EFFECT OF CHAMBER PRESSURE ON BURNING RATE

FOR THE

POTASSIUM NITRATE - DEXTROSE

AND

POTASSIUM NITRATE - SORBITOL

ROCKET PROPELLANTS

By

Richard Nakka

June 1999

Issue 1
Introduction

In the design or analysis of a solid rocket motor (SRM), one of the fundamental parameters is that of the motor chamber pressure ($P_o$). For example, prediction of the chamber pressure is necessary for structural sizing the motor casing. Hoop stress, the predominant stress experienced by the casing walls, is directly proportional to chamber pressure:

$$\sigma_{\text{hoop}} = \frac{P_o D}{2 t}$$

where $D$ and $t$ are the casing diameter and wall thickness, respectively.

As another example, the thrust ($F$) that the motor develops is directly proportional to chamber pressure:

$$F = C_F A_t P_o$$

where $C_F$ and $A_t$ are the thrust coefficient and nozzle throat area, respectively.

As well, the nozzle exhaust velocity ($V_e$), from which motor thrust may be alternatively determined (together with mass flow rate), is given by

$$V_e = \sqrt{\frac{2 k R T_o}{k-1} \left[1-\left(\frac{P_e}{P_o}\right)^{\frac{k-1}{k}}\right]}$$

where $k$ and $R$ are the effective ratio of specific heats and the effective gas constant of the exhaust products, and $T_o$ and $P_e$ are the combustion temperature and nozzle exit pressure, respectively.

As can be seen from these examples, it is imperative to be able to predict what chamber pressure will arise from the combustion of the propellant in a particular rocket motor. The pressure that develops in the chamber is the result of a balancing act between the burning of the propellant, which generates combustion gases at a certain rate, and the escaping of these gases through the nozzle opening (throat), also at a certain rate. If the rate of the former process is greater than the rate of the latter, the gases will accumulate in the chamber, resulting in a pressure rise. Interestingly, both processes are a function of the chamber pressure, and at a certain pressure level, an equilibrium situation will occur, where the pressure will remain constant (assuming steady-state conditions).

The rate at which the exhaust products flow through the nozzle is given by

$$m_n = A_t P_o \sqrt{\frac{k}{R T_o} \left(\frac{2}{k+1}\right)^{\frac{k-1}{k}}}$$

and the rate at which combustion products are produced by the burning propellant is given by

$$m_c = \rho_p A_b r$$

where $\rho_p$, $A_b$, and $r$ are the density of the propellant, burning surface area, and propellant burn rate, respectively. As mentioned, the propellant burn rate is a function of chamber pressure and is usually modeled using the deSt.Robert's burning rate equation, which is characterized by a straight-line relationship between the log-burning rate and log-pressure as illustrated in Figure 1:

$$r = a P_o^n + b$$

where $a$ and $n$ are the burn rate coefficient and burn rate pressure exponent, respectively.
Introduction  (cont.)

![Log Pressure Diagram](image)

$\log \text{Pressure} \quad r = a P_o^n + b$

Figure 1 – Pressure – burn rate relationship

The intercept term, $b$, is usually taken as equal to zero, for convenience.

$$r = a P_o^n$$

The values of $a$ and $n$ are determined empirically, either by the *strand burner* method, or by utilizing a *ballistic evaluation motor* (BEM) specifically designed for this purpose. In the strand burner method, $P_o$ is taken as the pressure within the firing vessel. Once the relationship between burn rate and chamber pressure has been established, it is possible to predict the chamber pressure that a rocket motor will develop, by the following equation, which is derived from the concept described earlier:

$$P_o = \left[ \frac{A_b}{A_t} \left( \frac{a \rho_p}{k R T_0 \left( \frac{2}{k+1} \right)^{k+1/\kappa-1}} \right)^{1-n} \right]$$

The terms $A_b$ and $A_t$ are simply geometric quantities associated with the propellant grain and the motor nozzle. In fact, the ratio $A_b/A_t$ is an important parameter in rocket motor design and is referred to as *Klemmung*, usually symbolized as $K_n$. The propellant density is readily determined, either empirically, or idealized from the known densities of the individual constituents. The thermochemical properties $R$, $T_0$ and $k$ may be determined with the aid of a chemical equilibrium computer program such as PEP or CET.

Therefore, the only other properties that are required in order to be able to predict chamber pressure are the burn rate coefficient, $a$, and the burn rate pressure exponent, $n$. Therein lies the intent of this exercise. To experimentally determine these important properties for two of the rocket propellants ideal for amateur experimental use: Potassium Nitrate-Dextrose (referred to as KN-Dextrose) and the Potassium Nitrate-Sorbitol (KN-Sorbitol) propellants. The method that was chosen was the *Strand Burner* method, being the most convenient means to achieve accurate results.
Preparation of Propellant Strands

For both propellants tested, the 65/35 oxidizer/fuel ratio was utilized exclusively, being considered as the “standard” ratio that has been proven by experience to be the best compromise in terms of performance and grain castability. Mixtures with a higher fraction of KN have greater viscosity and are thus more difficult to pour. As well, such mixtures have a greater tendency to retain trapped air bubbles. Mixtures with lower O/F ratios deliver reduced performance.

In preparation of the propellant, the sorbitol and KN were proportioned in the “as purchased” form, as prior testing had confirmed that absorbed moisture content was negligible. The dextrose monohydrate, however, was first desiccated by drying in an electric oven at 80°C, for one hour such that the end product was in the anhydrous form. The KN, dextrose, and Sorbitol were separately pulverized using an electric coffee grinder, the type equipped with a single pair of blades that rotate at high speed. Approximately two tablespoons (30 ml) was put into the grinder, then run for about 15-20 seconds. From experience, it was found that the sound made during the grinding process was a good indicator of when the particles had become fully ground. The particles could be heard breaking up initially, the sound of which diminished rapidly. After 20 seconds, it was obvious that no more pulverization was occurring, and that the powder was merely being spun around. Final particle size estimation is given in Appendix A.

After grinding, the constituents were carefully weighed out using a beam-balance scale with an accuracy and resolution estimated to be 0.5 gram. Typical prepared batch size was 400 grams. After weighing, the constituents were placed into a single bowl, then blended lightly. A mortar and pestle was used, if necessary, to break up any lumps that remained after blending. This “dry mixture” was then placed into a plastic tupperware container and secured to an electrical mixer that rotated at 28 RPM. Mixing then occurred for typically 4 to 5 hours. A record was maintained of the details pertaining to the dry mixture batches as well as the propellant batches. This is given in Appendix B.

Strands of propellant were prepared by slowly heating the mixture (typically, in 100 gram lots) in a thermostatically controlled electric “deep fryer” utilizing a paraffin bath. A thermocouple (type K) probe was used to monitor the temperature of the slurry, which was typically between 125-135°C for the KN-Dextrose, and between 110-120°C for the KN-Sorbitol. When the slurry became fully fluid and had no lumps of unmelted mixture remaining, the slurry was scooped into a preheated extruding tool (see Appendix C), and immediately extruded onto a lightly oiled galvanized steel sheet, and allowed to cool. Typically, the “raw” extruded strands were 10-20 cm long. Extruding proved to be quite challenging, as trapped air in the tool formed an occasional bubble in the strand, which made that portion of the strand useless. Usually, about fifty percent of the extruded strand length was discarded due to bubbles or other defects such as necking or discontinuities.

For the KN-Dextrose strands, the process of inspecting, cleaning, cutting, trimming, inhibiting and marking could be done immediately after cooling (one-half hour). The KN-Sorbitol strands, however, had to be allowed to “cure” for 24 hours (minimum) before handling. This is because, after cooling, the strands were still very pliable and would deform if handled. However, after curing, the strands became as rigid as the KN-Dextrose. The physical mechanism of this “curing” behaviour is not yet understood.

Inspection of the raw strands was performed to locate flaws (bubbles, voids, etc.) and subsequently mark off the portions that were acceptable. Inspection was visual, by examining the external surface, and also by using an “illumination” technique to locate hidden voids. This technique involved holding the translucent strand up to a strong light source. Voids were readily detectable as lighter regions. Fully sound regions were nearly opaque.

Cleaning of the KN-Sorbitol strands was done with lacquer thinner to remove any traces of oil. The KN-Dextrose strands, which were somewhat hygroscopic, were scraped with a knife to remove the superficial damp layer. Cutting to length was done utilizing a fine tooth saw, cutting about one-third way through the strand, then fractured by careful bending. Trimming of the strand was done with a sharp Olfa knife (if necessary). Typical finished strand length was 10 cm, and had an approximately oval cross section, typically with a minor diameter of 4 mm and a major diameter of 6 mm. The cross-section of a typical strand is shown in Figure 2.
Preparation of Propellant Strands  (cont.)

Inhibiting the surfaces of the strands was found to be necessary. This is because the strands were originally mounted vertically, and liquid products of combustion would drool down the strands (like wax down a candle), causing ignition along the side. Inhibiting was done by painting the strands with heat resistant aluminum spray paint (the type used to paint barbecues). At least two full coats were applied, and allowed to dry for a minimum of twenty-four hours.

Burn rate measurement (in open air) of inhibited versus uninhibited strands confirmed that this coating did not affect burn rate (see Appendix B).

After painting the strands, they were measured, labeled, and notation made of minor flaws. For each lot of strands produced, a sample was burned (in open air) to measure the burn rate, which was then compared to the known burn rate, as a means of “quality control” testing.

Longer length strands tended to be used in the higher pressure tests, due to greater rate of burning at more elevated pressures.

