	0.00/ 0.00	0.000	15	17319	4.2			
101	2.2/15.8	0.517	0.045	0.00/ 0.56	0.041	18	2919	4.1			
101	8.0/13.2	0.145	0.027	0.00/ 0.00	0.000	7	4940	4.2			
101	8.0/15.8	0.675	0.087	0.00/ 0.56	0.071	10	1514	4.1			
101	13.4/15.8	0.531	0.221	0.00/ 0.56	0.231	3	586	4.1			
102	1.4/ 7.0	0.314	0.056	0.00/ 0.40	0.072	6	2026	3.3	GS R 10F	75	31
102	1.4/11.2	0.353	0.036	0.00/ 0.41	0.042	11	3133	3.3			
102	7.0/11.2	0.039	0.009	0.40/ 0.41	0.002	5	12162	3.3			
103	2.0/ 7.4	0.485	0.090	1.34/ 1.80	0.085	8	1788	4.6	GS R 10H	75	32
103	2.0/12.2	0.993	0.097	1.34/ -5.97	-0.717	16	1613	4.5			
103	7.4/12.2	0.510	0.106	1.80/ -5.97	-1.619	7	1467	4.5			
104	1.6/10.0	1.789	0.213	2.14/ 3.90	0.209	14	773	4.7	GS R 10H	75	32
104	1.6/17.3	2.347	0.145	2.14/ 4.39	0.139	26	1126	4.7			
104	1.6/27.4	3.273	0.127	2.14/ 5.33	0.124	41	1272	4.6			
104	10.0/17.3	0.568	0.073	3.90/ 4.39	0.063	12	2207	4.6			
104	10.0/27.4	1.510	0.087	3.90/ 5.33	0.083	27	1829	4.5			
104	17.3/27.4	0.948	0.099	4.39/ 5.33	0.099	15	1593	4.5			
105	3.0/11.2	1.368	0.166	5.31/ 6.61	0.159	13	1043	4.8	GS R 10H	75	32
105	3.0/20.8	2.660	0.149	5.31/ 7.95	0.149	29	1141	4.7			
105	3.0/31.8	4.278	0.149	5.31/ 9.36	0.141	46	1130	4.6			
105	11.2/20.8	1.320	0.138	6.61/ 7.95	0.139	15	1223	4.7			
105	11.2/31.8	2.960	0.144	6.61/ 9.36	0.134	32	1152	4.6			
105	20.8/31.8	1.662	0.151	7.95/ 9.36	0.128	17	1081	4.5			
106	0.8/ 4.0	0.096	0.030	1.36/ 8.38	0.006	7	7290	4.4	GS R 5H	100	0
106	0.8/ 8.8	0.177	0.022	1.36/ 1.40	0.005	17	9812	4.4			
106	0.8/11.8	-0.079	-0.007	1.36/ 0.94	-0.038	23	999999	4.4			
106	4.0/ 8.8	0.082	0.017	1.38/ 1.40	0.004	10	12755	4.3			
106	4.0/11.8	-0.175	-0.022	1.38/ 0.94	-0.056	17	999999	4.3			
106	8.8/11.8	-0.257	-0.086	1.40/ 0.94	-0.153	6	999999	4.3			

RUN NO.	T1/T2 (MIN)	100X (%)	100 Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE	MTG. COOL. FILTER	TO (F)	DI (F)
107	1-8/ 4-8	0.067	0.022	0.91/ 0.92	0.003	3	4462	2.0	GS R 5F	100	0
107	1-8/ 8-8	-0.035	-0.005	0.91/ 0.47	-0.063	7	999999	2.0			
107	1-8/11-8	-0.332	-0.033	0.91/ 0.47	-0.044	10	999999	2.0			
107	4-8/ 8-8	-0.102	-0.025	0.92/ 0.47	-0.113	4	999999	2.0			
107	4-8/11-8	-0.399	-0.057	0.92/ 0.47	-0.064	7	999999	2.0			
107	8-8/11-8	-0.297	-0.099	0.47/ 0.47	0.001	3	999999	2.0			
108	1-0/ 4-4	0.209	0.061	2.63/ 2.64	0.003	5	2647	6.4	GS R 10H	100	0
