## ⚒ ACTIVITY: SSME Console

### Space Shuttle Main Engines Sequencing Guide

**Step one:** Establish the baseline for each pump and valve. Use the Baseline worksheet to calculate each of your baselines. Once these have been calculated, enter them on your Data Collection worksheet.

**Step two:** Look at the printout of the computer control to identify where each pump and valve is located. Enter the baseline NUMBERS you calculated for the FP OXIDIZER VALVE and the MAIN FUEL VALVE into the computer.

**Step three:** When the countdown begins, start recording the data and perform the math functions as required. Keep the worksheet current and accurate.

**Step four:** Watch (analysis) your data for any changes that reflect numerical data that is outside of your established baselines.

**Step five:** Identify what equipment or system is causing the change.

**Step six:** Find a solution to correct the change and bring the data back into the established baselines.

**Step seven:** Enter the correction into your computer.

**Step eight:** Record new changes to data and verify that they are in the established baselines.

**Steps nine:** After the launch, explain what problems or situations happened. Explain, using your data, how you corrected these problems. If you were to launch the Shuttle again, would you change, in any way the methods you used last time to identify and solve problems?

**Step ten:** Using the Launch rubric, grade yourself and your team. Justify your grade. How could you have done better? If you could do this exercise again, could you show any improvement?

## Baseline Worksheet (HPFTP)

**RPM Rate of the High-Pressure Fuel Turbopump (HPFTP)**

The rpm rate of the HPFTP relies on the amount of propellant driving the turbine. Both fuel (LH2) and oxidizer (LOX) are consumed in order to drive the turbopump's turbine. As we increase the flow rate of either propellant, the turbine spins faster. Rpm is related to the oxidizer and fuel flow rates with the following formula:

$$rpm_{HPFTP} = [(c_h \times x_h) + (c_o \times x_o)] \times c$$

The fuel flow rate is $c_h \times x_h$ (h is for hydrogen) and the oxidizer rate is $c_o \times x_o$ (o is or oxygen).

There are two basic parts of the rpm formula:

- the sum of the flow rates $(c_h \times x_h) + (c_o \times x_o)$ and
- a fuel turbopump constant *c.*

> **Did You Know?**
>
> When establishing your baseline numbers, you should round to the hundredth's place.

The fuel turbopump constant is 232.438. We know this because we know the maximum flow rate and maximum rpm for the HPFTP. The manufacturer of the turbopump rates maximum rpm at 33,936 with a maximum total flow rate of 146. If we plug in these values, that leaves *c* as the only unknown.

$$33,936 = 146 \times c$$

If we now take the rated maximum rpm rate and divide it by the maximum flow rate, we know what this constant should be.

$$33,936 = 146 \times c$$
$$c = \frac{33,936}{146}$$
$$c = 232.438$$

This is what the manufacturer would have determined so that rpm can be calculated for any supplied flow rate. It is, after all, the flow rates you will be able to control with the fuel and oxidizer valves. You'll need to know how adjusting these valves affects the flow rate and how the flow rate in turn affects the turbopump's rpm rate.

Now you can look at the first formula for calculating rpm and fill in the constant.

$$rpm_{HPFTP} = [(c_h \times x_h) + (c_o \times x_o)] \times 232.438$$

### Working with the HPFTP Worksheet

The **maximum rpm rate** for the HIGH PRESS FUEL TURBOPUMP (HPFTP) is _____.
In the row labeled Baseline on your worksheet, enter the RPM rate in column **B.**

Since the pump and turbine will not operate at speeds less than 10% of calculated maximum rpm, the lowest rpm the HPFTP will run is _____.
In the top row where the column titles are on your worksheet, enter the minimum RPM rate in column **B** where it says "min: _____".

The highest speed the HPFTP can run is 105% of calculated maximum rpm. The highest speed the HPFTP can run is _____.
In the top row where the column titles are on your worksheet, enter the maximum RPM rate in column **C** where it says "max: _____".

> ### The Main Fuel Valve
>
> - The Main Fuel Valve provides fuel (hydrogen) to both the HPFPT and the HPOTP.
>
> - The Fuel Pump Oxidizer Valve only provides oxygen to the HPFTP. This is important to know. If both turbopumps start to slow down, the problem is typically a lack of fuel.
>
> - If only one turbopump slows down, it could mean that one of the oxidizer valves is closing. This means the turbine is not getting enough oxygen.

Divide the baseline value in column B by the fuel turbopump constant. This is the **flow rate** of fuel and oxidizer coming through the valves needed to maintain the RPM rate. The flow rate to maintain rated maximum RPM is _____.
In the row labeled Baseline on your worksheet, enter the flow rate in column **C.**

### Calculating the Flow Rate for the Oxidizer Valve

If a valve is open all the way, it is open 100%. The oxidizer valve (FPOV) has a constant that relates how much the valve is opened to the resulting flow rate. For the HPFTP's oxidizer valve, this constant is 68 pps (That's 68 pounds per second.). If we multiply this constant by how much the valve is opened by the constant, we get a resulting flow rate. Opening the valve completely results in the maximum flow rate for the valve.

To calculate the flow rate, we can use the formula

flow rate = constant $\times$ percent valve is open

or,

$$f_o = c_o \times x_o$$

where

$f_o$ = flow rate of the FPOV

$x_o$ = valve opening

$c_o$ = 68 pps

Note: Be careful with the valve opening value. This value should be between 0 and 1 (0 = 0% and 1 = 100%). On the SSME Console, values for valve openings are in percents and need to be converted to decimal forms to calculate flow rate.