![Figure 2 – Cross-section of typical strand](image-url)
Apparatus

The apparatus (Figure 3) consisted primarily of a firing vessel in which the propellant strand was burned under pressure. This consisted of a 4.86 litre, 14 cm. diameter steel cylinder with hemispherical end caps, modified by the addition of a flanged pipe welded to the lower end cap, for attachment of the strand holder (Figure 4). The strand holder consisted of a flanged pipe to which electrical leads in the form of 1/16 inch stainless steel rods were fitted through insulated access holes. This provided electrical connections for the thermocouples and igniter. The strand holder was secured to the firing vessel by means of six ¼-20NC bolts/nuts (SAE grade 8) which joined mating flanges. A fibre gasket was put between the flanges for sealing. The strand holder was also equipped with a flared type fitting for connection to the pressurizing gas supply. The pressurizing gas was nitrogen, supplied from a standard 2200 psi rechargeable cylinder. An orifice of 0.020 inch diameter was installed in the fill line to restrict the flow rate during pressurization.

Measurement of the burning rate was performed with the aid of two thermocouples (T/C), one attached to the strand with its bead near the upper end (nearest the igniter), the other near the bottom end. The T/C was secured to the strand with fine gauge “wire wrap” wire. The T/C’s were connected, in parallel, to terminals on the strand holder. These T/C’s were replaced after each firing, as they normally became quite scorched. Either of two types of T/C’s were used. Type K (chromel-alumel), 0.010 inch diameter, glass-braided insulation, or type E (chromel-constantan), 0.010 inch diameter, teflon coated. The distance between the two thermocouple beads was carefully measured and recorded as the gauge length. Ignition of the strand was achieved by use of a nichrome wire filament soldered to a pair of lead wires connected in turn to terminals on the strand holder. The filament was sandwiched between the top surface of the strand and a (split) match head, which was tacked to the strand with small dabs of hot (polyethylene) glue. The use of a match head, which was incorporated after some initial problems with ignition, subsequently resulted in 100% ignition reliability. Power for the igniter was supplied by four AA nicad cells, mounted inside the ignition box. The ignition box incorporated a continuity check feature which supplied voltage across the igniter at low current accomplished by means of an LED and resistor connected in series with the igniter filament.

A third thermocouple, mounted onto the strand holder, was utilized for ambient temperature measurement inside the firing vessel.

Prior to conducting any actual experimentation, the entire system, including the firing vessel, was hydrostatically tested to 2500 psi, by first filling the vessel with water, bleeding the system of all air, then utilizing a hydraulic jack to pressurize the system with oil. The maximum operational pressure was taken to be 1700 psi, thus the test pressure represents a safety margin of 1.5.

Measurement of the firing vessel pressure was done with a 0-5000 psi bourdon “test” gauge, rated at 0.25% (full scale) accuracy. Low pressure (< 200 psi) measurements were taken with a high quality 0-300 psi bourdon gauge. Comparison testing showed only a small discrepancy in reading between the two gauges over the range 100-300 psi.

The thermocouples were connected to a Micronta 22-168A digital volt meter (DVM) that was interfaced to a 80286 PC. A software routine was written (Appendix E) which sampled the DVM output emf (mV) at the maximum available sample rate (3.3 samples/sec). This data was stored in an array in memory, then written to a text file for permanent storage.
**Apparatus** (cont)

![Experimental apparatus](image)

**Figure 3** – Experimental apparatus

![Dimensions of Firing Vessel](image)

**Figure 4** – Dimensions of Firing Vessel
Experimental Technique

A total of 37 burns were conducted. Of this total, 18 were of the KN-Dextrose propellant, of which 14 produced useable data, over a pressure range of 0 psig to 1610 psig (11.1 MPa). For the KN-Sorbitol propellant, a total of 19 tests were conducted, of which 13 produced useable data, over the pressure range 0 psig to 1533 psig (10.6 MPa).

For each burn conducted, the experimental technique involved performing the following series of steps. Mounting of the strand in the holder, attachment of thermocouples and igniter, joining the strand holder to the firing vessel, connecting the N2 filling line at the strand holder inlet port, connection of the N2 supply tank to the fill valve. The firing vessel was then purged by pressurizing to 30 psig, dumping, then repeating this sequence twice more. This effectively reduced residual O₂ content to less than 1%. Pressurization of the system was accomplished next. Upon completion of the pressurization, the thermocouple reading was taken to record the vessel ambient pressure, and the initial pressure was recorded. Data recording was initiated, then the firing button pressed to ignite the strand. The pressure rise due to the burning strand was then observed and the maximum pressure recorded.

Most of the burns were conducted with the strand mounted vertically, as it was originally felt that this would assure minimal influence of the flame upon the rate of burning. There were occasional problems with drooling molten products of combustion rolling down the strand resulting in false voltage spikes if the lower T/C burn sensor was contacted. It was later decided to investigate mounting the firing vessel (and thus the strand) horizontally to avoid this problem. Burn rate testing of horizontally mounted strands (in the open air, for convenience) was conducted to measure the burn rate. It was found that the burning rate was not detrimentally affected and thus all the subsequent tests were conducted with the firing vessel mounted horizontally.

Analysis

The T/C voltage output data was read into an Excel spreadsheet and plotted in the form of a line graph, an example of which is shown in Figure 5. Nominal results would be in the form of two voltage spikes, which represent the flame front reaching the first, then second T/C (see Figure 6). Both spikes were usually positive, although not necessarily. The time period between spikes was taken as the time required to burn the gauge length. The first data point, at which the slope of the curve sharply increased, at each spike, was taken as the two reference points defining this time period. In the example, the beginning data points are #24 and #64. Judgement was occasionally required to estimate this point when the slope did not rise rapidly or when secondary spikes were present. The pressure at which burning was considered to occur was taken as the average of the initial pressure and the maximum pressure (delta was typically 30-50 psi). Burn rate was taken as gauge length divided by burn time, and thus represents the average burn rate at the average vessel pressure over the duration of the burn.

![Figure 5](image-url) – Example of thermocouple output plotted to show voltage spikes
Experimental Technique (cont)

Figure 6 – Electrical circuit diagram
Results

A summary of the experimental burn rate results (excluding invalidated results) are given in Table 1. Note that the units given are those of the measuring instruments (psig and centimetres).

In Table 2 and Table 3, the results are reproduced in both English and SI units, with pressure converted to absolute units. A plot of the results for KN-Dextrose is given in Figure 7, and for KN-Sorbitol in Figure 8, in English units. A plot of the results for KN-Dextrose is given in Figure 9, and for KN-Sorbitol in Figure 10, in SI units.

A comparison of experimental results for both of these propellants with the results for KN-Sucrose is given in Figure 11. The KN-Sucrose results were obtained from a similar burn rate investigation conducted several years prior. Note that the amount of scatter in the earlier data was significantly greater than with recent testing. The reduced scatter with the recent investigation is attributed to much improved experimental technique.

Some of the results obtained were deemed invalid, and the data was not used. In these, burning of the strand did not proceed in a normal “cigarette” manner, rather, burning of the strand (as indicated by the lower burn sensor) was rapid. This event was almost certainly the result of liquid combustion product “drooling” down the side of the strand, causing either combustion to occur along the side, or the liquid product coming into contact with the lower burn sensor, falsely indicating the burn time. It was therefore decided, commencing with burn PB-25, to mount the firing vessel horizontally, rather than vertically, to eliminate drooling and thus avoid uncontrolled burning. This seemed to solve the problem, as in the twelve subsequent burns, only once did an uncontrolled burning occur. Burn rate testing to validate this had demonstrated that, contrary to earlier thought, that mounting the strand horizontally did not adversely effect the burn rate.

<table>
<thead>
<tr>
<th>Vessel pressure</th>
<th>Burn rate</th>
<th>Vessel pressure</th>
<th>Burn rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>psig</td>
<td>cm/sec</td>
<td>psig</td>
<td>cm/sec</td>
</tr>
<tr>
<td>0</td>
<td>0.215</td>
<td>0</td>
<td>0.256</td>
</tr>
<tr>
<td>98</td>
<td>0.759</td>
<td>95</td>
<td>0.898</td>
</tr>
<tr>
<td>148</td>
<td>0.751</td>
<td>103</td>
<td>0.937</td>
</tr>
<tr>
<td>224</td>
<td>0.754</td>
<td>192</td>
<td>0.784</td>
</tr>
<tr>
<td>325</td>
<td>0.798</td>
<td>203</td>
<td>0.781</td>
</tr>
<tr>
<td>425</td>
<td>0.830</td>
<td>301</td>
<td>0.765</td>
</tr>
<tr>
<td>523</td>
<td>0.932</td>
<td>401</td>
<td>0.792</td>
</tr>
<tr>
<td>651</td>
<td>1.100</td>
<td>535</td>
<td>0.765</td>
</tr>
<tr>
<td>845</td>
<td>1.308</td>
<td>659</td>
<td>0.952</td>
</tr>
<tr>
<td>953</td>
<td>1.314</td>
<td>830</td>
<td>0.977</td>
</tr>
<tr>
<td>1144</td>
<td>1.285</td>
<td>1005</td>
<td>1.102</td>
</tr>
<tr>
<td>1218</td>
<td>1.232</td>
<td>1194</td>
<td>1.091</td>
</tr>
<tr>
<td>1405</td>
<td>1.300</td>
<td>1533</td>
<td>1.129</td>
</tr>
<tr>
<td>1610</td>
<td>1.392</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 – Summary of experimental results
Results (cont.)

