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Liquid Acquisition Device Design Sensitivity Study

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NOMENCLATURE

a	surface area to unit volume ratio of screen wire, m^{-1} (ft^{-1}) constant for a given screen
B	screen thickness, cm (ft); constant for a given screen
D	hydraulic diameter, cm (ft)
d	measured pore diameter, cm (ft); represents the average or effective open space between the wires
e	flow friction factor (dimensionless); constant for a given screen
g	ratio of actual acceleration to acceleration of Earth gravity, dimensionless
g_c	dimension conversion constant, 980 m/s^2 ($lbm \cdot ft/lbf \cdot s^2$)
h	LAD height, m (ft)
L	LAD distance between screen and liquid level, m (ft)
n	number of channels in LAD
P_{BP}	screen bubble point, kPa/m^2 (lb/ft^2)
P_{screen}	screen pressure
P_{total}	total pressure
R^2	multiple regression correlation coefficient
V	volumetric flow rate, L/s (ft^3/s)
W	LAD width, m (ft)
α	viscous resistance coefficient; experimental constant
β	inertial resistance coefficient; experimental constant
ΔP_D	pressure losses due to dynamic flow
ΔP_{FR}	pressure losses associated with friction as the fluid flows down the channel

NOMENCLATURE (Continued)

ΔP_{FTS}	pressure losses associated with flow through the screen
ΔP_{H}	pressure losses due to head
ε	screen volume void fraction; ratio of open space volume between wires compared to wire volume
μ	fluid viscosity, Newton-s/m^2 (lbm/ ft·s)
ρ	density of fluid, kg/m^3 (lb/ft^3)

TECHNICAL MEMORANDUM

LIQUID ACQUISITION DEVICE DESIGN SENSITIVITY STUDY

1. INTRODUCTION

1.1 Liquid Acquisition Devices Background

In-space propulsion can require reduced gravity engine startups, propellant transfer, and venting for pressure control, all of which can necessitate special provisions for liquid acquisition. The special provisions can be one of either of two categories: (1) Use of a settling acceleration to ensure the desired liquid-vapor positioning or (2) use of a capillary liquid acquisition device (LAD), which takes advantage of surface tension forces to either position the bulk liquid and vapor (a vane device) or to act as a barrier to vapor flow (a screen channel device), permitting the passage of liquid only. Settling acceleration forces, either intermittent or continuous, have been implemented on cryogenic upper stages to support one to two main engine starts and pressure control venting. However, future cryogenic applications, such as on-orbit transfer and a reaction control system (RCS), cannot necessarily use acceleration due to conflict with other vehicle requirements and/or because of the random nature of RCS thrust directions and durations. In such cases, a LAD, either vaned or screened, must be considered.

Vane devices are designed to take advantage of surface tension forces to favorably position both liquid and gas within a tank, but typically encompass almost the entire tank volume. Therefore, vane devices historically have been used only in special cases, i.e., as small storable propellant tanks operating with low acceleration forces and flow rates.

Screen channel LADs with fine mesh screens are designed to act as capillary barriers that allow gas-free liquid to be expelled regardless of the liquid's position within the tank. Referring to figure 1, pressurized outflow is typically used to push liquid from the tank into the channel and then to the feed system outlet. The channels typically consist of rectangular or triangular stainless steel tubing with screen-covered openings on one side. The screened openings allow fluid to enter the channel while simultaneously surface tension blocks the passage of vapor.

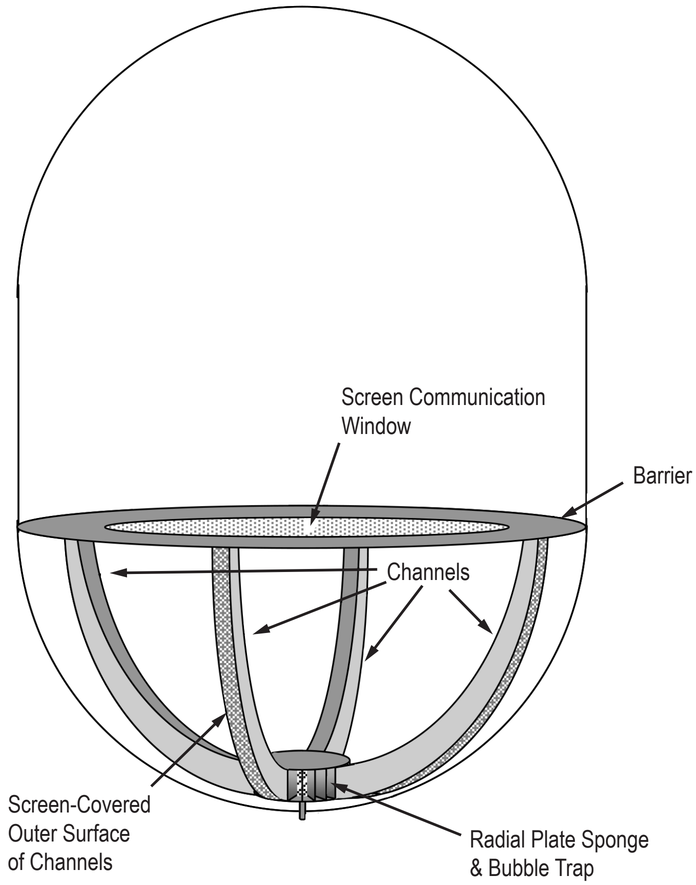

Figure 1. Screen-channel-type LAD propulsion system example application.

Screen channels have been implemented extensively for storable propellant orbital maneuvering and reaction control flight systems. Despite extensive on-orbit experience with storable propellants, experience with cryogenic applications is currently limited to ground testing. Although the principles of surface tension are the same for both storable and cryogenic liquids, there are additional thermal control challenges inherent in the cryogen application. The results presented herein have application to both storable and cryogenic propellants, assuming that the cryogen technology exists to remove the thermodynamic uncertainties.

1.2 Study Objective

The objective of this study is to define an analytical approach for selecting the best screen mesh for representative LAD performance requirements, wherein the best screen is defined as one that results in the smallest LAD area when compared to any other screen candidates. For example, under what conditions is a 325×2,300 screen mesh the best choice when designing a LAD? The approach for achieving this objective is discussed in the following sections.

2. ANALYTICAL APPROACH

The analysis of a screen channel necessitates a basic understanding of the candidate screen geometries, their physical parameters/notations, and the pressure drop sources and equations. These elements, along with the analytical sequence, are discussed in this section.

2.1 Candidate Screen Geometries and Physical Parameters

Available screens are identified by the weave pattern used to generate the mesh. The wires are denoted as warp or shute, depending on their direction in the weave; warp and shute wires are perpendicular to one another. Weave patterns can be plain square, full twill, plain Dutch, and twilled Dutch (each shute wire travels over two warp wires before going under a warp wire). The weave pattern of a twilled Dutch screen is shown in figure 2.

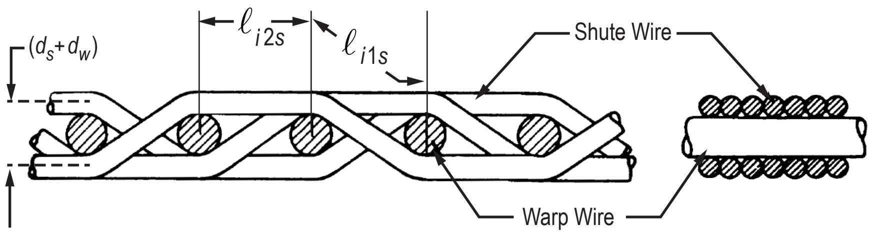

Figure 2. Twilled Dutch screen weave pattern.

In addition to being identified by its weave pattern, a screen is identified by the number of wires per inch associated with the shute and warp wires. A 325×2,300 twilled Dutch screen means that, for every square inch of wire, there are 325 wires in the warp direction and 2,300 wires perpendicular to the warp direction, or in the shute direction. A 325×2,300 screen has a very fine mesh weave, whereas a 160×800 screen has a very relatively coarse mesh weave. If a screen-type device is chosen for the LAD, then as described in subsequent sections, the LAD designer must determine the appropriate number of channels, the best screen mesh, and the channel dimensions.