108	1-0/ 8-2	0.092	0.013	2.63/ 2.65	0.003	11	12700	6.4			
108	1-0/13-2	0.047	0.069	2.63/ 3.17	0.044	19	2305	6.3			
108	4-4/ 8-2	-0.117	-0.031	2.64/ 2.65	0.003	6	999999	6.4			
108	4-4/13-2	0.639	0.073	2.64/ 3.17	0.060	14	2197	6.3			
108	8-2/13-2	0.756	0.151	2.65/ 3.17	0.103	2	1054	6.3			
109	0-2/ 4-0	3.121	0.913	14.91/ 17.75	0.334	7	246	3.7	GS R 5H	100	10
109	0-6/ 7-2	5.493	0.753	14.91/ 19.74	0.671	14	293	3.7			
109	0-6/11-0	7.497	0.721	14.91/ 21.37	0.621	20	303	3.6			
109	4-0/ 7-2	2.449	0.645	17.75/ 19.74	0.525	7	344	3.6			
109	4-0/11-0	4.517	0.645	17.75/ 21.37	0.517	13	341	3.6			
109	7-2/11-0	2.120	0.662	19.74/ 21.37	0.508	6	329	3.6			
110	0-8/ 4-4	10.153	2.815	11.37/ 20.72	2.596	5	52	5.0	GS R 10H	100	10
110	0-8/ 3-2	19.603	2.649	11.37/ 29.00	2.382	9	53	4.3			
110	0-8/11-2	26.763	2.573	11.37/ 35.56	2.326	13	53	4.7			
110	4-4/ 3-2	10.538	2.773	20.72/ 29.00	2.180	5	49	4.7			
110	4-4/11-2	18.505	2.721	20.72/ 35.56	2.133	3	49	4.5			
110	8-2/11-2	8.905	2.968	29.00/ 35.56	2.137	3	43	4.4			
112	1-0/ 4-8	-0.153	-0.040	0.95/ 0.97	0.004	3	999999	4.2	GS R 5H	100	0
112	1-0/ 8-8	0.536	0.069	0.95/ 1.96	0.129	16	3000	4.2			
112	1-0/12-4	0.208	0.018	0.95/ 1.51	0.049	23	11182	4.1			
112	4-8/ 8-8	0.687	0.172	0.97/ 1.96	0.249	8	1190	4.1			
112	4-8/12-4	0.360	0.047	0.97/ 1.51	0.071	15	4270	4.1			
112	8-8/12-4	-0.329	-0.091	1.96/ 1.51	-0.126	7	999999	4.0			
113	1-4/ 9-0	-0.142	-0.019	0.50/ 0.52	0.002	11	999999	5.7	GS R 10H	100	0
113	1-4/12-6	-0.770	-0.069	0.50/ 0.53	0.003	15	999999	5.6			
113	9-0/12-6	-0.627	-0.174	0.52/ 0.53	0.003	5	999999	5.5			
114	1-4/ 7-4	1.197	0.199	2.31/ 3.29	0.162	13	1070	4.0	GS R 5H	100	10
114	1-4/14-0	1.539	0.126	2.31/ 3.81	0.119	26	1676	4.0			
114	1-4/18-8	1.539	0.091	2.31/ 3.86	0.099	36	2297	3.9			
114	7-4/14-0	0.397	0.060	3.29/ 3.81	0.079	13	3468	3.9			
114	7-4/18-3	0.398	0.036	3.29/ 3.86	0.051	23	5943	3.9			
114	14-0/18-3	0.000	0.000	3.31/ 3.86	0.012	10	999999	3.9			

RUN NO.	T1/T2 (MIN)	100X (%)	100 Y (%/MIN)	100M1/100M2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE NTG, COOL, FILTER	TO DT (F) (F)
115	1.4/ 7.2	1.161	0.200	-0.49/ 0.50	0.170	8	719	5.6 GS R 10H	100 10
115	1.4/11.8	1.167	0.112	-0.49/ 1.00	0.143	15	1276	5.5	
115	1.4/18.6	2.167	0.126	-0.49/ 2.04	0.147	24	1120	5.4	
115	7.2/11.8	0.006	0.001	0.50/ 1.00	0.109	7	106491	5.5	
115	7.2/18.6	1.013	0.039	0.50/ 2.04	0.136	16	1560	5.4	