<table>
<thead>
<tr>
<th>KN-Dextrose</th>
<th>Vessel pressure</th>
<th>Burn rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>psig</td>
<td>psia</td>
<td>Mpaa</td>
</tr>
<tr>
<td>0</td>
<td>14.7</td>
<td>0.101</td>
</tr>
<tr>
<td>98</td>
<td>113</td>
<td>0.777</td>
</tr>
<tr>
<td>148</td>
<td>162</td>
<td>1.12</td>
</tr>
<tr>
<td>224</td>
<td>238</td>
<td>1.64</td>
</tr>
<tr>
<td>325</td>
<td>340</td>
<td>2.34</td>
</tr>
<tr>
<td>425</td>
<td>440</td>
<td>3.03</td>
</tr>
<tr>
<td>523</td>
<td>537</td>
<td>3.70</td>
</tr>
<tr>
<td>651</td>
<td>666</td>
<td>4.59</td>
</tr>
<tr>
<td>845</td>
<td>860</td>
<td>5.93</td>
</tr>
<tr>
<td>953</td>
<td>968</td>
<td>6.67</td>
</tr>
<tr>
<td>1144</td>
<td>1159</td>
<td>7.99</td>
</tr>
<tr>
<td>1218</td>
<td>1233</td>
<td>8.50</td>
</tr>
<tr>
<td>1405</td>
<td>1420</td>
<td>9.79</td>
</tr>
<tr>
<td>1610</td>
<td>1625</td>
<td>11.20</td>
</tr>
</tbody>
</table>

Table 2 – Experimental results for KN-Dextrose, English and SI units

<table>
<thead>
<tr>
<th>KN-Sorbitol</th>
<th>Vessel pressure</th>
<th>Burn rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>psig</td>
<td>psia</td>
<td>Mpaa</td>
</tr>
<tr>
<td>0</td>
<td>14.7</td>
<td>0.101</td>
</tr>
<tr>
<td>95</td>
<td>110</td>
<td>0.756</td>
</tr>
<tr>
<td>103</td>
<td>117</td>
<td>0.808</td>
</tr>
<tr>
<td>192</td>
<td>207</td>
<td>1.43</td>
</tr>
<tr>
<td>203</td>
<td>218</td>
<td>1.50</td>
</tr>
<tr>
<td>301</td>
<td>316</td>
<td>2.18</td>
</tr>
<tr>
<td>401</td>
<td>416</td>
<td>2.87</td>
</tr>
<tr>
<td>535</td>
<td>549</td>
<td>3.79</td>
</tr>
<tr>
<td>659</td>
<td>674</td>
<td>4.65</td>
</tr>
<tr>
<td>830</td>
<td>845</td>
<td>5.83</td>
</tr>
<tr>
<td>1005</td>
<td>1020</td>
<td>7.03</td>
</tr>
<tr>
<td>1194</td>
<td>1209</td>
<td>8.33</td>
</tr>
<tr>
<td>1533</td>
<td>1548</td>
<td>10.67</td>
</tr>
</tbody>
</table>

Table 3 – Experimental results for KN-Sorbitol, English and Metric units
Results (cont.)

Figure 7 – Experimental results for KN-Dextrose, plotted (English units)

Figure 8 – Experimental results for KN-Sorbitol, plotted (English units)
Results (cont.)

Figure 9 – Experimental results for KN-Dextrose, plotted (SI units)

Figure 10 – Experimental results for KN-Sorbitol, plotted (SI units)
Results (cont.)

Figure 11 – Comparison of experimental results for KN-Dextrose, KN-Sorbitol, and KN-Sucrose
**Discussion:**

It was originally planned to conduct burn rate measurements at about six different pressure levels (for each propellant) over the range of 100 to 1600 psi. It was felt that this may be sufficient to apply a “least squares fit”, using regression techniques, through the data points to obtain representative values for the pressure exponent $n$ and pressure coefficient $a$ as applicable to the de St. Robert model of burn rate behaviour. However, after conducting a number of burn rate measurements over this pressure range, it was clear that the burn rate behaviour was too complex to fit the data to a single curve of this form. In the end, about twice as many data points were collected.

The most striking feature of the results for both the KN-Dextrose and KN-Sorbitol propellants is the marked difference in the burn rate behaviour compared with the KN-Sucrose propellant, as illustrated in Figure 11. The latter propellant clearly follows the classic de Saint Robert model of burn rate behaviour. However, the two recently tested propellants deviate significantly from this behaviour. Indeed, for many rocket propellants, the value of $n$ deviates greatly through various pressure regimes. Propellants showing a markedly reduced $n$ are known as plateau propellants. Propellants that show negative values of $n$ over short pressure ranges are known as mesa propellants. This concept is illustrated in Figure 12.

In order to better comprehend the behaviour of the KN-Dextrose and KN-Sorbitol propellants, the experimental burn rate results were each plotted on a Log pressure-Log burn rate graph, as shown in Figures 13 and 14.

A straight line was drawn through those points which best represent the various regimes where the pressure exponent may be considered to be constant, that is, linear on the log-log plot.

Based on this analysis approach, KN-Dextrose would appear to be a plateau propellant, and KN-Sorbitol would appear to be a mesa (or rather, inverted-mesa) propellant.

As such, it is possible to isolate the various pressure regimes and to obtain values for the pressure coefficient $a$ and the pressure exponent $n$ for each of these regimes. Indeed, this was performed, and the results are presented in Tables 4 and 5. The tables are split into English units (left half) where burn rate is given in inch/sec with pressure given in psi (absolute), and in SI units (right half) where burn rate is given in mm/sec with pressure given in Mpa (absolute).

![Figure 12](image-url) – Various concepts of propellant burn rate behaviour (ref. NASA SP–8039 Solid Rocket Motor Performance Analysis and Prediction)
Discussion (cont.)

Figure 13 – Defining linear pressure regimes, KN-Dextrose

Figure 14 – Defining linear pressure regimes, KN-Sorbitol
Discussion (cont.)

<table>
<thead>
<tr>
<th>Pressure range</th>
<th>a</th>
<th>n</th>
<th>Pressure range</th>
<th>a</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>psia</td>
<td>in/sec, (psia)</td>
<td>Mpa</td>
<td>mm/sec, (Mpa)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 to 113</td>
<td>0.016</td>
<td>0.619</td>
<td>0.103 to 0.779</td>
<td>8.88</td>
<td>0.619</td>
</tr>
<tr>
<td>113 to 373</td>
<td>0.311</td>
<td>-0.009</td>
<td>0.779 to 2.57</td>
<td>7.55</td>
<td>-0.009</td>
</tr>
<tr>
<td>373 to 860</td>
<td>0.005</td>
<td>0.688</td>
<td>2.57 to 5.93</td>
<td>3.84</td>
<td>0.688</td>
</tr>
<tr>
<td>860 to 1233</td>
<td>1.416</td>
<td>-0.148</td>
<td>5.93 to 8.50</td>
<td>17.2</td>
<td>-0.148</td>
</tr>
<tr>
<td>1233 to 1625</td>
<td>0.021</td>
<td>0.442</td>
<td>8.50 to 11.20</td>
<td>4.78</td>
<td>0.442</td>
</tr>
</tbody>
</table>

Table 4 – Burn rate coefficients and exponents for KN-Dextrose propellant

<table>
<thead>
<tr>
<th>Pressure range</th>
<th>a</th>
<th>n</th>
<th>Pressure range</th>
<th>a</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>psia</td>
<td>in/sec, (psia)</td>
<td>Mpa</td>
<td>mm/sec, (Mpa)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 to 117</td>
<td>0.019</td>
<td>0.625</td>
<td>0.103 to 0.807</td>
<td>10.71</td>
<td>0.625</td>
</tr>
<tr>
<td>117 to 218</td>
<td>1.648</td>
<td>-0.314</td>
<td>0.807 to 1.50</td>
<td>8.763</td>
<td>-0.314</td>
</tr>
<tr>
<td>218 to 550</td>
<td>0.330</td>
<td>-0.013</td>
<td>1.50 to 3.79</td>
<td>7.852</td>
<td>-0.013</td>
</tr>
<tr>
<td>550 to 1020</td>
<td>0.011</td>
<td>0.535</td>
<td>3.79 to 7.03</td>
<td>3.907</td>
<td>0.535</td>
</tr>
<tr>
<td>1020 to 1548</td>
<td>0.277</td>
<td>0.064</td>
<td>7.03 to 10.67</td>
<td>9.653</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Table 5 – Burn rate coefficients and exponents KN-Sorbitol propellant
Conclusion

Values for the pressure coefficient $a$ and pressure exponent $n$ over specified pressure regimes, have been determined for the KN-Dextrose and KN-Sorbitol propellants, and are suitable for use in design and analysis of rocket motors utilizing either of these propellants.

Since most rocket motors are designed, for optimum performance, to operate over a fairly narrow pressure range, often only a single value for $a$ and $n$ need be utilized, applicable to that pressure range.

Note that the results obtained in this experimentation do not reflect the effects of erosive burning phenomenon. However, if a motor is designed with a sufficiently large port area to nozzle throat area ratio (typically greater than 6), the consequence of erosive burning in augmenting burn rate is not significant.
Appendices
Appendix A

Oxidizer Particle Size Estimation

A simple method was used to obtain an estimate of the typical oxidizer particle size. A tiny, random sample of ground oxidizer was placed on piece of standard graphing paper, with one millimetre minor grid lines. Using a 20x eyepiece magnifier, the sample was observed and the particles were compared in size to the 1 mm grid spacing. The 1 mm grid spacing represents a distance of 1000 microns \((1000 \times 10^{-6} \text{ metres})\). One tenth of this spacing, therefore, represents a distance of 100 microns. Using this method, it is relatively easy to judge particles that are of this order of size. This concept is illustrated in the figure below.

From this examination, it was found that the vast majority of the particles were of the range of \(1/8\text{th}\) to \(1/15\text{th}\) of the grid spacing, consistently, for all of the batches prepared for this series of burn rate tests. This places the oxidizer particle size mainly in the range of about \textbf{60 to 125 micron}.

A sample of oxidizer from each propellant batch was retained for more accurate determination of particle size and distribution at a future date.
Appendix B

Dry Mixture and Propellant Batch Particulars

**Dry Mix Batch #**

KNAD-240199

**Particulars**

- 140 g. Anhydrous Dextrose (AD), consumer grade
- 260 g. Potassium Nitrate (KN), Veterinarian grade
- 400 g. Total dry mix
- Both constituents ground finely using electric coffee grinder (approx. 20 sec.)
- Both constituents accurately weighed using balance beam scale; rated 0.5 gram accuracy
- Blended in rotation mixer (28 RPM) for 6 hours.

**Propellant Batch #**

KNAD-240199-290199-1

**Particulars**

- Prepared using paraffin bath. Bath temperature 150-155 C.; Slurry temperature 130 C.
- Extruded into strands (1/4”nominal dia.) for burnrate testing
- Colour was light tan; some caramelization was apparent
- Hygroscopic. Immediately after cooling to room temp, surfaces were damp.