2.2 Screen Channel Pressure Drop Sources

Choosing a screen mesh is not always straightforward. The total pressure drop of the LAD has four different components (fig. 3): (1) Pressure losses due to head (ΔP_H), (2) pressure losses associated with flow through the screen (ΔP_{FTS}), (3) pressure losses associated with friction as the

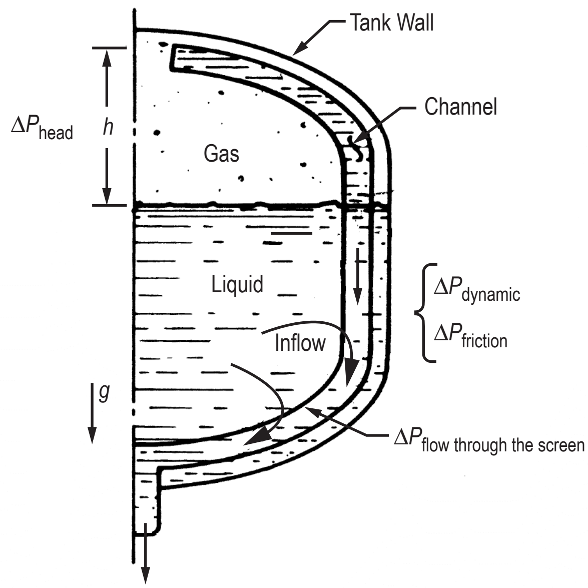

Figure 3. Individual pressure drop contributors.

fluid flows down the channel (ΔP_{FR}), and (4) pressure losses due to dynamic flow (ΔP_{D}). As shown in equation (1), the summation of these four components (P_{total}) must be less than the screen bubble point pressure (P_{BP}) to avoid screen breakdown and vapor ingestion into the LAD channel:

$$P_{BP} > \Delta P_{total} = \Delta P_{H} + \Delta P_{FTS} + \Delta P_{FR} + \Delta P_{D} \ . \quad (1)$$

Table 1 identifies equations for each individual pressure drop.

Table 1. Individual pressure drop terms.

Pressure Drop Term (lb/ft^2)	**Physical Representation**	**Equation**
ΔP_H	Pressure losses due to head	ρgh
ΔP_{FTS}	Pressure losses due to flow through the screen (into the channel)	$\frac{\beta\alpha\mu a^2 V}{\varepsilon^2 nLWg_c} + \frac{\beta B\rho V^2}{n^2L^2W^2\varepsilon^2 dg_c}$
ΔP_{FR}	Pressure losses due to friction from the flow down the LAD channel (to the engine)	$\frac{96\mu V}{2g_c D^2 nW} + \frac{\rho V^2}{n^2LW^2 8g_c D(\log(3.7D/e))^2}$
ΔP_D	Pressure losses due to dynamic flow down the LAD channel	$\frac{\rho V^2}{2L^2W^2n^2g_c}$

Integration of the table 1 equations into equation (1) yields the following:

$$P_{\text{total}} > \rho gh + \frac{\beta\alpha\mu a^2 V}{\varepsilon^2 nLWg_c} + \frac{\beta B\rho V^2}{n^2 L^2 W^2 \varepsilon^2 dg_c} + \frac{96\mu V}{2g_c D^2 nW}$$

$$+ \frac{\rho V^2}{n^2 LW^2 8g_c D(\log(3.7D/e))^2} + \frac{\rho V^2}{2L^2 W^2 n^2 g_c} \ . \qquad (2)$$

Application of the preceding relationships and definitions are discussed in the following section.

2.3 Analysis Sequence and Assumptions

The terms used in the statistical modeling applied herein are defined in appendix A. Because pressure losses due to head are independent of screen choice, pressure losses due to head were examined first. In cases in which acceleration was not the major contributor to the total pressure drop, a statistical regression analysis was used to determine which predictor variables (conditions) and variable interactions are drivers for screen LAD widths. At first glance, it would appear that the predictor variables of interest in the regression would be as defined in table 1: g, h, β, α, a, V, ε, n, L, B, d, e, and P_{BP}. However, because some predictor variables are determined by other choices (e.g., α is determined by screen choice), the choice of which predictor variables to use in the regression model were not straightforward.

The physical factors that could be varied are as follows: percent tank fill and the total LAD length (which determine L and h), liquid flow rate (V), the number of LAD channels (n), the acceleration (g), and the screen choice (which determines β, α, a, ε, B, d, e, and P_{BP}). Although the number of channels is known to affect the LAD width, earlier studies indicate that the LAD width multiplied by the number of channels is a constant.[2,3] Therefore, the effect of the number of channels is already understood and was removed as a variable in this study. Data from reference 3 was used in this current study.

Data for the regression analysis were obtained from a series of computer calculations using equation (2) to determine a minimum screen width versus the imposed conditions. The predictor variables chosen for the regression were the conditions that the engineer could change. These were acceleration, flow rate, percent fill, and type of screen. The regression model included only the main variables and two-way interactions. The acceleration levels and LAD heights were chosen (for the regression model) such that the ΔP_{H} losses did not dominate ΔP_{total}. To maintain computer computations at an acceptable level, only twilled Dutch weaves and isopropyl alcohol as the liquid were included in the analysis. The values of β, α, a, ε, B, d, e, and P_{BP} were treated as constants dependent upon the screen choice. Minitab, a piece of computer software, was used to analyze the data. Table 2 shows the predictor variable levels used for the analysis, while table 3 shows the screen constants for the Dutch twilled screens.

Table 2. Variable requirement levels used in analysis.

Main Variable	Low Level	High Level
Flow rate, kg/hr (lb/hr)	1,633 (3,600)	7,711 (17,000)
Fill level, %	5	95
LAD length, m (ft)	0.305 (1)	0.475 (1.557)
Acceleration, *g*	0.025	0.0095

Table 3. Screen constants for twilled Dutch screens.

	Screen Types		
Constants*	**165×800**	**200×1,400**	**325×2,300**
β	0.17	0.2	0.19
α	3.3	4.2	3.2
a	12,606	19,930	33,598
ε	0.426	0.248	0.245
B	0.000575	0.00050	0.000292
d	0.000082	0.0000328	0.0000164
e	0.012	0.0096	0.006
P_{BP}	4.95	12.23	17.66

* English units

3. ANALYTICAL RESULTS

The screen channel design sensitivity results due to head pressure (due to acceleration), the flow through the screen losses associated with fill level and flow rate, screen mesh, and bubble point are presented in the following sections.

3.1 Head Pressure Losses

The pressure losses due to head pressure, ΔP_H, are functions of LAD height and acceleration only. Although ΔP_H is not dependent on screen choice, there are limitations on the ΔP_H that each screen can tolerate. Setting ΔP_{total} equal to P_{BP}, the coarser screens (e.g., the 165×800 mesh) cannot sustain as much head before breakdown because of the reduced surface tension retention capability, or P_{BP}. To demonstrate this trend, a sensitivity analysis was conducted with isopropyl alcohol; the results are shown in table 4. Because the head losses do not depend on channel width, the calculations show the uncovered LAD height (*h*) each screen can sustain at the specified acceleration levels before breakdown. Note that, for this analysis, the acceleration levels were chosen such that the ΔP_H losses dominate ΔP_{total}. (For the regression analyses in sections 3.2 and 3.3, the acceleration levels are chosen such that the ΔP_H losses *do not* dominate ΔP_{total}.)

Table 4. Isopropyl alcohol head height at bubble point breakdown.