115	11.3/18.6	1.012	0.149	1.00/ 2.04	0.153	9	931	5.4	
116	2.4/ 5.4	0.131	0.044	4.50/ 4.56	0.014	6	5043	3.8 GS R 5H	100 20
116	2.4/ 9.6	1.217	0.169	4.50/ 5.50	0.139	15	1294	3.8	
116	2.4/14.8	1.396	0.153	4.50/ 6.43	0.159	26	1418	3.7	
116	5.4/ 9.6	1.037	0.259	4.55/ 5.50	0.223	9	341	3.8	
116	5.4/14.8	1.767	0.188	4.55/ 6.43	0.206	19	1148	3.7	
116	9.6/14.8	0.687	0.132	5.50/ 6.43	0.188	11	1616	3.7	
117	1.2/ 4.8	0.533	0.143	0.96/ 1.45	0.137	5	1000	5.3 GS R 10H	100 20
117	1.2/ 8.6	1.036	0.140	0.96/ 1.96	0.136	11	1048	5.3	
117	1.2/14.6	0.874	0.065	0.96/ 2.00	0.078	19	2223	5.2	
117	4.8/ 3.6	0.505	0.133	1.45/ 1.96	0.136	5	1096	5.2	
117	4.8/14.6	0.342	0.035	1.45/ 2.00	0.056	14	4128	5.2	
117	8.6/14.6	-0.164	-0.027	1.96/ 2.00	0.007	3	999999	5.1	
118	1.4/ 4.6	1.275	0.338	6.25/ 7.56	0.410	7	506	3.8 GS R 5H	100 30
118	1.4/ 8.0	1.757	0.266	6.25/ 7.69	0.219	15	835	3.8	
118	1.4/11.0	3.046	0.317	6.25/ 9.01	0.238	21	736	3.7	
118	4.6/ 8.0	0.488	0.144	7.56/ 7.69	0.033	7	1619	3.7	
118	4.6/11.0	1.794	0.280	7.56/ 9.01	0.227	14	822	3.7	
118	8.0/11.0	1.312	0.437	7.69/ 9.01	0.440	6	522	3.7	
119	0.8/ 5.0	0.017	0.004	0.90/ 0.92	0.005	7	38069	5.3 GS R 10H	100 30
119	0.8/ 8.8	-0.201	-0.025	0.90/ 0.47	-0.053	12	999999	5.3	
119	0.8/11.6	0.526	0.049	0.90/ 1.42	0.049	17	3175	5.2	
119	5.0/ 3.8	-0.219	-0.053	0.92/ 0.47	-0.110	6	999999	5.2	
119	5.0/11.6	0.509	0.077	0.92/ 1.42	0.076	10	1933	5.2	
119	8.8/11.6	0.726	0.259	0.47/ 1.42	0.340	4	584	5.1	
120	1.2/ 4.8	0.000	0.000	4.20/ 4.20	0.000	5	999999	1.6 GS R 5H	50 0
121	0.4/ 5.2	1.138	0.237	2.72/ 3.91	0.246	12	1076	3.8 GS R 5H	50 0
122	0.8/ 4.4	0.407	0.113	3.86/ 4.34	0.134	14	3669	6.1 GS R 5H	50 0
123	2.4/ 4.4	0.317	0.158	3.57/ 3.57	0.000	3	883	2.1 GS R 5H	50 0
123	2.4/ 7.0	0.631	0.137	3.57/ 3.57	0.000	6	1021	2.1	
123	4.4/ 7.0	0.315	0.121	3.57/ 3.57	0.000	4	1156	2.1	
124	0.4/ 2.8	1.235	0.535	2.71/ 3.95	0.521	11	891	7.1 GS R 5H	50 0
124	0.4/ 4.6	2.042	0.436	2.71/ 4.53	0.446	19	978	7.0	
124	2.8/ 4.6	0.767	0.426	3.96/ 4.53	0.347	8	1103	7.0	

RUN NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE	HTC, COOL. FILTER	TO (F)	DT (F)
125	1.4/ 4.0	1.384	0.532	5.02/ 7.17	0.444	5	495	3.3	GS R 5H	50	0
125	1.4/ 5.4	1.340	0.543	6.02/ 7.60	0.318	12	675	3.7			
125	4.0/ 6.4	0.563	0.236	7.17/ 7.60	0.131	6	1109	3.7			