**Strands**

Initially, strands were left bare (not painted)
- Trial test at 200 psig indicated problem with bare strands. Dribbling of liquid at flame front caused entire strand to become engulfed.
- Subsequently, strands were painted using aluminum hi-heat spray paint (damp surfaces on strands did not pose a problem. Paint adhered well.)
- Atmospheric burnrate test conducted on bare strand:

  \[
  \begin{align*}
  L_1 &= 2.28 \text{ cm} \\
  L_2 &= 4.95 \text{ cm} \\
  t_1 &= 10.64 \text{ sec} \\
  t_2 &= 22.6 \text{ sec} \\
  r_1 &= 0.214 \text{ cm/sec} \\
  r_2 &= 0.219 \text{ cm/sec} \\
  P_{\text{atm}} &= 30.85 \text{ in.Hg.} \\
  T_{\text{ambient}} &= 20 \text{ C}
  \end{align*}
  \]

  Atmospheric burnrate test conducted on painted strand:

  \[
  \begin{align*}
  L_1 &= 1.55 \text{ cm} \\
  L_2 &= 3.11 \text{ cm} \\
  t_1 &= 7.12 \text{ sec} \\
  t_2 &= 14.13 \text{ sec} \\
  r_1 &= 0.218 \text{ cm/sec} \\
  r_2 &= 0.220 \text{ cm/sec} \\
  P_{\text{atm}} &= 31.05 \text{ in.Hg.} \\
  T_{\text{ambient}} &= 20 \text{ C}
  \end{align*}
  \]
Appendix B (cont.)

**Propellant Batch #** KNAD-240199-310199-1

**Particulars**
Extruded into strands (3/16" nominal dia.) for burnrate testing
Colour was ivory; slight caramelization was apparent
Hygroscopic. Immediately after cooling to room temp, surfaces were damp.

**Strands**
All strands were painted with hi-heat aluminum paint.
Atmospheric burnrate test conducted (for quality test) on 2 bare strands, 1st extruded strand and last extruded strand:

1st strand:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>2.45 cm</td>
</tr>
<tr>
<td>L2</td>
<td>4.19 cm</td>
</tr>
<tr>
<td>t1</td>
<td>11.71 sec</td>
</tr>
<tr>
<td>t2</td>
<td>19.84 sec</td>
</tr>
<tr>
<td>r1</td>
<td>0.209 cm/sec</td>
</tr>
<tr>
<td>r2</td>
<td>0.211 cm/sec</td>
</tr>
</tbody>
</table>

P<sub>atm</sub> = 31.125 in.Hg.
T<sub>ambient</sub> = 20 C approx.

Last strand:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>2.09 cm</td>
</tr>
<tr>
<td>L2</td>
<td>4.95 cm</td>
</tr>
<tr>
<td>t1</td>
<td>* sec</td>
</tr>
<tr>
<td>t2</td>
<td>23.75 sec</td>
</tr>
<tr>
<td>r1</td>
<td>n.a. cm/sec</td>
</tr>
<tr>
<td>r2</td>
<td>0.208 cm/sec</td>
</tr>
</tbody>
</table>

* not recorded

**Dry Mix Batch #** KNSB-060299

**Particulars**
105 g. Sorbitol (less than 0.5% absorbed moisture), consumer grade
194 g. Potassium Nitrate (KN), Veterinarian grade
299 g. Total dry mix
Both constituents ground finely using electric coffee grinder (approx. 20 sec.)
Both constituents accurately weighed using balance beam scale; rated 0.5 gram accuracy
Blended in rotation mixer (28 RPM) for 5 hours.

**Propellant Batch #** KNSB-060299-060299-1

**Particulars**
Slurry cast temperature recorded at 113 C. (with T.C.).
Ambient conditions: temperature 20.8 C.; R.H. 60%
Extruded into strands (3/16" nominal dia.) for burn rate testing. Extruded easily.
Appendix B (cont.)

Colour was pure white.
Hygroscopic. Immediately after cooling to room temp, surfaces were damp.
Strand were soft and plastic, easily deformable after cooling to ambient.

*Strands*
After curing for 24 hours, strands were rigid and brittle.
All strands were painted with hi-heat aluminum paint.
An atmospheric burn rate test was conducted on an extruded strand, but data was lost.

**Propellant Batch #** KNSB-060299-060399-1

**Particulars**
Extruded into strands (3/16"nominal dia.) for burn rate testing. Extruded easily.
Colour was pure white.
Hygroscopic. Immediately after cooling to room temp, surfaces were damp.
Strand were soft and plastic, easily deformable after cooling to ambient.

*Strands*
After curing for 24 hours, strands were rigid and brittle.
All strands were painted with hi-heat aluminum paint.
An atmospheric burn rate test was conducted on an extruded strand:

\[
\begin{align*}
\text{Tamb:} & \quad 22 \text{ C.} \\
\text{B.P.:} & \quad 30.47 \text{ in.Hg.} \\
L_1 & = 2.29 \text{ cm.} \\
t_1 & = 9.31 \text{ sec.} \\
r_1 & = 0.246 \text{ cm/sec}
\end{align*}
\]

Comment: Inhibitor paint was scraped off of one side of strand to allow for better visual of flame front for more accurate gauge time measurement.

**Dry Mix Batch #** KNAD-110399

**Particulars**
105 g. Anhydrous Dextrose (AD), consumer grade
195g. Potassium Nitrate (KN), Veterinarian grade
300 g. Total dry mix
Both constituents ground finely using electric coffee grinder (approx. 20 sec.)
Both constituents accurately weighed using balance beam scale; rated 0.5 gram accuracy
Blended in rotation mixer (28 RPM) for 6 hours.

**Propellant Batch #** KNAD-110399-120399-2

**Particulars**
Extruded into strands (3/16"nominal dia.) for burn rate testing
Colour was ivory; slight caramelization was apparent.
Hygroscopic. Immediately after cooling to room temp, surfaces were damp.

*Strands*
All strands were painted with hi-heat aluminum paint.
Atmospheric burn rate test not conducted.
Propellant Batch #  KNSB-060299-180399-1

Particulars  
Extruded into strands (3/16"nominal dia.) for burnrate testing. Extruded easily. Colour was pure white 
Hygroscopic. Immediately after cooling to room temp, surfaces were damp. Strand were soft and plastic, easily deformable after cooling to ambient

Strands  
After curing for 24 hours, strands were somewhat flexible. All strands were painted with hi-heat aluminum paint. Atmospheric burn rate testing conducted on two strands:

\[
\begin{align*}
\text{Tamb:} & \quad 19.4 \text{ C.} \\
\text{B.P.:} & \quad 30.61 \text{ in.Hg.}
\end{align*}
\]

<table>
<thead>
<tr>
<th>Strands</th>
<th>L1 (cm)</th>
<th>t1 (sec)</th>
<th>r1 (cm/sec)</th>
<th>L2 (cm)</th>
<th>t2 (sec)</th>
<th>r2 (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strand #1</td>
<td>4.18</td>
<td>16.73</td>
<td>0.250</td>
<td>8.00</td>
<td>32.06</td>
<td>0.250</td>
</tr>
<tr>
<td>Strand #2</td>
<td>1.95</td>
<td>7.93</td>
<td>0.246</td>
<td>4.38</td>
<td>17.66</td>
<td>0.248</td>
</tr>
</tbody>
</table>

Comment: Strands were unpainted. Tested 24 hours after extruding. Strands were still somewhat flexible.

Figure B-1 – Atmospheric strand burning test setup showing gauge lengths
Appendix C

Strand Extruding Tool

The propellant strand extruding tool is shown in the figure below. It consists of a barrel into which the molten propellant slurry is loaded, a nozzle containing a circular orifice from which the propellant is extruded into the form of strands, and a handle. The plunger, which is a sliding fit (loose enough to help trapped air to escape), is pushed into the barrel as the tool is slowly moved along the recipient surface.

Prior to loading, the extruding tool was preheated in an oven at 80°C.

Insulated gloves were required to be worn when using this tool.

Three significant difficulties were encountered when using the extruding tool:

1. Even with insulated gloves, the tool quickly became uncomfortable to hold
2. Trapped air in the barrel resulted in occasional bubbles forming in the strands, which rendered that portion of the strand worthless.
3. Even though the tool was preheated, it was often a race to extrude the material before it began to “freeze”, when significant force would have been required to extrude the strands.

Figure C-1 – Diagram of Strand Extruding tool
Appendix D

Strand Burn Rate Trials

PB-1
Test DX300199-1  Strand Burning Test
KN-Dextrose (anhydrous) propellant
65/35 O/F ratio
Batch no.  KNAD-240199-290199-1

\[
\begin{align*}
\text{P}_{\text{initial}} &= 202 \text{ psig} \\
\text{P}_{\text{max}} &= 245 \text{ psig} \\
&= 43 \text{ psig} \\
\text{P}_{\text{average}} &= 223.5 \text{ psig}
\end{align*}
\]

Spike 1  24 (start pt.)
Spike 2  47 (start pt.)
23 Samples between spikes
3.333 Sample/sec. rate
\[\Delta t = 6.90 \text{ sec.}\]
\[L_{\text{gauge}} = 5.2 \text{ cm}\]
\[r = 0.754 \text{ cm/sec.}\]
\[(r = 0.297 \text{ in/sec.})\]

Notes:
1. Strand had slight flaw about 1/2 way down, an oval shallow concavity.
Appendix D (cont.)