Screens	**165×800**	**200×1,400**	**325×2,300**
P_{BP}, kPa (psf)	0.24 (4.95)	0.59 (12.23)	0.85 (17.66)
Acceleration	Uncovered LAD height (or head) at breakdown, cm (in)		
0.01 *g*	22.6 (88.93)	55.8 (219.6)	80.57 (317.2)
0.1 *g*	2.26 (8.893)	5.58 (21.96)	8.06 (31.72)
1 *g*	0.23 (0.8893)	0.56 (2.196)	0.81 (3.172)

Table 4 shows that, as the acceleration increases an order of magnitude, so do the uncovered screen heights. The fine mesh screen held almost four times as much head as the coarse screen before breakdown. Therefore, it is apparent that some screens can be ruled out on the basis of acceleration requirements alone.

3.2 Flow Across Screen Losses

While table 4 showed that a finer mesh screen is better for large head retention requirements, or ΔP_H, it may not be the best choice if flow loss across the screen, or ΔP_{FTS}, is considered as an additional requirement. Using the predictor variables in table 3 and equation (2), minimum LAD widths necessary to avoid screen breakdown for various predictor variable level combinations were calculated and are listed in table 5. The data significance can best be visualized if it is presented in the form of a histogram, which is a graphical representation showing a visual impression of the distribution of data. As presented in figure 4, the data were arranged to show relative frequencies, or the proportion of cases versus channel width for each of the three meshes evaluated. Further details regarding individual pressure drops for each LAD width are presented in appendix B.

Table 5. Minimum LAD widths versus performance requirements.

Independent Variables (Performance Requirements)				Dependent Variables—Screen Width, cm (in)		
Flow Rate kg/hr (lb/hr)	Percent Fill	LAD Length m (ft)	Acceleration *g*	Screen 1 165×800	Screen 2 200×1,400	Screen 3 325×2,300
1,633 (3,600)	5	0.305 (1)	0.025	6.86 (2.7)	12.45 (4.9)	10.7 (4.2)
1,633 (3,600)	5	0.305 (1)	0.0095	5.84 (2.3)	11.68 (4.6)	10.4 (4.1)
1,633 (3,600)	5	0.475 (1.557)	0.025	5.39 (2.2)	8.64 (3.4)	7.11 (2.8)
1,633 (3,600)	5	0.475 (1.557)	0.0095	4.06 (1.6)	7.62 (3)	6.86 (2.7)
1,633 (3,600)	95	0.305 (1)	0.025	1.27 (0.5)	1.02 (0.4)	1.02 (0.4)
1,633 (3,600)	95	0.305 (1)	0.0095	1.27 (0.5	1.02 (0.4)	1.02 (0.4)
1,633 (3,600)	95	0.475 (1.557)	0.025	1.27 (0.5)	1.02 (0.4)	1.02 (0.4)
1,633 (3,600)	95	0.475 (1.557)	0.0095	1.27 (0.5)	1.02 (0.4)	1.02 (0.4)
7,711 (17,000)	5	0.305 (1)	0.025	32.26 (12.7)	59.2 (23.3)	50.8 (20)
7,711 (17,000)	5	0.305 (1)	0.0095	27.18 (10.7)	55.37 (21.8)	48.8 (19.2)
7,711 (17,000)	5	0.475 (1.557)	0.025	25.85 (10.1)	40.64 (16)	34.3 (13.5)
7,711 (17,000)	5	0.475 (1.557)	0.0095	18.8 (7.4)	36.32 (14.3)	31.75 (12.5)
7,711 (17,000)	95	0.305 (1)	0.025	2.8 (1.1)	3.3 (1.3)	3.05 (1.2)
7,711 (17,000)	95	0.305 (1)	0.0095	2.8 (1.1)	3.3 (1.3)	3.05 (1.2)
7,711 (17,000)	95	0.475 (1.557)	0.025	2.54 (1)	2.54 (1)	2.29 (0.9)
7,711 (17,000)	95	0.475 (1.557)	0.0095	2.54 (1)	2.54 (1)	2.29 (0.9)

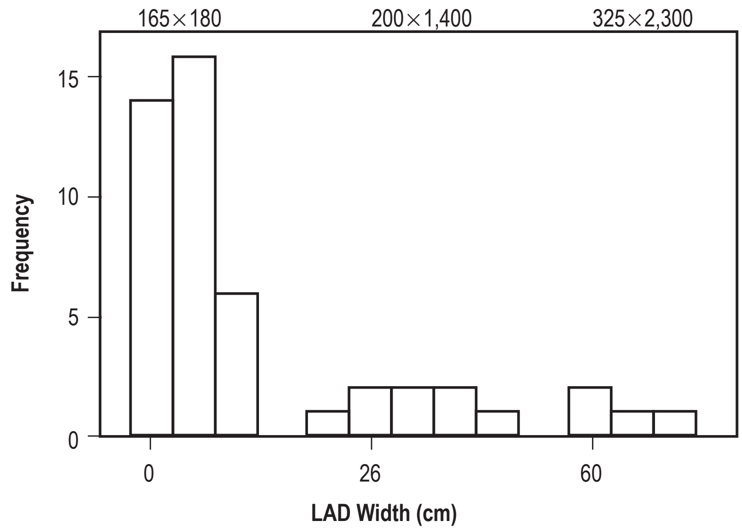

Figure 4. Histograms for minimum LAD widths with three screen meshes.

The coarsest mesh screen always returned the smallest LAD width for the conditions specified in table 2. In other words, for a given length, percent fill, flow rate, etc., the coarsest mesh screen would be the screen of choice because its LAD width is the smallest out of the three screens. This is because the flow through a coarse mesh screen is less impeded than the flow through a finer mesh screen; thus, the coarse mesh screen widths do not need to be as large to sustain flow. The data also show that, with the exception of the third data point (see app. B), all LAD widths greater than 25.4 cm (10 in) occur when the flow rate is high and the fill level is low. The high fill level exhibits a similar pattern when combined with high flow rates. This suggests that flow rates and fill levels may drive the LAD widths. Therefore, the preceding results were used to guide inputs for the 'stepwise and linear regression modeling' described in the next section (see app. A for definitions of statistical terms).

3.3 Stepwise and Linear Regression Modeling

With 5 main variables and 10 two-way interactions, a total of 15 terms could be used as predictor variables for the regression model. Including all these candidates is cumbersome and would not reveal any information on the most influential factors. Therefore, only those variables and/or interactions that highly influence LAD widths need to be included. Minitab offers a procedure called a 'stepwise regression,' which uses both forward selection and backward elimination techniques to identify a useful subset of predictor variables to use in the linear regression model. Both stepwise techniques were performed, and the predictor variables identified as significant variables to include in the linear modeling are listed in table 6, with further stepwise modeling details listed in appendix C.

Table 6. Stepwise regression significant variables.

Backward Stepwise Regression	Forward Stepwise Regression	Backward and Forward Stepwise Regression Common Predictor Variables
Screen	Percent fill	Flow rate
Flow rate	Flow rate	Flow rate × percent fill
Screen × flow rate	Flow rate × percent fill	Flow rate × LAD length
Screen × percent fill	Flow rate × LAD length	Screen × flow rate
Screen × LAD length	Screen × flow rate	Percent fill × LAD length
Flow rate × percent fill	Percent fill × LAD length	Screen × percent fill
Flow rate × LAD length	Screen × percent fill	–
Percent fill × LAD length	–	–

As expected, the flow rate and percent fill are the major drivers in both stepwise regression procedures. The screen choice and LAD length also affect the LAD width. Using the predictor variables identified in both regression techniques, a linear regression was performed and resulted in a model with a 92% R^2 value. The plot of the 'residuals' versus LAD widths and a histogram of the residuals are presented in figures 5 and 6, respectively (see app. D for further details). The residuals look fairly normal, and the high R^2 value for the regression model indicates that the variables chosen as the main drivers for the LAD widths are correct.