125	0.6/ 2.4	0.355	0.137	21.51/ 21.51	0.000	2	372	2.0	GS R 5H	50	5
125	0.3/ 5.0	0.913	0.209	21.51/ 22.09	0.132	6	322	2.0			
125	2.4/ 5.0	0.564	0.217	21.51/ 22.09	0.224	3	790	2.0			
127	0.4/ 3.4	2.138	0.713	8.76/ 10.55	0.595	7	331	3.7	GS R 5H	50	5
127	0.4/ 5.4	2.536	0.507	3.76/ 10.91	0.430	12	535	3.7			
127	3.4/ 5.4	0.407	0.203	10.55/ 10.91	0.182	5	1324	3.6			
128	1.2/ 3.4	0.879	0.400	10.36/ 11.75	0.391	9	1125	5.9	GS R 5H	50	5
128	1.2/ 5.6	2.134	0.485	10.36/ 12.80	0.441	18	922	5.9			
128	3.4/ 5.6	1.266	0.576	11.73/ 12.80	0.490	9	774	5.9			
129	1.3/ 3.8	0.000	0.000	10.60/ 10.60	0.000	3	999999	2.0	GS R 5H	50	5
129	1.6/ 6.0	0.241	0.056	10.60/ 11.26	0.151	6	2750	2.0			
129	3.3/ 6.0	0.241	0.109	10.60/ 11.26	0.301	3	1375	2.0			
130	0.4/ 3.4	1.344	0.448	0.00/ 0.00	0.000	14	0	7.0	GS R 5H	50	5
131	2.4/ 4.4	1.393	0.697	13.92/ 14.56	0.316	3	226	1.9	GS R 5H	50	10
131	2.4/ 7.2	2.552	0.532	13.92/ 15.72	0.375	6	295	1.9			
131	4.4/ 7.2	1.175	0.420	14.56/ 15.72	0.417	4	372	1.0			
132	1.0/ 3.2	1.527	0.694	14.09/ 15.36	0.577	5	418	3.6	GS R 5H	50	10
132	1.0/ 5.4	2.120	0.482	14.09/ 15.93	0.419	11	601	3.6			
132	3.2/ 5.4	0.603	0.274	15.36/ 15.93	0.261	5	1054	3.6			
133	0.0/ 3.2	1.620	0.506	14.19/ 15.60	0.439	13	914	5.7	GS R 5H	50	10
133	0.0/ 3.4	2.349	0.445	14.13/ 16.30	0.375	25	1035	5.7			
133	3.2/ 3.4	1.250	0.390	15.60/ 16.60	0.312	13	1174	5.6			
134	2.2/ 5.2	0.624	0.208	16.15/ 16.67	0.173	4	774	1.9	GS R 5H	50	10
134	2.2/ 3.2	1.034	0.172	16.15/ 17.13	0.171	8	934	1.9			
134	5.2/ 3.2	0.412	0.137	16.67/ 17.13	0.170	4	1171	1.9			
135	0.6/ 4.8	-0.003	-0.001	-3.31/ -3.33	-0.007	5	999999	14.1	G L 40F	75	21
135	0.6/ 9.4	0.393	0.045	-3.31/ -2.94	0.041	10	2436	14.0			
135	4.8/ 9.4	0.397	0.086	-3.33/ -2.94	0.035	5	1252	14.0			
135	1.3/ 4.6	0.000	0.000	0.00/ 0.00	0.000	2	999999	3.0	G L 40F	75	21
135	1.3/ 7.6	0.000	0.000	0.00/ 0.00	0.000	4	999999	3.0			
135	4.6/ 7.6	0.000	0.000	0.00/ 0.00	0.000	2	999999	8.0			
137	1.3/ 4.2	0.212	0.033	0.25/ 0.49	0.103	4	2090	22.9	G L 40F	75	21
137	1.3/ 3.4	0.140	0.030	0.25/ 0.50	0.054	8	6043	22.9			
137	4.2/ 3.4	-0.072	-0.033	0.49/ 0.50	0.001	4	999999	22.9			

RUN NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE	NTC, COOL. FILTER	TC (F)	DT (F)
138	0.2/ 2.0	-0.141	-0.078	3.47/ 3.47	0.000	2	999999	14.2	G L 40F	75	21
138	0.2/ 4.0	-0.495	-0.130	3.47/ 3.10	-0.098	4	999999	14.2			