PB-2
Test DX300199-2        Strand Burning Test
KN-Dextrose (anhydrous) propellant
65/35 O/F ratio
Batch no.   KNAD-240199-290199-1

$P_{\text{initial}} = 602 \text{ psig}$
$P_{\text{max}} = 700 \text{ psig}$
$P_{\text{average}} = 651 \text{ psig}$

Spike 1       24 (start pt.)
Spike 2       44 (start pt.)
20 Samples between spikes
3.333 Sample/sec. rate
$\Delta t = 6.00 \text{ sec.}$
$L_{\text{gauge}} = 6.6 \text{ cm}$
$r = 1.100 \text{ cm/sec.}$ ($r = 0.433 \text{ in/sec.}$)

Notes:
1. Lab thermometer placed on side of tank recorded $T_{\text{amb}}=21.6 \text{ C.}$ prior to test
2. Strand dimensions:
   $L_{\text{total}} = 8.3 \text{ cm.}$
   $D_{\text{maj}} = 0.80 \text{ cm.}$
   $D_{\text{min}} = 0.55 \text{ cm.}$
3. Strand had no apparent defects
Appendix D  (cont.)

PB-3
Test DX310199-1    Strand Burning Test
KN-Dextrose (anhydrous) propellant
65/35 O/F ratio
Batch no.   KNAD-240199-310199-1

\[ P_{\text{initial}} = 820 \, \text{psig} \]
\[ P_{\text{max}} = 880 \, \text{psig} \]
\[ P_{\text{average}} = 850 \, \text{psig} \]

Spike 1 \hspace{1cm} 50 \text{ (start pt.)}
Spike 2 \hspace{1cm} 60 \text{ (start pt.)}
10 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 3.00 \, \text{sec.} \]
\[ L_{\text{gauge}} = 7.25 \, \text{cm} \]
\[ r = 2.417 \, \text{cm/sec.} \]
\[ (r = 0.951 \, \text{in/sec.}) \]

**Note:** Result invalidated -- uncontrolled combustion occurred

**Notes:**
1. Strand had no apparent defects
2. Burning was initially even, then suddenly rate appeared to increase dramatically (based on pressure rise).

![Burn Sensor Output data](image)

Burn Sensor Output data
KN-Dextrose 65/35

Burn Sensor emf (mV)

Data point

850 psig
Appendix D  (cont.)

PB-4
Test DX020299-1  Strand Burning Test
KN-Dextrose (anhydrous) propellant
65/35 O/F ratio
Batch no.  KNAD-240199-310199-1

\[ P_{\text{initial}} = 915 \text{ psig} \]
\[ P_{\text{max}} = 990 \text{ psig} \]
\[ P_{\text{average}} = 952.5 \text{ psig} \]

Spike 1  19 (start pt.)
Spike 2  38 (start pt.)
   19 Samples between spikes
   3.333 Sample/sec. rate
\[ \Delta t = 5.70 \text{ sec.} \]
\[ L_{\text{gauge}} = 7.49 \text{ cm} \]
\[ r = 1.314 \text{ cm/sec.} \]
\[ (r = 0.517 \text{ in/sec.}) \]

Notes:
1. Strand painted with hi-heat paint, two coats, allowed to dry 24 hours.
2. Strand had a minor defect at mid length.
3. Failed to ignite at first attempt. Igniter was replaced with a shorter length nichrome wire.
4. Appeared to burn evenly, judging by sound and pressure rise.
Appendix D  (cont.)

PB-5
Test DX050299-1  Strand Burning Test
KN-Dextrose (anhydrous) propellant
65/35 O/F ratio
Batch no.  KNAD-240199-310199-1

\[ P_{\text{initial}} = 796 \text{ psig} \]
\[ P_{\text{max}} = 893 \text{ psig} \]
\[ P_{\text{average}} = 844.5 \text{ psig} \]

Spike 1  30 (start pt.)
Spike 2  56 (start pt.)
26 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 7.80 \text{ sec.} \]
\[ L_{\text{gauge}} = 10.2 \text{ cm} \]
\[ r = 1.308 \text{ cm/sec.} \]
\( (r = 0.515 \text{ in/sec.}) \)

**Notes:**
1. Strand had no apparent defects
2. Strand painted with hi-heat paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 12.45 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.37 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.65 \text{ cm} \]
Appendix D (cont.)

Test SB090299-1  Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no.  KNSB-060299-060299-1

\[ P_{\text{initial}} = 630 \text{ psig} \]
\[ P_{\text{max}} = 688 \text{ psig} \]
\[ P_{\text{average}} = 659 \text{ psig} \]

Spike 1 24 (start pt.)
Spike 2 52 (start pt.)
28 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 8.40 \text{ sec.} \]
\[ L_{\text{gauge}} = 8.00 \text{ cm} \]
\[ r = 0.952 \text{ cm/sec.} \]
\[ (r = 0.375 \text{ in/sec.}) \]

Notes:
1. Strand had no apparent defects
2. Strand painted with hi-heat paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 9.9 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.38 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.54 \text{ cm} \]

![Burn Sensor Output data](image)
Appendix D  (cont.)

PB-7
Test SB100299-1  Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no.  KNSB-060299-060299-1

\[ P_{\text{initial}} = 380 \text{ psig} \]
\[ P_{\text{max}} = 422 \text{ psig} \]
\[ P_{\text{average}} = 401 \text{ psig} \]

Spike 1  29 (start pt.)
Spike 2  55 (start pt.)

26 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 7.80 \text{ sec.} \]
\[ L_{\text{gauge}} = 6.18 \text{ cm} \]
\[ r = 0.792 \text{ cm/sec.} \]
\[ (r = 0.312 \text{ in/sec.}) \]

Notes:
1. Strand had no apparent defects
2. Strand painted with hi-heat paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 7.5 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.37 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.63 \text{ cm} \]
4. Ambient room temp 18.9 C.

![Burn Sensor Output data](image-url)
Appendix D (cont.)

PB-8
Test SB110299-1 Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no. KNSB-060299-060299-1

\[ P_{\text{initial}} = 180 \text{ psig} \]
\[ P_{\text{max}} = 220 \text{ psig} \]
\[ P_{\text{average}} = 200 \text{ psig} \]

Spike 1  32 (start pt.)
Spike 2  60 (start pt.)
28 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 8.40 \text{ sec.} \]
\[ L_{\text{gauge}} = 6.60 \text{ cm} \]
\[ r = 0.786 \text{ cm/sec.} \]
\( \left( r = 0.309 \text{ in/sec.} \right) \)

Notes:
1. Strand had no apparent defects
2. Strand painted with hi-heat paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 8.5 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.45 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.64 \text{ cm} \]
4. Ambient room temp 19.6 C.
Appendix D  (cont.)

PB-9
Test SB120299-1   Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no. KNSB-060299-060299-1

\[ P_{\text{initial}} = 1500 \text{ psig} \]
\[ P_{\text{max}} = 1565 \text{ psig} \]
\[ P_{\text{average}} = 1532.5 \text{ psig} \]

Spike 1    17 (start pt.)
Spike 2    48 (start pt.)

31 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 9.30 \text{ sec.} \]
\[ L_{\text{gauge}} = 10.50 \text{ cm} \]
\[ r = 1.129 \text{ cm/sec.} \]
\[ (r = 0.445 \text{ in/sec.}) \]

Notes:
1. Strand had no apparent defects
2. Strand painted with hi-heat paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 12.3 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.36 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.56 \text{ cm} \]
4. Ambient room temp 20.5 C.

![Burn Sensor Output data](image-url)
Appendix D  (cont.)

PB-10
Test DX130299-1  Strand Burning Test
KN-Dextrose (anhydrous) propellant
65/35 O/F ratio
Batch no.  KNAD-240199-310199-1

\[ P_{\text{initial}} = 1570 \text{ psig} \]
\[ P_{\text{max}} = 1650 \text{ psig} \]
\[ 80 \text{ psig} \]
\[ P_{\text{average}} = 1610 \text{ psig} \]

Spike 1  12 (start pt.)
Spike 2  36 (start pt.)
24 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 7.20 \text{ sec.} \]
\[ L_{\text{gauge}} = 10.02 \text{ cm} \]
\[ r = 1.392 \text{ cm/sec.} \]
\[ (r = 0.548 \text{ in/sec.}) \]

Notes:
1. Strand had no apparent defects
2. Strand painted with hi-heat paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 11.75 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.39 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.65 \text{ cm} \]
4. Ambient room temp 21.2C.

Burn Sensor Output data
KN-Dextrose 65/35
Appendix D (cont.)

PB-11
Test DX130299-2  Strand Burning Test
KN-Dextrose (anhydrous) propellant
65/35 O/F ratio
Batch no.  KNAD-240199-310199-1

\[ P_{\text{initial}} = 1230 \text{ psig} \]
\[ P_{\text{max}} = 1390 \text{ psig} \]
\[ P_{\text{average}} = 1310 \text{ psig} \]

Spike 1  18 (start pt.)
Spike 2  30 (start pt.)
12 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 3.60 \text{ sec.} \]
\[ L_{\text{gauge}} = 8.23 \text{ cm} \]
\[ r = 2.286 \text{ cm/sec.} \]
\[ (r = 0.900 \text{ in/sec.}) \]

Note: Result invalidated --uncontrolled combustion occurred

Notes:
1. Strand had two minor blemishes (concavities)
2. Strand painted with hi-heat paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 9.50 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.60 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.89 \text{ cm} \]
4. Strand began burning normally, then a sudden pressure rise was observed, and the sound emanating from the Firing Vessel grew briefly louder. This effect had been observed in earlier test that had premature ignition of the strand due to "drooling" of molten product. At Pmax, a slight metallic "crack" sound was heard emanating from the Firing Vessel. Later inspection revealed nothing unusual. Note that the strand used in this test was significantly “fatter” than typical (see dimensions).
Appendix D  (cont.)