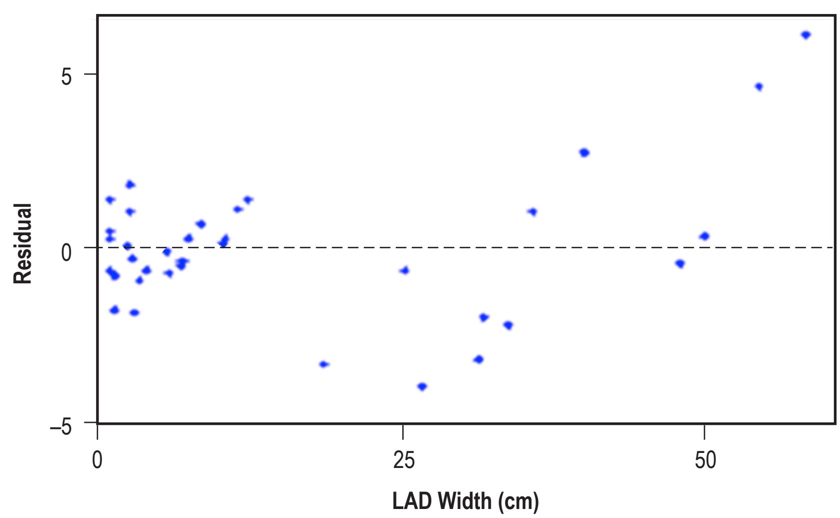

Figure 5. Residuals versus LAD width using linear regression model.

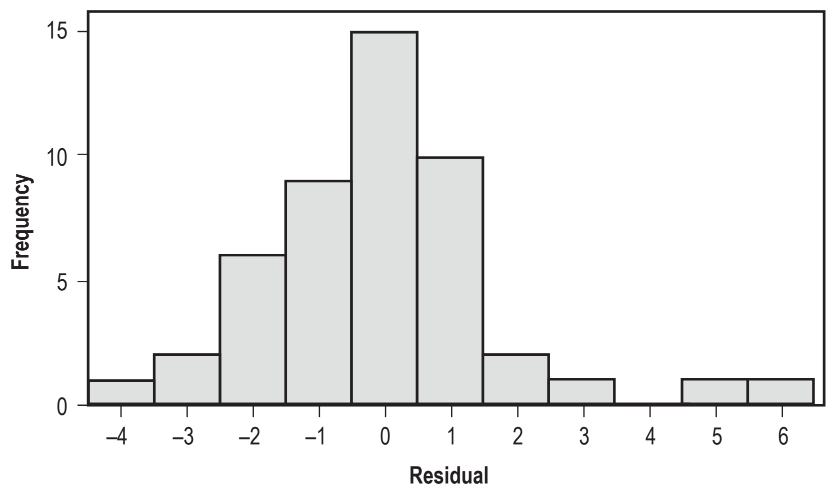

Figure 6. Residuals histogram for LAD width using linear regresison model.

Regardless of the screen chosen, the flow rate and percent fill are major drivers for determining the screen widths. Physically, this is easy to understand. For example, with a high flow rate and a low fill level (which leaves a large portion of the screen exposed), both ΔP_H and ΔP_{FTS} are at a maximum. Because ΔP_{FTS} is inversely proportional to the screen width, the screen width needs to be large enough to accommodate the flow requirements and avoid breakdown. If the width is too small, ΔP_{FTS}, in combination with the other pressure drop terms, will exceed ΔP_{BP} and cause screen breakdown. If the acceleration is low enough so that ΔP_{H} is a minor influence, then ΔP_{FTS} and ΔP_{FR} are the largest contributors to $\Delta P_{\mathrm{total}}$, making the coarse mesh screens a better choice.

What is peculiar about the data is that the finest mesh screen is the second best choice (e.g., the next-smallest LAD width). If lack of flow impedance is the reason why the coarsest mesh screen is better than the finest mesh screen, then it should reason that the second-most coarse screen should give the next-smallest LAD width for the same set of conditions. This trend is consistent throughout the data (i.e., at any variable level combination, the coarsest mesh screen always has the smallest LAD width, the finest mesh screen has the next-smallest LAD width, and the middle mesh screen has the largest LAD width). Therefore, the study described below was conducted to more closely investigate the combined design sensitivity of flow losses across the screen and bubble point.

3.4 Flow-Through Screen Loss and Bubble Point Combination

To investigate the combined influence of flow losses across the screen and bubble point, the ratio of ΔP_{FTS} to P_{BP} for a constant LAD width was compared. The three screens at all the combination of variable levels from table 2, with the exception of the high flow rates and low fill level combinations, were examined. If the LAD width was set to the largest LAD width, then the comparisons would not be meaningful, as the ratio of ΔP_{FTS} to P_{BP} would be too small in magnitude for most of the conditions. Ignoring the high flow rate and low fill level combinations, all other LAD widths are less than 12.5 cm (5 in), and so a constant LAD width of 12.5 cm was used for the calculations. Table 7 shows the ratio of ΔP_{FTS} to P_{BP} for the various combinations of conditions from table 2. Note that, for these calculations, ΔP_{total} will always be less than the P_{BP} of each screen. Appendix E contains further details on the total pressure drop, the ratio of ΔP_{FR} to P_{BP}, and the ratio of ΔP_{FTS+FR} to P_{BP}.

Table 7 shows that the coarsest mesh screen returns the smallest ratio of ΔP_{FTS} to P_{BP}, followed by the finest mesh screen, and then the middle screen. Therefore, the screen that will yield the smallest width for a given LAD design will be the screen that has the smallest ratio of ΔP_{FTS} to P_{BP}. This implies the designer must have a basic idea of the LAD configuration before beginning calculations for comparing screens. Note that the comparisons must be based on the same LAD geometry (i.e., same lengths and widths), or some means to correct for the different LAD geometries must be taken into account. A designer cannot compare screens based on P_{BP} and pressure head losses (H) alone. For example, if a designer tried to subtract the pressure head losses (H) from the bubble point pressure, and set this equal to the ΔP_{FTS} losses, the ratio of ΔP_{FTS} to P_{BP} would not follow the same trend as table 7. This is because the ΔP_{FTS} losses would be based upon different widths, and therefore different LAD performance capabilities. The effects of other screen parameters on the ratio of ΔP_{FTS} to P_{BP} are discussed in the following section.

Table 7. Ratio of ΔP_{FTS} to P_{BP} under various conditions.

Independent Variables				Dependent Variables (Ratio of ΔP_{FTS} to P_{BP}), Dimensionless		
Flow Rate kg/hr (lb/hr)	**Percent Fill**	**LAD Length m (ft)**	**Acceleration *g***	**Screen 1 165×800**	**Screen 2 200×1,400**	**Screen 3 325×2,300**
1,633 (3,600)	5	0.305 (1)	0.025	0.26	0.84	0.73
1,633 (3,600)	5	0.305 (1)	0.0095	0.26	0.84	0.73
1,633 (3,600)	5	0.475 (1.557)	0.025	0.15	0.48	0.42
1,633 (3,600)	5	0.475 (1.557)	0.0095	0.15	0.48	0.42
1,633 (3,600)	95	0.475 (1.557)	0.025	0.01	0.03	0.03
1,633 (3,600)	95	0.305 (1)	0.0095	0.01	0.03	0.03
1,633 (3,600)	95	0.475 (1.557)	0.025	0.01	0.02	0.02
1,633 (3,600)	95	0.475 (1.557)	0.0095	0.01	0.02	0.02
7,711 (17,000)	95	0.305 (1)	0.025	0.05	0.16	0.14
7,711 (17,000)	95	0.305 (1)	0.0095	0.05	0.16	0.14
17,000	95	0.475 (1.557)	0.025	0.03	0.10	0.09
17,000	95	0.475 (1.557)	0.0095	0.03	0.10	0.09

3.5 Screen Parameter Influences

To investigate the potential effects of the screen constants on the ratio of ΔP_{FTS} to P_{BP}, a correlation analysis using Minitab was performed on the results of table 7 and correlation details are presented in appendix F. However, no strong correlations were indicated (0.7 or higher) between the screen constants (β, α, a, ε, B, d, e, and P_{BP}) and the ratio of ΔP_{FTS} to P_{BP}. Because the high flow rate and low fill level combination data were not included in the analysis (see explanation in the previous section), the correlation was calculated using only the data for the 95% fill level with both the high and low flow rates. Only flow rate showed a strong correlation with the ratio of ΔP_{FTS} to P_{BP}. The calculation was repeated with the 1,633 kg/hr (3,600 lb/hr) flow rate and including both 5% and 95% fill. The fill level showed a strong correlation to the ratio of ΔP_{FTS} to P_{BP}. Therefore, as expected, the flow rate and fill levels drive the values for the ratio of ΔP_{FTS} to P_{BP}. However, it is cautioned that, because the flow rate and fill levels are such strong drivers, the screen constant effects may be 'masked.'