138	2.0/ 4.0	-0.354	-0.177	3.47/ 3.10	-0.137	2	999999	14.2			
139	0.2/ 2.6	-0.295	-0.123	6.12/ 6.12	0.000	2	999999	7.8	G L 40F	75	21
140	1.0/ 3.4	0.465	0.206	4.03/ 4.76	0.233	3	711	2.2	G L 5H	75	21
140	1.0/ 6.4	0.709	0.131	4.03/ 4.76	0.126	8	1115	2.2			
140	3.4/ 6.4	0.216	0.072	4.76/ 4.76	0.000	4	2030	2.2			
141	1.2/ 4.4	0.949	0.296	5.34/ 6.15	0.253	8	877	3.8	G L 5H	75	21
141	1.2/ 6.6	1.560	0.289	5.34/ 6.56	0.226	13	896	3.8			
141	4.4/ 6.6	0.617	0.281	6.15/ 6.56	0.186	5	915	3.8			
142	0.6/ 3.0	0.479	0.200	1.00/ 1.75	0.312	9	2002	6.2	G L 5H	75	21
142	0.6/ 6.0	1.719	0.313	1.00/ 3.00	0.371	21	1245	6.1			
142	3.0/ 6.0	1.247	0.416	1.75/ 3.00	0.413	12	950	6.1			
143	1.0/ 5.6	0.943	0.206	0.00/ 1.42	0.308	6	677	2.5	G R 5H	75	0
143	1.0/10.0	1.179	0.131	0.00/ 1.42	0.158	13	1066	2.5			
143	5.6/10.0	0.234	0.053	1.42/ 1.42	0.000	6	2615	2.4			
144	2.4/ 5.2	0.800	0.211	7.41/ 8.15	0.195	9	1277	4.4	G R 5H	75	0
144	2.4/ 9.2	0.948	0.139	7.41/ 8.18	0.113	17	1925	4.4			
144	6.2/ 9.2	0.149	0.050	8.15/ 8.18	0.010	7	5366	4.4			
145	0.6/ 3.4	0.250	0.089	3.17/ 3.42	0.090	11	4575	7.0	G R 5H	75	0
145	0.6/ 6.6	0.754	0.126	3.17/ 4.16	0.164	24	3240	6.9			
145	3.4/ 6.6	0.505	0.158	3.42/ 4.16	0.229	13	2573	6.9			
146	1.8/ 4.6	-0.229	-0.082	2.82/ 2.82	0.000	4	999999	2.3	G R 5H	75	6
146	1.8/ 9.2	0.454	0.061	2.82/ 2.82	0.000	10	2317	2.3			
146	4.6/ 9.2	0.631	0.143	2.82/ 2.82	0.000	6	959	2.3			
147	0.6/ 4.4	-0.250	-0.066	9.59/ 9.52	-0.018	9	999999	4.2	G R 5H	75	6
147	0.6/ 7.6	1.758	0.251	9.59/ 11.59	0.286	17	1077	4.2			
147	4.4/ 7.6	2.004	0.626	9.52/ 11.59	0.647	8	434	4.2			
148	1.0/ 5.2	0.501	0.119	2.37/ 2.78	0.097	5	960	14.8	G R 40F	75	10
148	1.0/ 7.8	0.441	0.056	2.37/ 2.79	0.061	9	1763	14.8			
148	5.2/ 7.8	-0.061	-0.023	2.78/ 2.79	0.004	3	999999	14.8			
149	1.2/ 4.2	0.000	0.000	0.73/ 0.73	0.000	2	999999	8.2	G R 40F	75	10
149	1.2/ 8.6	-0.692	-0.094	0.73/ 0.73	0.000	5	999999	8.2			
149	4.2/ 8.6	-0.692	-0.157	0.73/ 0.73	0.000	3	999999	8.2			

RUN NO	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE NT, COOL, FILTER	TO DT (F) (F)
150	0.4/ 2.8	-0.321	-0.134	1.74/ 1.75	0.002	4	999999	23.8 G R 40F	75 10
150	0.4/ 4.4	-0.043	-0.011	1.74/ 2.00	0.055	7	999999	23.7	
150	2.8/ 4.4	0.277	0.173	1.75/ 2.00	0.159	3	1050	23.7	
151	1.4/ 5.2	-0.293	-0.077	3.32/ 3.45	-0.097	4	999999	14.3 G R 40F	75 21