PB-12  
Test SB130299-1  Strand Burning Test  
KN-Sorbitol propellant  
65/35 O/F ratio  
Batch no.  KNSB-060299-060299-1  

\[ P_{\text{initial}} = 975 \text{ psig} \]
\[ P_{\text{max}} = 1035 \text{ psig} \]
\[ P_{\text{average}} = 1005 \text{ psig} \]

Spike 1  22 (start pt.)  
Spike 2  54 (start pt.)  
32 Samples between spikes  
3.333 Sample/sec. rate  
\[ \Delta t = 9.60 \text{ sec.} \]
\[ L_{\text{gauge}} = 10.58 \text{ cm} \]
\[ r = 1.102 \text{ cm/sec.} \]
\[ (r = 0.434 \text{ in/sec.}) \]

Notes:  
1. Strand had no apparent defects  
2. Strand painted with hi-heat paint  
3. Strand nominal dimensions:  
   \[ L_{\text{TOT}} = 12.05 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.39 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.55 \text{ cm} \]
4. Appeared to burn well. Pressure rise was even. Sound from the Firing Vessel was slight.
Appendix D  (cont.)

PB-13
Test SB060399-1  Strand Burning Test
KN-Sorbitol  propellant
65/35 O/F ratio
Batch no.  KNSB-060299-060399-1

\[ P_{\text{initial}} = 800 \text{ psig} \]
\[ P_{\text{max}} = 860 \text{ psig} \]
\[ P_{\text{average}} = 830 \text{ psig} \]

Spike 1  27 (start pt.)
Spike 2  52 (start pt.)

25 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 7.50 \text{ sec.} \]
\[ L_{\text{gauge}} = 7.33 \text{ cm} \]
\[ r = 0.977 \text{ cm/sec.} \]
\[ (r = 0.385 \text{ in/sec.}) \]

Notes:
1. Strand had no apparent defects
2. Strand painted with hi-heat paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 9.15 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.35 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.70 \text{ cm} \]
4. Appeared to burn well. Pressure rise was even. Sound from the Firing Vessel was very slight.
5. Thermocouple reading went to OL (out of range) after sample # 55.

![Burn Sensor Output data]

Burn Sensor Output data
KN-Sorbitol 65/35
Appendix D (cont.)

PB-14
Test SB060399-2 Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no. KNSB-060299-060399-1

\[ P_{\text{initial}} = 260 \text{ psig} \]
\[ P_{\text{max}} = 295 \text{ psig} \]
\[ P_{\text{average}} = 277.5 \text{ psig} \]

Spike 1 \(= 34 \) (start pt.)
Spike 2 \(= 67 \) (start pt.)
33 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 9.90 \text{ sec.} \]
L\( \text{gauge} = 8.40 \text{ cm} \)
\[ r = 0.848 \text{ cm/sec.} \]
\( (r = 0.334 \text{ in/sec.}) \)

**Note**: Result invalidated -- flawed strand resulted in uncontrolled burn

![Burn Sensor Output data
KN-Sorbitol 65/35](image-url)
Appendix D  (cont.)

PB-15
Test DX070399-1  Strand Burning Test
KN-Dextrose propellant
65/35 O/F ratio
Batch no.  KNAD-060299-060399-1

\[ P_{\text{initial}} = 502 \text{ psig} \]
\[ P_{\text{max}} = 558 \text{ psig} \]
\[ P_{\text{average}} = 530 \text{ psig} \]

Spike 1  26 (start pt.)
Spike 2  48 (start pt.)
22 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 6.60 \text{ sec.} \]
\[ L_{\text{gauge}} = 8.10 \text{ cm} \]
\[ r = 1.227 \text{ cm/sec.} \]
\[ (r = 0.483 \text{ in/sec.}) \]

Result invalidated - see note 5.
PB-16
Test DX070399-2    Strand Burning Test
KN-Dextrose propellant
65/35 O/F ratio
Batch no.    KNAD-060299-060399-1

\[ P_{\text{initial}} = 500 \text{ psig} \]
\[ P_{\text{max}} = 545 \text{ psig} \]
\[ P_{\text{average}} = 522.5 \text{ psig} \]

Spike 1    27 (start pt.)
Spike 2    54 (start pt.)
27 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 8.10 \text{ sec.} \]
\[ L_{\text{gauge}} = 7.55 \text{ cm} \]
\[ r = 0.932 \text{ cm/sec.} \]
\[ (r = 0.367 \text{ in/sec.}) \]

Notes:
1. Strand had no discernible flaws.
2. Strand painted with hi-heat paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 9.6 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.54 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.38 \text{ cm} \]
4. Appeared to burn well. Pressure rise was even, as was the sound from the Firing Vessel.
Appendix D (cont.)

PB-17
Test DX140399-1  Strand Burning Test
KN-Dextrose propellant
65/35 O/F ratio
Batch no.  KNAD-110399-120399-2

\[ P_{\text{initial}} = 400 \text{ psig} \]
\[ P_{\text{max}} = 450 \text{ psig} \]
\[ P_{\text{average}} = 425 \text{ psig} \]

Spike 1  19 (start pt.)
Spike 2  54 (start pt.)
35 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 10.50 \text{ sec.} \]
\[ L_{\text{gauge}} = 8.72 \text{ cm} \]
\[ r = 0.830 \text{ cm/sec.} \]
\[ (r = 0.327 \text{ in/sec.}) \]

Notes:
1. Strand had no discernible flaws.
2. Strand painted with hi-heat paint
3. Strand (#7) nominal dimensions:
   \[ L_{\text{TOT}} = 10.4 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.37 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.60 \text{ cm} \]
4. Appeared to burn well. Pressure rise was even, almost no sound
5. Apparatus modified by the addition of an adjustable pressure release valve.
   The valve was set to vent at 405 psi. Provided some venting, but could not eliminate pressure rise.

Burn Sensor Output data
KN-Dextrose 65/35

![Burn Sensor Output Data](image)
Appendix D (cont.)

PB-18
Test DX160399-1 Strand Burning Test
KN-Dextrose propellant
65/35 O/F ratio
Batch no. KNAD-110399-120399-2

\[ P_{\text{initial}} = 305 \text{ psig} \]
\[ P_{\text{max}} = 345 \text{ psig} \]
\[ P_{\text{average}} = 325 \text{ psig} \]

Spike 1 24 (start pt.)
Spike 2 56 (start pt.)
32 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 9.60 \text{ sec.} \]
\[ L_{\text{gauge}} = 7.66 \text{ cm} \]
\[ r = 0.798 \text{ cm/sec.} \]
\[ (r = 0.314 \text{ in/sec.}) \]

Notes:
1. Strand had no discernible flaws.
2. Strand painted with hi-heat paint
3. Strand (#8) nominal dimensions:
   \[ L_{\text{TOT}} = 8.75 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.35 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.58 \text{ cm} \]
4. Appeared to burn well. Pressure rise was even, almost no sound
5. Apparatus modified by the addition of an adjustable pressure release valve.
   The valve was set to vent at 305 psi. Provided some venting, but could not eliminate pressure rise.
Appendix D (cont.)

PB-19
Test DX170399-1 Strand Burning Test
KN-Dextrose propellant
65/35 O/F ratio
Batch no. KNAD-110399-120399-2

\[ P_{\text{initial}} = 142 \text{ psig} \]
\[ P_{\text{max}} = 170 \text{ psig} \]
\[ P_{\text{average}} = 156 \text{ psig} \]

Spike 1: 30 (start pt.)
Spike 2: 56 (start pt.)
26 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 7.80 \text{ sec.} \]
L\(_{\text{gauge}} = 6.40 \text{ cm} \]
\[ r = 0.821 \text{ cm/sec.} \]
\[ (r = 0.323 \text{ in/sec.}) \]

Result invalidated. Foothill indicates 2nd sensor caught drool...premature ignition?

![Burn Sensor Output data](chart.png)

Title: Burn Sensor Output data
Subtitle: KN-Dextrose 65/35
Appendix D  (cont.)

PB-20
Test DX180399-1  Strand Burning Test
KN-Dextrose propellant
65/35 O/F ratio
Batch no.  KNAD-110399-120399-2

\[ P_{\text{initial}} = 130 \text{ psig} \]
\[ P_{\text{max}} = 165 \text{ psig} \]
\[ P_{\text{average}} = 147.5 \text{ psig} \]

Spike 1 \quad 13 \text{ (start pt.)}
Spike 2 \quad 48 \text{ (start pt.)}
35 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 10.50 \text{ sec.} \]
L gauge = 7.89 cm
\[ r = 0.751 \text{ cm/sec.} \]
\[ (r = 0.296 \text{ in/sec.}) \]

Notes:
1. Strand had no discernible flaws.
2. Strand painted with hi-heat paint
3. Strand (#6) nominal dimensions:
   \[ L_{\text{TOT}} = 9.65 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.38 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.61 \text{ cm} \]
4. Appeared to burn well. Pressure rise was even, almost no sound

![Burn Sensor Output data](image-url)

KN-Dextrose 65/35
Appendix D (cont.)

PB-21
Test DX180399-2  Strand Burning Test
KN-Dextrose propellant
65/35 O/F ratio
Batch no.   KNAD-060299-060399-1

$P_{\text{initial}} = 0 \text{ psig}$
$P_{\text{max}} = 0 \text{ psig}$
$P_{\text{average}} = 0 \text{ psig}$

Spike 1  29 (start pt.)
Spike 2  106 (start pt.)
77 Samples between spikes
3.333 Sample/sec. rate
$\Delta t = 23.10 \text{ sec.}$
$L_{\text{gauge}} = 4.96 \text{ cm}$
$r = 0.215 \text{ cm/sec.}$
$(r = 0.085 \text{ in/sec.}')$

Notes:
1. Strand had a cavity, but was not located in the gauge length
2. Strand painted with hi-heat paint
3. Strand was from previous batch, with nominal dimensions:
   $L_{\text{TOT}} = 6.75 \text{ cm}$
   $D_{\text{MIN}} = 0.42 \text{ cm}$
   $D_{\text{MAJ}} = 0.55 \text{ cm}$
4. This test was conducted at atmospheric pressure, inside the strand burner (fill tube disconnected and attach bolts were loosened to allow a gap. Vessel was purged prior to firing.
5. Appeared to burn well. Some smoke issued from the port, less than expected.
Appendix D  (cont.)