Therefore, to understand the potential effects of the screen constants, the correlation analysis was performed with the following conditions: (1) 1,633 kg/hr and 5% fill, (2) 1,633 kg/hr and 95% fill, and (3) 7,711 kg/hr and 95% fill. In all three cases, the ratio of ΔP_{FTS} to P_{BP} was highly correlated with β, e, d, and P_{BP}. Because screen widths correlate to the ratio of ΔP_{FTS} to P_{BP}, the values of β, e, d, and P_{BP} could be very influential in determining screen widths at a given flow rate and fill level. Accurate determination of these screen constants is very important.

4. CONCLUSIONS

It was confirmed that optimum screen mesh selection is highly dependent on screen channel LAD performance requirements. For example, a high expulsion rate at low fill levels' drives the LAD channel width to larger values to mitigate flow losses, regardless of screen choice. If accelerations are high during LAD expulsion, a screen with a high bubble point is desired to accommodate the large head retention requirement. After ruling out some screens on the basis of acceleration requirements alone, candidate screens were identified by using statistical regression analyses to compare the ratios of ΔP_{FTS} to P_{BP} for given constant conditions, i.e., through comparisons at fixed flow rates and fill levels.

Within the same flow rate and fill level, the screen constants, that is, screen thickness (B), flow friction factor (e), effective pore diameter (d), and bubble point (P_{BP}), can become the driving forces for the ΔP_{FTS} to P_{BP} ratio. Note that the comparison of these ratios for different screens must be based on the same LAD geometry (i.e., same lengths and widths), or some means for correcting for the different LAD geometries must be taken into account. This implies that the designer must have a basic idea of the LAD configuration before beginning calculations for comparing screens. The designer may wish to run several minor modifications to the LAD geometries to determine if the optimum screen choice changes for the given application. Analysis did indicate that coarse mesh screens may offer an advantage over fine mesh screens if the head retention requirement (ΔP_H) does not exceed the screen's bubble point (P_{BP}). Therefore, it is generally recommended that sensitivity studies always include the coarsest mesh screen that can support the head retention requirement as a candidate.

As noted above, the statistical analyses assumed fixed magnitudes for some mission requirements that actually are likely to be transient. Therefore, it is imperative that the conditions for which the LAD is expected to operate be clearly defined before beginning any analysis. An analysis for the expected screen widths, comparing a few candidate screens (using the procedures defined in the previous paragraph), can be performed using the following approach:

Step 1—Determine the worst-case acceleration requirement and the tank conditions at the time of the experienced acceleration (flow rate, tank fill level at end of maneuver, etc.). Calculate a minimum LAD width for several screen candidates.

Step 2—Determine the worst-case flow rate requirement (highest flow rate) and conditions at the time of the experienced flow rate (acceleration, tank fill level at end of maneuver). Calculate a minimum LAD width for several screen candidates.

Step 3—Determine the worst-case tank fill level requirement and corresponding conditions (flow rate and acceleration) at the end of the maneuver. Calculate a minimum LAD width for several screen candidates.

Step 4—Take the largest minimum LAD width from steps 1–3 for each screen candidate and choose the screen that results in the smallest channel width.

Step 5—Verify that the screen choice for the chosen LAD width was correct by comparing the ratios of ΔP_{FTS} to P_{BP} using the LAD width chosen from step 4 for each screen candidate.

Step 6—As a final check, verify that the LAD would not break down at other various stages in the mission.

Note that the evaluation of screen channel LAD performance described herein did not address any manufacturing aspects, tank sizes, or thermal conditions of the propellant and/or tank, all or any of which could also drive LAD design sensitivities. However, in the case of cryogenic propellants, for example, if tank conditioning is such that thermal effects are neutralized, then the results presented herein can be considered applicable.

APPENDIX A—STATISTICAL PROCEDURES AND TERMS DEFINITION

The various statistical procedures and terms implemented to assist in the evaluation LAD design sensitivities are described below.

A.1 Regression Analysis

In statistics, 'regression analysis' includes many techniques for modeling and analyzing several variables, when the emphasis is on the relationship between a dependent variable and one or more independent variables.[4] More specifically, regression analysis assists in understanding how a typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed. Most commonly, a regression analysis is used to estimate the conditional expectation of the dependent variable given the independent variables, i.e., the average value of the dependent variable when the independent variables are fixed. In all cases, the estimation target is a function of the independent variables called the regression function. In regression analysis, it is also of interest to characterize the variation of the dependent variable around the regression function, which can be described by probability distribution.

Regression analysis is also used to understand which among the independent variables are related to the dependent variable and to explore the forms of these relationships. A substantial number of techniques for performing regression analysis has been developed. Familiar methods such as 'linear and least ordinary squares regressions' are parametric, in that the regression function is defined in terms of a finite number of unknown parameters that are estimated from the data.

The performance of regression analysis methods in practice depends on the form of the data-generating process, and how it relates to the regression approach being used. Since the true form of the data-generating process is generally not known, regression analysis often depends, to some extent, on making assumptions about this process. These assumptions are sometimes testable if a large amount of data are available. Regression models for predictions are often useful even when the assumptions are moderately violated, although the results may not be optimal.

A.2 Multiple and Nonlinear Regressions

The intent of a 'multiple linear regression' is to find a linear relationship between a response variable and several possible predictor variables. The intent of a 'nonlinear regression' is to describe the relationship between a response variable and one or more explanatory variables in a nonlinear fashion.

A.3 Residual

The term 'residual' (or error) represents unexplained (or residual) variation after fitting a regression model. It is the difference (or left over) between the observed value of the variable and the value suggested by the regression model. A 'residual plot' is a graph that shows the residuals on the vertical axis and the independent variable on the horizontal axis. If the points in a residual plot are randomly dispersed around the horizontal axis, a linear regression model is appropriate for the data, otherwise, a nonlinear model is more appropriate. Residual plots show three typical patterns. A random pattern indicates a good fit for a linear model. Plot patterns that are nonrandom (U-shaped and inverted U) suggest a better fit for a nonlinear model.

A.4 Multiple Regression Correlation Coefficient

The 'multiple regression correlation coefficient,' R^2, is a measure of the proportion of variability explained by, or due to, the regression (linear relationship) in a sample of paired data. It is a number between zero and 1; a value close to zero suggests a poor model. However, a very high value of R^2 can arise even though the relationship between the two variables is nonlinear. The fit of a model should never simply be judged from the R^2 value.

A.5 Stepwise Regression

A 'best' regression model is sometimes developed in stages. In such applications a list of several potential explanatory variables are available and is repeatedly searched for variables that should be included in the model. The best explanatory variable is used first, then the second best, and so on. This procedure is known as 'stepwise regression.'

APPENDIX B—MINIMUM LIQUID ACQUISITION DEVICE WIDTH RESULTS

Table 8 gives minimum LAD width results; note that units of measure are not metric.

Table 8. Minimum LAD width results.