151	1.4/ 9.4	-0.635	-0.035	3.32/ 3.10	-0.090	9	999999	14.2	
151	5.2/ 9.4	-0.391	-0.093	3.45/ 3.10	-0.033	5	999999	14.2	
152	2.0/ 4.2	0.036	0.016	2.27/ 2.53	0.113	4	10912	21.3 G R 40F	75 21
152	2.0/ 7.6	0.131	0.023	2.27/ 2.54	0.049	10	7631	21.3	
152	2.0/11.4	-0.036	-0.004	2.27/ 2.55	0.030	16	999999	21.3	
152	4.2/ 7.6	0.095	0.028	2.53/ 2.54	0.004	6	6375	21.7	
152	4.2/11.4	-0.072	-0.010	2.53/ 2.55	0.003	13	999999	21.7	
152	7.6/11.4	-0.168	-0.044	2.54/ 2.55	0.002	7	999999	21.7	
153	1.6/ 3.6	0.273	0.139	0.00/ 0.72	0.362	3	935	2.4 G L 5H	100 25
153	1.6/ 5.8	0.323	0.197	0.00/ 1.44	0.343	6	635	2.4	
153	3.6/ 5.8	0.561	0.250	0.72/ 1.44	0.325	3	547	2.4	
154	3.2/ 5.0	0.000	0.000	3.14/ 3.14	0.000	7	999999	4.3 G L 5H	100 25
154	3.2/10.0	0.373	0.055	3.14/ 3.39	0.111	17	4662	4.3	
154	6.0/10.0	0.373	0.093	3.14/ 3.39	0.133	10	2737	4.3	
155	2.0/ 4.4	0.132	0.076	2.16/ 1.46	-0.291	3	1323	2.4 G L 5H	100 25
155	2.0/ 6.8	0.132	0.033	2.16/ 1.46	-0.146	7	3647	2.4	
155	4.4/ 6.8	0.000	0.000	1.46/ 1.46	0.000	3	999999	2.4	
156	0.6/ 2.6	-0.141	-0.071	0.24/ 0.24	0.000	3	999999	7.2 G L 5H	100 25
156	0.6/ 5.0	0.067	0.015	0.24/ 0.49	0.056	18	26775	7.2	
156	2.6/ 5.0	0.203	0.087	0.24/ 0.49	0.102	10	4710	7.2	
157	3.6/ 5.6	0.255	0.123	0.74/ 1.47	0.363	1	432	7.7 B L 40F	75 19
157	3.6/ 3.6	0.255	0.051	0.74/ 1.47	0.147	3	1206	7.7	
157	5.6/ 3.6	0.000	0.000	1.47/ 1.47	0.000	2	999999	7.7	
158	2.0/ 4.8	0.103	0.037	0.40/ 0.40	0.000	3	3104	14.3 B L 40F	75 19
158	2.0/ 3.3	0.270	0.040	0.30/ 0.30	0.000	3	2053	14.2	
158	4.8/ 3.3	0.168	0.042	0.40/ 0.30	0.101	5	2707	14.2	
159	1.6/ 3.6	0.115	0.053	-0.49/ -0.25	0.123	4	3139	23.3 B L 40F	75 19
159	1.6/ 6.8	-0.097	-0.013	-0.49/ -0.25	0.047	10	999999	23.2	
159	3.6/ 6.8	-0.213	-0.066	-0.25/ -0.25	-0.001	6	999999	23.1	
160	1.3/ 3.0	-0.130	-0.029	N/A / N/A	N/A	7	N/A	0.7 B R 2F	76 16
160	1.3/14.6	0.113	0.009	N/A / N/A	N/A	14	N/A	0.7	
160	1.3/20.2	-0.001	-0.000	N/A / N/A	N/A	20	N/A	0.7	
160	3.0/14.6	0.233	0.045	N/A / N/A	N/A	7	N/A	0.7	
160	3.0/20.2	0.178	0.015	N/A / N/A	N/A	13	N/A	0.7	
160	14.6/20.2	-0.120	-0.021	N/A / N/A	N/A	6	N/A	0.7	
161	0.6/ 2.4	0.035	0.047	N/A / N/A	N/A	2	N/A	0.9 B R 2F	76 0
161	0.6/ 4.2	0.027	0.007	N/A / N/A	N/A	4	N/A	0.9	
161	2.4/ 4.2	-0.059	-0.033	N/A / N/A	N/A	2	N/A	0.9	