PB-22
Test SB200399-1  Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no.  KNSB-060299-180399-1

\[ P_{\text{initial}} = 280 \text{ psig} \]
\[ P_{\text{max}} = 308 \text{ psig} \]
\[ P_{\text{average}} = 294 \text{ psig} \]

Spike 1  27 (start pt.)
Spike 2  66 (start pt.)
39 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 11.70 \text{ sec.} \]
\[ L_{\text{gauge}} = 8.53 \text{ cm} \]
\[ r = 0.729 \text{ cm/sec.} \]
\[ (r = 0.287 \text{ in/sec.}) \]

Notes:
1. Strand had no apparent defects
2. Strand painted with hi-heat aluminum paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 9.55 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.30 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.50 \text{ cm} \]
4. Appeared to burn well.
5. On the graph, the spike that occurs at data pt.55 is considered to be a result of a ball of molten product dribbling onto the second TC sensor. The flame front is considered to reach the second TC sensor at data pt.66, at the start of the next spike.

![Burn Sensor Output data](image-url)
Appendix D (cont.)

PB-23
Test SB210399-1 Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no. KNSB-060299-180399-1

\[ P_{\text{initial}} = 180 \text{ psig} \]
\[ P_{\text{max}} = 208 \text{ psig} \]
\[ P_{\text{average}} = 194 \text{ psig} \]

Spike 1 29 (start pt.)
Spike 2 54 (start pt.)
25 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 7.50 \text{ sec.} \]
\[ L_{\text{gauge}} = 6.41 \text{ cm} \]
\[ r = 0.855 \text{ cm/sec.} \]
\( (r = 0.336 \text{ in/sec.}) \)

Result valid?. Strand flaws may have caused rapid burn.

Notes:
1. Strand had a number of surface defects. However, all blemishes were well coated with the hi-heat paint.
2. Strand painted with hi-heat aluminum paint
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 7.6 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.39 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.55 \text{ cm} \]
4. Appeared to burn well.

![Burn Sensor Output data](image-url)
Appendix D (cont.)

PB-24
Test SB220399-1 Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no. KNSB-060299-180399-1

\[ P_{\text{initial}} = 180 \text{ psig} \]
\[ P_{\text{max}} = 209 \text{ psig} \]
\[ P_{\text{average}} = 194.5 \text{ psig} \]

Spike 1 27 (start pt.)
Spike 2 45 (start pt.)
18 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 5.40 \text{ sec.} \]
\[ L_{\text{gauge}} = 6.60 \text{ cm} \]
\[ r = 4.222 \text{ cm/sec.} \]
\( (r = 0.481 \text{ in/sec.}) \)

**Result valid? Uncontrolled burned appears to have occurred.**

![Burn Sensor Output data](image)
Appendix D (cont.)

PB-25
Test SB260399-1  Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no.  KNSB-060299-180399-1

\[ P_{\text{initial}} = 180 \text{ psig} \]
\[ P_{\text{max}} = 204 \text{ psig} \]
\[ P_{\text{average}} = 192 \text{ psig} \]

Spike 1  29 (start pt.)
Spike 2  56 (start pt.)
27 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 8.10 \text{ sec.} \]
L\text{gauge} = 6.37 cm
\[ r = 0.786 \text{ cm/sec.} \]
\[ (r = 0.310 \text{ in/sec.}) \]

Notes:
1. Strand had a small cavity near centre, but was well painted
2. Strand painted with hi-heat aluminum paint. Paint scraped away at gauge marks
3. Strand nominal dimensions:
\[ L_{\text{TOT}} = 7.55 \text{ cm} \]
\[ D_{\text{MIN}} = 0.36 \text{ cm} \]
\[ D_{\text{MAJ}} = 0.45 \text{ cm} \]
4. Appeared to burn well
5. Strand burner vessel was mounted horizontally, rather than vertical as in previous tests, to avoid the dribbling problem.
Appendix D  (cont.)

PB-26
Test SB290399-1  Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no.  KNSB-060299-180399-1

\[
\begin{align*}
\text{P}_{\text{initial}} &= 1170 \text{ psig} \\
\text{P}_{\text{max}} &= 1218 \text{ psig} \\
\text{P}_{\text{average}} &= 1194 \text{ psig}
\end{align*}
\]

Spike 1  26 (start pt.)
Spike 2  59 (start pt.)
33 Samples between spikes
3.333 Sample/sec. rate
\[
\Delta t = 9.90 \text{ sec.}
\]

\[
\text{L}_{\text{gauge}} = 10.80 \text{ cm}
\]

\[
\text{r} = 1.091 \text{ cm/sec.}
\]
\[
\text{(r} = 0.429 \text{ in/sec.})
\]

Notes:
1. Strand had no apparent flaws
2. Strand painted with hi-heat aluminum paint. Paint scraped away at gauge marks
3. Strand nominal dimensions:
   \[
   \begin{align*}
   L_{\text{TOT}} &= 12.1 \text{ cm} \\
   D_{\text{MIN}} &= 0.35 \text{ cm} \\
   D_{\text{MAJ}} &= 0.48 \text{ cm}
   \end{align*}
   \]
4. Appeared to burn well
5. Strand burner vessel was mounted horizontally, rather than vertical as in most previous tests, to avoid the drooling problem.

![Burn Sensor Output data]

KN-Sorbitol 65/35

---

51
PB-27  
Test DX300399-1  Strand Burning Test  
KN-Dextrose propellant  
65/35 O/F ratio  
Batch no.  KNAD-110399-120399-2

\[ \text{P}_{\text{Initial}} = 1370 \text{ psig} \]
\[ \text{P}_{\text{Max}} = 1440 \text{ psig} \]
\[ \text{P}_{\text{Average}} = 1405 \text{ psig} \]

Spike 1  33 (start pt.)  
Spike 2  63 (start pt.)  
30 Samples between spikes  
3.333 Sample/sec. rate  
\[ \Delta t = 9.00 \text{ sec.} \]

\[ L_{\text{Gauge}} = 11.70 \text{ cm} \]
\[ r = 1.300 \text{ cm/sec.} \]
\[ (r = 0.512 \text{ in/sec.}) \]

**Notes:**  
1. Strand had no apparent flaws  
2. Strand painted with hi-heat paint, but was scraped away at gauge marks  
3. Strand (#3) with nominal dimensions:  
   \[ L_{\text{TOT}} = 12.95 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.35 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.50 \text{ cm} \]
4. Appeared to burn well, although quite quickly  
5. Vessel mounted horizontally.
Appendix D (cont.)

PB-28
Test DX310399-1   Strand Burning Test
KN-Dextrose propellant
65/35 O/F ratio
Batch no. KNAD-110399-120399-2

\[ P_{\text{initial}} = 1178 \text{ psig} \]
\[ P_{\text{max}} = 1258 \text{ psig} \]
\[ 80 \text{ psig} \]
\[ P_{\text{average}} = 1218 \text{ psig} \]

Spike 1 23 (start pt.)
Spike 2 52 (start pt.)
29 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 8.70 \text{ sec.} \]
\[ L_{\text{gauge}} = 10.72 \text{ cm} \]
\[ r = 1.232 \text{ cm/sec.} \]
\[ (r = 0.485 \text{ in/sec.}) \]

Notes:
1. Strand had a minor imperfection near each end
2. Strand painted with hi-heat paint, but was scraped away at gauge marks
3. Strand (#4) with nominal dimensions:
   \[ L_{\text{TOT}} = 12.4 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.39 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.58 \text{ cm} \]
4. Appeared to burn well, although quite quickly
5. Vessel mounted horizontally.

![Burn Sensor Output data](image.png)
Appendix D  (cont.)

PB-29  
Test DX020499-1  Strand Burning Test  
KN-Dextrose  propellant  
65/35 O/F ratio  
Batch no.  KNAD-110399-120399-2  

\[ \begin{align*}  
P_{\text{initial}} &= 1110 \text{ psig}  
P_{\text{max}} &= 1178 \text{ psig}  
P_{\text{average}} &= 1144 \text{ psig}  
\end{align*} \]

Spike 1  21 (start pt.)  
Spike 2  48 (start pt.)  
27 Samples between spikes  
3.333 Sample/sec. rate  
\[ \Delta t = 8.10 \text{ sec.} \]
L_{\text{gauge}} = 10.41 cm  
r = 1.285 cm/sec.  
\( (r = 0.506 \text{ in/sec.}) \)

Notes:  
1. Strand had no apparent flaws  
2. Strand painted with hi-heat paint, but was scraped away at gauge marks  
3. Strand (#2) with nominal dimensions:  
\[ \begin{align*}  
L_{\text{TOT}} &= 11.4 \text{ cm}  
D_{\text{MIN}} &= 0.38 \text{ cm}  
D_{\text{MAJ}} &= 0.61 \text{ cm}  
\end{align*} \]
4. Appeared to burn well, although quite quickly  
5. Vessel mounted horizontally.

![Burn Sensor Output data](chart.png)
Appendix D  (cont.)

PB-30
Test DX020499-2  Strand Burning Test
KN-Dextrose propellant
65/35 O/F ratio
Batch no.  KNAD-110399-120399-2

\[ \begin{align*}
P_{\text{initial}} &= 90 \text{ psig} \\
P_{\text{max}} &= 106 \text{ psig} \\
P_{\text{average}} &= 98 \text{ psig} \\
\end{align*} \]

Spike 1  40 (start pt.)
Spike 2  67 (start pt.)
27 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 8.10 \text{ sec.} \]
L_{\text{gauge}} = 6.15 cm
\[ r = 0.759 \text{ cm/sec.} \]
\( (r = 0.299 \text{ in/sec.}) \)

**Notes:**
1. Strand had no apparent flaws
2. Strand painted with hi-heat paint, but was scraped away at gauge marks
3. Strand (#1) (cut into two pieces) with nominal dimensions:
   \[ \begin{align*}
   L_{\text{TOT}} &= 6.95 \text{ cm} \\
   D_{\text{MIN}} &= 0.35 \text{ cm} \\
   D_{\text{MAJ}} &= 0.54 \text{ cm} \\
   \end{align*} \]
4. Appeared to burn well.
5. Vessel mounted horizontally.
Appendix D  (cont.)