Predictor Variables					Response Variables					
Screen	Flow Rate	Percent Fill	LAD Length	Acceleration (*g*)	LAD Width	ΔP_H	ΔP_{FTS}	ΔP_{FR}	ΔP_D	P_{RP}/P_{screen}
165×800	3,600	5	1	0.025	2.7	1.59	3.08	0.17	0.11	1.61
165×800	3,600	5	1	0.0095	2.3	0.6	3.94	0.25	0.16	1.26
165×800	3,600	5	1.557	0.025	2.2	2.47	2.2	0.21	0.07	2.25
165×800	3,600	5	1.557	0.0095	1.6	0.94	3.44	0.44	0.13	1.44
165×800	3,600	95	1	0.025	0.5	0.08	0.55	4.31	0.01	9.09
165×800	3,600	95	1	0.0095	0.5	0.03	0.55	4.36	0.01	9.04
165×800	3,600	95	1.557	0.025	0.5	0.13	0.33	4.49	0	14.87
165×800	3,600	95	1.557	0.0095	0.5	0.05	0.34	4.56	0	14.76
165×800	17,000	5	1	0.025	12.7	15.9	3.12	0.13	0.12	1.59
165×800	17,000	5	1	0.0095	10.7	0.6	4.01	0.18	0.16	1.24
165×800	17,000	5	1.557	0.025	10.1	2.47	2.227	0.13	0.08	2.18
165×800	17,000	5	1.557	0.0095	7.4	0.94	3.62	0.25	0.14	1.37
165×800	17,000	95	1	0.025	1.1	0.08	1.5	3.22	0.04	3.29
165×800	17,000	95	1	0.0095	1.1	0.03	1.51	3.36	0.04	3.27
165×800	17,000	95	1.557	0.025	1	0.13	0.96	3.84	0.02	5.16
165×800	17,000	95	1.557	0.0095	1	0.05	0.97	3.91	0.02	5.11
200×1,400	3,600	5	1	0.025	4.9	1.59	10.54	0.07	0.03	1.16
200×1,400	3,600	5	1	0.0095	4.6	0.6	11.51	0.08	0.04	1.06
200×1,400	3,600	5	1.557	0.025	3.4	2.47	9.62	0.11	0.03	1.27
200×1,400	3,600	5	1.557	0.0095	3	0.94	11.12	0.14	0.04	1.10
200×1,400	3,600	95	1	0.025	0.4	0.08	5.27	6.87	0.01	2.32
200×1,400	3,600	95	1	0.0095	0.4	0.03	5.28	6.91	0.01	2.32
200×1,400	3,600	95	1.557	0.025	0.4	0.13	3.46	8.63	0.01	3.53
200×1,400	3,600	95	1.557	0.0095	0.4	0.05	3.48	8.7	0.01	3.52
200×1,400	17,000	5	1	0.025	23.3	1.59	10.5	0.11	0.03	1.16
200×1,400	17,000	5	1	0.0095	21.8	0.6	11.47	0.12	0.04	1.07
200×1,400	17,000	5	1.557	0.025	16	2.47	9.61	0.13	0.03	1.27
200×1,400	17,000	5	1.557	0.0095	14.3	0.94	11.11	0.15	0.04	1.1
200×1,400	17,000	95	1	0.025	1.3	0.08	9.61	2.51	0.03	1.27
200×1,400	17,000	95	1	0.0095	1.3	0.03	9.64	2.53	0.03	1.27

Table 8. Minimum LAD width results (Continued).

Predictor Variables					Response Variables					
Screen	Flow Rate	Percent Fill	LAD Length	Acceleration (*g*)	LAD Width	ΔP_H	ΔP_{FTS}	ΔP_{FR}	ΔP_D	P_{RP}/P_{screen}
200×1,400	17,000	95	1.557	0.025	1	0.13	7.75	4.33	0.02	1.58
200×1,400	17,000	95	1.557	0.0095	1	0.05	7.79	4.37	0.02	1.57
325×2,300	3,600	5	1	0.025	4.2	1.59	15.93	0.1	0.05	1.11
325×2,300	3,600	5	1	0.0095	4.1	0.6	16.9	0.11	0.05	1.05
325×2,300	3,600	5	1.557	0.025	2.8	2.47	14.99	0.16	0.04	1.18
325×2,300	3,600	5	1.557	0.0095	2.7	0.94	16.49	0.18	0.05	1.07
325×2,300	3,600	95	1	0.025	0.4	0.08	7.72	9.85	0.01	2.29
325×2,300	3,600	95	1	0.0095	0.4	0.03	7.73	9.89	0.01	2.28
325×2,300	3,600	95	1.557	0.025	0.4	0.13	5.09	12.44	0.01	3.47
325×2,300	3,600	95	1.557	0.0095	0.4	0.05	5.1	12.51	0.01	3.47
325×2,300	17,000	5	1	0.025	20	1.59	15.89	0.14	0.05	1.11
325×2,300	17,000	5	1	0.0095	19.2	0.6	16.86	0.15	0.05	1.05
325×2,300	17,000	5	1.557	0.025	13.5	2.47	14.98	0.17	0.04	1.18
325×2,300	17,000	5	1.557	0.0095	12.5	0.94	16.49	0.19	0.05	1.07
325×2,300	17,000	95	1	0.025	1.2	0.08	14.08	3.47	0.04	1.25
325×2,300	17,000	95	1	0.0095	1.2	0.03	14.11	3.48	0.04	1.25
325×2,300	17,000	95	1.557	0.025	0.9	0.13	11.4	6.11	0.03	1.55
325×2,300	17,000	95	1.557	0.0095	0.9	0.05	11.44	6.15	0.03	1.54

APPENDIX C—STEPWISE REGRESSION RESULTS

C.1 Backward Stepwise Regression

F-to-Enter: 1,000 F-to-Remove: 4
Response is W (LAD w on 15 predictors, with $N = 48$

Step: 1 2 3 4 5 6 7
Constant: –1.629 –1.114 –2.563 –1.983 –1.983 –1.983 –2.598

Screen: 2.6 2.3 2.7 2.7 2.7 2.7 2.5
T-Value: 1.37 1.36 2.22 2.24 2.26 2.25 2.1

Flowrate: 0.00110 0.00110 0.00113 0.00110 0.00113 0.00119 0.00117
T-Value: 4.53 4.59 5.14 5.30 5.58 5.99 5.9

% Fill: –0.028 –0.028 –0.025 –0.028 –0.037 –0.037
T-Value: –0.77 –0.78 –0.72 –0.83 –1.17 –1.17

LAD Length: –1.1 –1.1
T-Value: –0.35 –0.35

accel-er: 63 34 34
T-Value: 0.54 0.44 0.45

sc*fr: 0.00009 0.00009 0.00009 0.00009 0.00009 0.00009 0.00009
T-Value: 1.81 1.83 1.85 1.87 1.88 1.88 1.87

sc *%fil: –0.0206 –0.0206 –0.0206 –0.0206 –0.0206 –0.0206 –0.0246
T-Value: –2.72 –2.76 –2.79 –2.83 –2.84 –2.83 –3.79

sc*LL: –1.04 –1.04 –1.36 –1.36 –1.36 –1.36 –1.06
T-Value: –0.85 –0.86 –1.74 –1.76 –1.77 –1.76 –1.44

sc*accel: –15
T-Value: –0.34

fr*%fill: –0.00001 –0.00001 –0.00001 –0.00001 –0.00001 –0.00001 –0.00001
T-Value: –10.12 –10.26 –10.39 –10.50 –10.56 –10.53 –11.31

fr*ll: –0.00031 –0.00031 –0.00034 –0.00034 –0.00034 –0.00034 –0.00032
T-Value: –2.11 –2.14 –2.65 –2.68 –2.69 –2.69 –2.52

fr*accel: 0.0031 0.0031 0.0031 0.0048 0.0031
T-Value: 0.58 0.59 0.6 1.34 1.09

%fill*ll: 0.066 0.066 0.063 0.063 0.063 0.063 0.044
T-Value: 2.96 3 3.11 3.14 3.16 3.15 3.78

%fill*ac: –0.69 –0.69 –0.69 –0.51
T-Value: –0.87 –0.88 –0.89 –0.78

S: 1.93 1.9 1.88 1.86 1.85 1.85 1.86
R-Sq: 93.83 93.81 93.79 93.75 93.65 93.44 93.21

C.2 Forward Stepwise Regression

F-to-Enter: 4 F-to-Remove: 0
Response is W (LAD w on 15 predictors, with $N = 48$