RUN NO.	T1/T2 (MIN)	100X (%)	100Y (%/MIN)	100W1/100W2 (%)	100Z (%/MIN)	V (GAL/IN2)	1/L (GAL/IN2)	RE	MTG.	COOL. FILTER	TO (F)	DT (F)
102	5.3/ 3.3	-0.173	-0.059	N/A / N/A	N/A	5	N/A	0.3	B	3.2F	77	0
102	5.3/11.4	-0.155	-0.024	N/A / N/A	N/A	6	N/A	0.3				
102	5.3/11.4	0.012	0.110	N/A / N/A	N/A	7	N/A	0.3				
103	0.3/ 5.0	-0.012	-0.000	N/A / N/A	N/A	5	N/A	0.7		3.2F	76	11
103	0.3/ 5.0	0.001	0.000	N/A / N/A	N/A	6	N/A	0.7				
103	0.3/ 7.3	-0.055	-0.000	N/A / N/A	N/A	7	N/A	0.7				
103	5.0/ 6.6	0.065	0.013	N/A / N/A	N/A	4	N/A	0.7				
103	5.0/ 7.3	-0.050	-0.011	N/A / N/A	N/A	5	N/A	0.7				
103	6.7/ 7.3	-0.114	-0.030	N/A / N/A	N/A	1	N/A	0.7				
104	2.4/ 3.0	0.290	0.100	N/A / N/A	N/A	10	N/A	1.1	B	3.2F	75	12
104	2.4/12.3	0.476	0.046	N/A / N/A	N/A	13	N/A	1.1				
104	3.7/12.3	0.131	0.033	N/A / N/A	N/A	8	N/A	1.1				
105	0.8/ 3.6	0.103	0.000	N/A / N/A	N/A	6	N/A	1.4		3.2F	75	0
105	1.6/ 4.2	0.000	0.000	0.00/ 0.00	0.000	2	999999	7.3	B	L 40F	75	13
105	1.6/ 7.2	0.000	0.000	0.00/ 0.00	0.000	3	999999	7.3				
105	3.2/ 7.2	0.000	0.000	0.00/ 0.00	0.000	2	999999	7.3				
107	1.2/ 5.2	0.302	0.301	0.77/ 1.04	0.330	2	331	14.3	B	L 40F	75	13
107	1.2/ 5.2	0.302	0.120	0.77/ 1.04	0.154	5	975	14.3				
107	3.2/ 5.2	0.000	0.000	1.04/ 1.54	0.000	5	999999	14.7				
109	0.4/ 5.4	-0.331	-0.330	0.25/ 0.25	0.000	5	999999	23.4	B	L 40F	75	13
109	0.4/ 5.0	0.034	0.011	0.25/ 0.43	0.044	10	10155	23.4				
109	5.4/ 5.0	0.150	0.030	0.25/ 0.43	0.045	5	3101	23.5				
109	5.2/ 5.6	-0.203	-0.037	0.00/ -0.35	-0.177	5	999999	13.7	B	L 40F	75	13
109	5.2/ 7.3	-0.000	-0.000	0.00/ 0.00	0.000	5	999999	13.6				
109	5.6/ 7.3	0.203	0.030	-0.43/ 0.00	0.155	2	1127	13.5				
170	2.4/ 4.0	0.332	0.245	0.72/ 0.72	0.005	2	555	2.2	B	L 51	75	13
170	2.4/ 6.3	1.119	0.254	0.72/ 1.45	0.165	5	543	2.2				
170	4.0/ 6.3	0.750	0.261	0.72/ 1.45	0.250	4	527	2.2				
171	0.4/ 3.0	0.423	0.164	1.30/ 2.29	0.150	7	1593	4.1	B	L 51	75	13
171	0.4/ 6.6	1.421	0.223	1.30/ 3.07	0.153	15	1136	4.0				
171	3.0/ 6.6	0.333	0.277	2.23/ 3.07	0.215	9	956	4.0				
172	1.4/ 4.0	0.319	0.123	3.47/ 3.72	0.039	10	5237	6.2	B	L 51	75	13
172	1.4/ 6.6	0.331	0.073	3.47/ 3.37	0.097	20	5435	6.2				
172	4.0/ 6.6	0.032	0.024	3.72/ 3.97	0.095	10	15759	6.1				
173	5.2/ 3.4	0.000	0.000	5.07/ 5.07	0.000	3	999999	2.1	B	L 51	75	13
173	5.2/10.6	-0.337	-0.077	5.07/ 5.07	0.000	5	999999	2.1				
173	3.4/10.6	-0.337	-0.153	5.07/ 5.07	0.000	3	999999	2.1				