PB-31
Test SB020499-1  Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no.  KNSB-060299-180399-1

\[ P_{\text{initial}} = 178 \text{ psig} \]
\[ P_{\text{max}} = 202 \text{ psig} \]
\[ P_{\text{average}} = 190 \text{ psig} \]

<table>
<thead>
<tr>
<th>Spike 1</th>
<th>27 (start pt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spike 2</td>
<td>55 (start pt.)</td>
</tr>
</tbody>
</table>

28 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 8.40 \text{ sec.} \]
\[ L_{\text{gauge}} = 6.56 \text{ cm} \]
\[ r = 0.781 \text{ cm/sec.} \]
\[ (r = 0.307 \text{ in/sec.}) \]

Notes:
1. Strand had a minor blemish about 1/3 from bottom
2. Strand painted with hi-heat paint, but was scraped away at gauge marks
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 7.4 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.35 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.50 \text{ cm} \]
4. Appeared to burn well.
Appendix D (cont.)

PB-32
Test SB020499-2  Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no.  KNSB-060299-180399-1

P_{initial} = 290 psig
P_{max} = 312 psig
P_{average} = 301 psig

Spike 1  24 (start pt.)
Spike 2  64 (start pt.)
40 Samples between spikes
3.333 Sample/sec. rate
\Delta t = 12.00 sec.
L_{gauge} = 9.18 cm
r = 0.765 cm/sec.
(r = 0.301 in/sec.‘)

Notes:
1. Strand had a number of minor blemishes
2. Strand painted with hi-heat paint, but was scraped away at gauge marks
3. Strand nominal dimensions:
   \( L_{TOT} = 10.2 \text{ cm} \)
   \( D_{MIN} = 0.34 \text{ cm} \)
   \( D_{MAJ} = 0.41 \text{ cm} \)
4. Appeared to burn well (slowly).

![Burn Sensor Output data](image)
Appendix D  (cont.)

PB-33
Test SB030499-1    Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no.   KNSB-060299-180399-1

$P_{\text{initial}} = 519$ psig
$P_{\text{max}} = 550$ psig
$P_{\text{average}} = 534.5$ psig

Spike 1  32 (start pt.)
Spike 2  71 (start pt.)
39 Samples between spikes
3.33 Sample/sec. rate
$\Delta t = 11.70$ sec.
$L_{\text{gauge}} = 8.95$ cm
$r = 0.765$ cm/sec.
($r = 0.301$ in/sec.)

Notes:
1. Strand had a number of minor blemishes
2. Strand painted with hi-heat paint, but was scraped away at gauge marks
3. Strand nominal dimensions:
   $L_{\text{TOT}} = 10$ cm
   $D_{\text{MIN}} = 0.29$ cm
   $D_{\text{MAJ}} = 0.55$ cm
4. Appeared to burn well (quite slowly).

[Graph depicting Burn Sensor Output data for KN-Sorbitol 65/35]
Appendix D  (cont.)

PB-34  
Test SB030499-2  Strand Burning Test 
KN-Sorbitol propellant 
65/35 O/F ratio 
Batch no.  KNSB-060299-180399-1

\[ P_{\text{initial}} = 86 \text{ psig} \]  
\[ P_{\text{max}} = 103 \text{ psig} \]  
\[ P_{\text{average}} = 94.5 \text{ psig} \]

Spike 1  43 (start pt.)  
Spike 2  57 (start pt.)

14 Samples between spikes  
3.333 Sample/sec. rate  
\[ \Delta t = 4.20 \text{ sec.} \]  
\[ L_{\text{gauge}} = 5.54 \text{ cm} \]  
\[ r = 1.319 \text{ cm/sec.} \]  
\( r = 0.519 \text{ in/sec.} \)

Invalid result. Uncontrolled burn?

Notes: 
1. Strand had a number of minor blemishes and irregularities.  
2. Strand painted with hi-heat paint, but was scraped away at gauge marks  
3. Strand nominal dimensions:  
\[ L_{\text{TOT}} = 6.25 \text{ cm} \]  
\[ D_{\text{MIN}} = 0.37 \text{ cm} \]  
\[ D_{\text{MAJ}} = 0.44 \text{ cm} \]  
4. Appeared to burn well (quite slowly).

<table>
<thead>
<tr>
<th>Data point</th>
<th>Burn Sensor emf (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Burn Sensor Output data](image)
Appendix D (cont.)

PB-35
Test SB030499-3 Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no. KNSB-060299-180399-1

\[ P_{\text{initial}} = 90 \text{ psig} \]
\[ P_{\text{max}} = 115 \text{ psig} \]
\[ P_{\text{average}} = 102.5 \text{ psig} \]

Spike 1 36 (start pt.)
Spike 2 56 (start pt.)
20 Samples between spikes
3.333 Sample/sec. rate
\[ \Delta t = 6.00 \text{ sec.} \]
Lgauge = 5.62 cm
\[ r = 0.937 \text{ cm/sec.} \]
(\[ r = 0.369 \text{ in/sec.}' \])

Notes:
1. Strand had minor blemishes
2. Strand painted with hi-heat paint, but was scraped away at gauge marks
3. Strand nominal dimensions:
   \[ L_{\text{TOT}} = 6.3 \text{ cm} \]
   \[ D_{\text{MIN}} = 0.35 \text{ cm} \]
   \[ D_{\text{MAJ}} = 0.60 \text{ cm} \]
4. Appeared to burn well
Appendix D (cont.)

PB-36
Test SB040499-1 Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no. KNSB-060299-180399-1

\[
\begin{align*}
\text{P}_{\text{initial}} &= 82 \text{ psig} \\
\text{P}_{\text{max}} &= 108 \text{ psig} \\
\text{P}_{\text{average}} &= 26 \text{ psig} \\
\text{P}_{\text{average}} &= 95 \text{ psig}
\end{align*}
\]

Spike 1 25 (start pt.)
Spike 2 57 (start pt.)
32 Samples between spikes
3.333 Sample/sec. rate
\[\Delta t = 9.60 \text{ sec.}\]
L_{\text{gauge}} = 8.62 cm
\[r = 0.898 \text{ cm/sec.} \quad (r = 0.354 \text{ in/sec.}^{'})\]

Notes:
1. Strand had no apparent flaws
2. Strand painted with hi-heat paint, but was scraped away at gauge marks
3. Strand nominal dimensions:
   \[L_{\text{TOT}} = 9.86 \text{ cm}\]
   \[D_{\text{MIN}} = 0.31 \text{ cm}\]
   \[D_{\text{MAJ}} = 0.52 \text{ cm}\]
4. Appeared to burn well (quite slowly, but quicker at first).
Appendix D  (cont.)

PB-37
Test SB040499-2  Strand Burning Test
KN-Sorbitol propellant
65/35 O/F ratio
Batch no.  KNSB-060299-180399-1

\[
\begin{align*}
P_{\text{initial}} & = 0 \text{ psig} \\
P_{\text{max}} & = 0 \text{ psig} \\
P_{\text{average}} & = 0 \text{ psig} \\
\end{align*}
\]

Spike 1  20 (start pt.)
Spike 2  83 (start pt.)

63 Samples between spikes
3.333 Sample/sec. rate
\[\Delta t = 18.90 \text{ sec.}\]
\[L_{\text{gauge}} = 4.83 \text{ cm}\]
\[r = 0.256 \text{ cm/sec.}\]
\[r = 0.101 \text{ in/sec.}^{*}\]

**Notes:**
1. Strand had no apparent flaws
2. Strand painted with hi-heat paint, but was scraped away at gauge marks
3. Strand nominal dimensions:
   \[
   \begin{align*}
   L_{\text{TOT}} & = 5.6 \text{ cm} \\
   D_{\text{MIN}} & = 0.38 \text{ cm} \\
   D_{\text{MAJ}} & = 0.59 \text{ cm} \\
   \end{align*}
   \]
4. Appeared to burn well (quite slowly).
5. Test conducted at atmospheric pressure in firing vessel (purged).
Appendix E

Thermocouple Sampling Computer Program

'Program SAMP written by R. Nakka, Jan. 1999 (QuickBasic 4.5)
'The purpose of this program is to sample data from the Micronta 22-168A
'Digital Volt Meter that interfaces to a PC. The data sampled is for Strand
'Burn rate testing.
CLS
OPTION BASE 1
DIM valu$(1000)
COLOR 2
PRINT "Sampling Program for Propellant Burnrate Testing"
PRINT "*****************************************************************************"
PRINT
INPUT "Enter a name for output file: ", fout$
OPEN fout$ FOR OUTPUT AS #1
PRINT
COLOR 14
PRINT "Set Thermocouple selector switch to TEMPERATURE"
PRINT
PRINT "Then PURGE and PRESSURIZE system before continuing..."
COLOR 2
PRINT
PRINT "After pressurizing, hit any key to record vessel ambient TC reading..."
PRINT
dum$ = INPUT$(1)
OPEN "com1:1200,N,7,2,RS,CS,DS,CD" FOR RANDOM AS #2 'meter port
getsamp$ = "D" 'signal to get data
PRINT #2, "getsamp$"
Temp$ = INPUT$(14, #2)
PRINT "Vessel ambient TC reading =", Temp$
PRINT #1, Temp$
PRINT
COLOR 14
PRINT "Select Thermocouple selector switch to SENSOR"
COLOR 2
PRINT
INPUT "Enter number of data points to record (1000 max.)", Npts$
PRINT
PRINT "Hit any key to begin recording data..."
PRINT
dum$ = INPUT$(1)
PRINT "Recording..."
FOR count% = 1 TO Npts$
    PRINT #2, "getsamp$"
    valu$(count%) = INPUT$(14, #2)
NEXT count%
PRINT "Recording stopped. Data written to output file."
FOR count% = 1 TO Npts$
    PRINT #1, valu$(count%)
NEXT count%
CLOSE #1
CLOSE #2
END