Step: 1 2 3 4 5 6 7
Constant: 9.633796 4.804070 –0.007152 –0.007152 –0.007152 –0.007152 –0.007152

% fill: –0.093 –0.093 0.003 0.003 0.003 –0.059 –0.029
T-Value: –5.85 –7.57 0.19 0.21 0.22 –2.1 –0.96

Flowrate: 0.00047 0.00094 0.00133 0.00115 0.00137 0.00126
T-Value: 5.66 11.42 9.15 7.80 8.28 7.76

fr*%fill: –0.00001 –0.00001 –0.00001 –0.00001 –0.00001
T-Value: –7.67 –8.42 –9.11 –9.62 –10.15

fr*ll: –0.00031 –0.00031 –0.00048 –0.00048
T-Value: –3.17 –3.43 –4.35 –4.59

sc*frL: 0.00009 0.00009 0.00014
T-Value: 2.88 3.05 3.99

%fill*ll: 0.049 0.049
T-Value: 2.43 2.56

sc *%fil: –0.0153
T-Value: –2.37

S: 4.98 3.85 2.55 2.32 2.14 2.03 1.92
R-Sq: 42.67 66.50 85.66 88.37 90.30 91.52 92.56

APPENDIX D—LINEAR REGRESSION EQUATION RESULTS

D.1 Regression Analysis

The regression equation is:

$$W \text{ (LAD width)} = -0.215 + 0.00119 \text{ flowrate} - 0.000010 \text{ fr*\%fill} - 0.000425 \text{ fr*ll} + 0.000150 \text{ sc*fr} + 0.0336 \text{ \%fill*ll} - 0.0180 \text{ sc *\%fill}$$

Predictor Coef StDev T P
Constant: –0.2149 0.7290 –0.29 0.770
Flowrate: 0.0011924 0.0001456 8.19 0
fr*%fill: –0.00000963 0.00000087 –11.05 0
fr*ll: –0.00042475 0.00008921 –4.76 0
sc*fr: 0.00015043 0.00003401 4.42 0
%fill*ll: 0.03364 0.01094 3.07 0.004
sc *%fil: –0.018030 0.005810 –3.10 0.003

S = 1.921 R-Sq = 92.4% R-Sq(adj) = 91.3%

D.2 Analysis of Variance

Source: DF SS MS F P
Regression: 6 1836.84 306.14 82.97 0
Error: 41 151.28 3.69
Total: 47 1988.11

Source: DF Seq SS
Flowrate: 1 473.76
fr*%fill: 1 1228.99
fr*ll: 1 54.02
sc*fr: 1 38.21
%fill*ll: 1 6.33
sc *%fil: 1 35.53

Unusual Observations:

Obs	Flowrate	W	LAD w Fit	StDev	Fit Residual	St Residual
10	17,000	10.7	14.652	0.866	–3.952	–2.31R
25	17,000	23.3	17.119	0.703	6.181	3.46R
26	17,000	21.8	17.119	0.703	4.681	2.62R

R denotes an observation with a large standardized residual.

APPENDIX E—'FLOW THROUGH THE SCREEN LOSS' CONTRIBUTION AS A FUNCTION OF 'BUBBLE POINT PRESSURE' ANALYSIS

The predictor and response variables are given in table 9; note that units of measure are not metric.

Table 9. Predictor and response variables.

Predictor Variables					Response Variables			
Screen	Flow Rate	Percent Fill	LAD Length	Acceleration (*g*)	$\Delta P_{FTS}/P_{BP}$	$\Delta P_{FR}/P_{BP}$	ΔP_{FTS}+ $\Delta P_{FR}/P_{BP}$	ΔP_{total}
165×800	3,600	5	1	0.025	0.26	0.01	0.27	2.96
165×800	3,600	5	1	0.0095	0.26	0.01	0.27	1.98
165×800	3,600	5	1.557	0.025	0.15	0.01	0.15	3.25
165×800	3,600	5	1.557	0.0095	0.15	0.01	0.15	1.71
165×800	3,600	95	1	0.025	0.01	0	0.01	0.14
165×800	3,600	95	1	0.0095	0.01	0	0.01	0.09
165×800	3,600	95	1.557	0.025	0.01	0	0.01	0.17
165×800	3,600	95	1.557	0.0095	0.01	0	0.01	0.09
165×800	17,000	5	1	0.025	–	–	–	--
165×800	17,000	5	1	0.0095	–	–	–	--
165×800	17,000	5	1.557	0.025	–	–	–	--
165×800	17,000	5	1.557	0.0095	–	–	–	--
165×800	17,000	95	1	0.025	0.05	0.02	0.06	0.41
165×800	17,000	95	1	0.0095	0.05	0.02	0.06	0.35
165×800	17,000	95	1.557	0.025	0.03	0.01	0.04	0.34
165×800	17,000	95	1.557	0.0095	0.03	0.01	0.04	0.26
200×1,400	3,600	5	1	0.025	0.84	0.01	0.85	11.99
200×1,400	3,600	5	1	0.0095	0.84	0.01	0.85	11
200×1,400	3,600	5	1.557	0.025	0.48	0	0.48	8.38
200×1,400	3,600	5	1.557	0.0095	0.48	0	0.48	6.85
200×1,400	3,600	95	1	0.025	0.03	0	0.03	0.47
200×1,400	3,600	95	1	0.0095	0.03	0	0.03	0.42
200×1,400	3,600	95	1.557	0.025	0.02	0	0.02	0.38
200×1,400	3,600	95	1.557	0.0095	0.02	0	0.02	0.3
200×1,400	17,000	5	1	0.025	–	–	–	–
200×1,400	17,000	5	1	0.0095	–	–	–	–
200×1,400	17,000	5	1.557	0.025	–	–	–	–
200×1,400	17,000	5	1.557	0.0095	–	–	–	–

Table 9. Predictor and response variables (Continued).

Predictor Variables					Response Variables			
Screen	Flow Rate	Percent Fill	LAD Length	Acceleration (g)	$\Delta P_{FTS}/P_{BP}$	$\Delta P_{FR}/P_{BP}$	$\Delta P_{FTS}+\Delta P_{FR}/P_{BP}$	ΔP_{total}
200×1,400	17,000	95	1	0.025	0.16	0.01	0.17	2.14
200×1,400	17,000	95	1	0.0095	0.16	0.01	0.17	2.37
200×1,400	17,000	95	1.557	0.025	0.10	0.01	0.11	1.42
200×1,400	17,000	95	1.557	0.0095	0.10	0.01	0.11	1.33
325×2,300	3,600	5	1	0.025	0.73	0	0.73	14.51
325×2,300	3,600	5	1	0.0095	0.73	0	0.73	13.52
325×2,300	3,600	5	1.557	0.025	0.42	0	0.42	9.9
325×2,300	3,600	5	1.557	0.0095	0.42	0	0.42	8.36
325×2,300	3,600	95	1	0.025	0.03	0	0.03	0.58
325×2,300	3,600	95	1	0.0095	0.03	0	0.03	0.53
325×2,300	3,600	95	1.557	0.025	0.02	0	0.02	0.45
325×2,300	3,600	95	1.557	0.0095	0.02	0	0.02	0.37
325×2,300	17,000	5	1	0.025	–	–	–	–
325×2,300	17,000	5	1	0.0095	–	–	–	–
325×2,300	17,000	5	1.557	0.025	–	–	–	–
325×2,300	17,000	5	1.557	0.0095	–	–	–	–
325×2,300	17,000	95	1	0.025	0.14	0.01	0.15	2.68
325×2,300	17,000	95	1	0.0095	0.14	0.01	0.15	2.63
325×2,300	17,000	95	1.557	0.025	0.09	0	0.09	1.76
325×2,300	17,000	95	1.557	0.0095	0.09	0	0.09	1.68

Note: Shaded areas represent conditions excluded from analysis, i.e., low fill level with high flow rate.

Screen Type	P_{BP}
165×800	4.95
200×1,400	12.23
325×2,300	17.66

APPENDIX F—SCREEN CORRELATION PARAMETER ANALYSIS

(Pearson) correlations between the ratio of ΔP_{FTS} to P_{BP}, and ΔP_{FTS} to various screen parameters:

Using all data results from table 7:

ratio fts beta alpha a voidfrac d B
fts 0.959
beta 0.325 0.367
alpha 0.186 0.089 0.693
a 0.214 0.386 0.515 -0.261
voidfrac -0.324 -0.423 -0.940 -0.406 -0.776
d -0.302 -0.433 -0.839 -0.189 -0.899 0.974
B -0.190 -0.366 -0.434 0.348 -0.996 0.715 0.855
e -0.228 -0.396 -0.564 0.204 -0.998 0.811 0.923 0.989
Pbp 0.270 0.423 0.716 -0.007 0.967 -0.911 -0.981 -0.940
flowrate -0.296 -0.261 0.000 0.000 -0.000 0.000 0.000 0.000
fill lev -0.807 -0.712 -0.000 0.000 0.000 0.000 0.000 -0.000
lad heig -0.209 -0.185 0.000 0.000 0.000 -0.000 -0.000 0.000
accelera -0.000 -0.000 0.000 -0.000 0.000 0.000 0.000 -0.000

e Pbp flowrate fill lev lad heig
Pbp -0.980
flowrate -0.000 0.000
fill lev -0.000 0.000 0.500
lad heig 0.000 -0.000 -0.000 -0.000
accelera -0.000 0.000 0.000 0.000 -0.000

Using data results with 95% fill from table 7 (includes 3,600 and 17,000 flowrate values)

ratio fts beta alpha a voidfrac d B
fts 0.949
beta 0.456 0.495
alpha 0.249 0.107 0.693
a 0.314 0.537 0.515 -0.261
voidfrac -0.460 -0.578 -0.940 -0.406 -0.776
d -0.433 -0.594 -0.839 -0.189 -0.899 0.974
B -0.281 -0.511 -0.434 0.348 -0.996 0.715 0.855
e -0.334 -0.550 -0.564 0.204 -0.998 0.811 0.923 0.989

Pbp 0.391 0.584 0.716 -0.007 0.967 -0.911 -0.981 -0.940
flowrate 0.752 0.635 -0.000 0.000 0.000 0.000 -0.000 -0.000
lad heig -0.251 -0.212 -0.000 0.000 0.000 -0.000 -0.000 -0.000
accelera 0.000 0.000 -0.000 0.000 -0.000 -0.000 0.000 -0.000

e Pbp flowrate lad heig
Pbp -0.980
flowrate -0.000 -0.000
lad heig -0.000 -0.000 -0.000
accelera -0.000 0.000 0.000 -0.000

Using data results with 3,600 lb/hr flowrate from table 7 (includes 5% and 95 % fill)
ratio fts beta alpha a voidfrac d B
fts 0.957
beta 0.352 0.394
alpha 0.202 0.096 0.693
a 0.231 0.414 0.515 -0.261
voidfrac -0.350 -0.455 -0.940 -0.406 -0.776
d -0.326 -0.465 -0.839 -0.189 -0.899 0.974
B -0.205 -0.393 -0.434 0.348 -0.996 0.715 0.855
e -0.246 -0.426 -0.564 0.204 -0.998 0.811 0.923 0.989
Pbp 0.292 0.454 0.716 -0.007 0.967 -0.911 -0.981 -0.940
lad heig -0.232 -0.204 -0.000 0.000 0.000 -0.000 -0.000 -0.000
accelera 0.000 0.000 -0.000 0.000 -0.000 -0.000 0.000 -0.000
fill lev -0.801 -0.702 0.000 -0.000 0.000 -0.000 0.000 -0.000

e Pbp lad heig accelera
Pbp -0.980
lad heig -0.000 -0.000
accelera -0.000 0.000 -0.000
fill lev -0.000 0.000 0.000 0.000

Using data results with 3,600 lb/hr flowrate from table 7 (95 % fill)
ratio fts beta alpha a voidfrac d B
fts 0.936
beta 0.818 0.726
alpha 0.363 0.079 0.693
a 0.664 0.878 0.515 -0.261
voidfrac -0.866 -0.883 -0.940 -0.406 -0.776
d -0.841 -0.929 -0.839 -0.189 -0.899 0.974
B -0.610 -0.845 -0.434 0.348 -0.996 0.715 0.855
e -0.695 -0.895 -0.564 0.204 -0.998 0.811 0.923 0.989
Pbp 0.784 0.930 0.716 -0.007 0.967 -0.911 -0.981 -0.940
lad heig -0.408 -0.286 0.000 -0.000 0.000 -0.000 -0.000 0.000
accelera -0.000 0.000 -0.000 0.000 0.000 -0.000 0.000 -0.000

e Pbp lad heig
Pbp -0.980
lad heig -0.000 -0.000
accelera -0.000 0.000 -0.000

Using data results with 3,600 lb/hr from table 7 (includes 5% fill)
ratio fts beta alpha a voidfrac d B
fts 0.927
beta 0.804 0.755
alpha 0.466 0.188 0.693
a 0.523 0.788 0.515 -0.261
voidfrac -0.800 -0.869 -0.940 -0.406 -0.776
d -0.744 -0.887 -0.839 -0.189 -0.899 0.974
B -0.464 -0.747 -0.434 0.348 -0.996 0.715 0.855
e -0.558 -0.810 -0.564 0.204 -0.998 0.811 0.923 0.989
Pbp 0.665 0.866 0.716 -0.007 0.967 -0.911 -0.981 -0.940
lad heig -0.536 -0.394 0.000 -0.000 0.000 -0.000 -0.000 0.000
accelera 0.000 0.000 -0.000 0.000 0.000 -0.000 0.000 -0.000

e Pbp lad heig
Pbp -0.980
lad heig -0.000 -0.000
accelera -0.000 0.000 -0.000

Using data results with 17,000 lb/hr from table 7 (includes 95% fill)
ratio fts beta alpha a voidfrac d B
fts 0.926
beta 0.847 0.777
alpha 0.478 0.183 0.693
a 0.567 0.823 0.515 -0.261
voidfrac -0.848 -0.898 -0.940 -0.406 -0.776
d -0.793 -0.920 -0.839 -0.189 -0.899 0.974
B -0.504 -0.781 -0.434 0.348 -0.996 0.715 0.855
e -0.603 -0.845 -0.564 0.204 -0.998 0.811 0.923 0.989
Pbp 0.712 0.900 0.716 -0.007 0.967 -0.911 -0.981 -0.940
lad heig -0.474 -0.337 0.000 -0.000 0.000 -0.000 -0.000 0.000
accelera -0.000 -0.000 -0.000 0.000 0.000 -0.000 0.000 -0.000

e Pbp lad heig
Pbp -0.980
lad heig -0.000 -0.000
accelera -0.000 0.000 -0.000

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14. ABSTRACT
In-space propulsion often necessitates the use of a capillary liquid acquisition device (LAD) to assure that gas-free liquid propellant is available to support engine restarts in microgravity. If a capillary screen-channel device is chosen, then the designer must determine the appropriate combination screen mesh and channel geometry. A screen mesh selection which results in the smallest LAD width when compared to any other screen candidate (for a constant length) is desirable; however, no 'best' screen exists for all LAD design requirements. Flow rate, percent fill, and acceleration are the most influential drivers for determining screen widths. Increased flow rates and reduced percent fills increase the 'through-the-screen' flow pressure losses, which drive the LAD to increased widths regardless of screen choice. Similarly, increased acceleration levels and corresponding liquid head pressures drive the screen mesh selection toward a higher bubble point (liquid retention capability). After ruling out some screens on the basis of acceleration requirements alone, candidates can be identified by examining screens with small 'flow-loss-to-bubble point ratios' for a given condition (i.e., comparing screens at certain flow rates and fill levels). Within the same flow rate and fill level, the screen constants inertia resistance coefficient, void fraction, screen pore or opening diameter, and bubble point can become the driving forces in identifying the smaller flow-loss-to-bubble point ratios.

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