The flow rate equation should look familiar; it's a linear equation of the form $y = mx \times b$ where

flow rate is $y$,

78 is the slope, $m$, and

the $y$-intercept $b$ equals 0.

## Working with the HPFTP Worksheet

The maximum oxidizer flow rate for the FPOV is _____.

In the row labeled Baseline on your worksheet, enter the flow rate in column **E.**

## Calculating the Flow Rate for the Main Fuel Valve

If a valve is open all the way, it is open 100%. The Main Fuel Valve (MFV) has a constant that relates how much the valve is opened to the resulting flow rate to the HPFTP. This constant is 78 pps (That's 78 pounds per second.). If we multiply the constant by how much the valve is opened, we get a resulting flow rate. Opening the valve completely results in the maximum flow rate for the valve.

To calculate the flow rate, we can use the formula

flow rate = constant $\times$ percent valve is open

or,

$$f_h = c_h \times x_h$$

where

$f_h$ = flow rate of the MFV,

$x_h$ = valve opening, and

$c_h$ = 78 pps.

If we look at the flow rate equation in the form $y = mx \times b$:

flow rate is $y$,

78 is the slope, $m$, and

the $y$-intercept b = 0 (no fuel produces 0 rpm).

**Working with the HPFTP Worksheet**

The maximum fuel flow rate for the Main Fuel Valve is _____.

In the row labeled Baseline on your worksheet, enter the maximum flow rate in column **G.**

For the HPFTP's total flow rate, add the flow rates for the two valves.

$f_h + f_h$ = maximum flow rate for both valves

_____ + _____ = _____

In the row labeled Baseline on your worksheet, enter the sum in column **H.**

## HPFTP Worksheet

| Time | RPM min: _____ max: _____ | Calculated Flow Rate (RPM/constant) | FPOV (Oxidizer Valve position) | Oxidizer Flow Rate $(x_o \times c_o)$ | MFV (Main Fuel Valve position) | Fuel Flow Rate $(x_h \times c_h)$ | Total Flow Rate (sum of flow rates) |
|---|---|---|---|---|---|---|---|
| Baseline | min: _____ max:_____ | | | | | | |
| | min: _____ max:_____ | | | | | | |
| | min: _____ max:_____ | | | | | | |
| | min: _____ max:_____ | | | | | | |
| | min: _____ max:_____ | | | | | | |
| | min: _____ max:_____ | | | | | | |
| | min: _____ max:_____ | | | | | | |
| | min: _____ max:_____ | | | | | | |
| | min: _____ max:_____ | | | | | | |
| | min: _____ max:_____ | | | | | | |
| | min: _____ max:_____ | | | | | | |

## Baseline Worksheet (HPOTP)

**RPM Rate of the High-Pressure Oxidizer Turbopump (HPOTP)**
The rpm rate of the HPOTP relies on the amount of propellant driving the turbine. Both fuel (LH2) and oxidizer (LOX) are consumed in order to drive the turbopump's turbine. As we increase the flow rate of either propellant, the turbine spins faster. Rpm is related to the oxidizer and fuel flow rates with the following formula:

$$rpm_{HPOTP} = [(c_h \times x_h) + (c_o \times x_o)] \times c$$

The fuel flow rate is $c_h \times x_h$ (*h* is for hydrogen), and the oxidizer rate is $c_o \times x_o$ (*o* is or oxygen).

There are two basic parts of the rpm formula:
- the sum of the flow rates $(c_h \times x_h) + (c_o \times x_o)$ and
- an oxidizer turbopump constant *c*.

> **Did You Know?**
>
> When establishing your baseline numbers, you should round to the hundredth's place.

The oxidizer turbopump constant is 343.954. We know this because we know the maximum flow rate and the maximum rpm for the HPOTP. The manufacturer of the turbopump rates the maximum rpm at 22,357, with a maximum total flow rate of 65. If we plug in these values, that leaves *c* as the only unknown.

$$22,357 = 65 \times c$$

If we now take the rated maximum rpm rate and divide it by the maximum flow rate, we know what this constant should be.

$$22,357 = 65 \times c$$
$$c = \frac{22,357}{65}$$
$$c = 343.954$$

This is what the manufacturer would have determined so that rpm can be calculated for any supplied flow rate. It is, after all, the flow rates you will be able to control with the fuel and oxidizer valves. You'll need to know how adjusting these valves affects the flow rate and how the flow rate in turn affects the turbopump's rpm rate.

Now you can look at the first formula for calculating rpm and fill in the constant.

$$rpm_{HPOTP} = [(c_h \times x_h) + (c_o \times x_o)] \times 343.954$$

**Working with the HPOTP Worksheet**

The **maximum rpm rate** for the HIGH PRESS OXIDIZER TURBOPUMP (HPOTP) is _____.
In the row labeled Baseline on your worksheet, enter the RPM rate in column **B.**

Since the pump and turbine will not operate at speeds less than 10% of calculated maximum rpm, the lowest rpm the HPFTP will run is _____.
In the top row where the column titles are on your worksheet, enter the minimum RPM rate in column **B** where it says "min: _____".

The highest speed the HPOTP can run is 105% of calculated maximum rpm. The highest speed the HPOTP can run is _____.
In the top row where the column titles are on your worksheet, enter the maximum RPM rate in column **C** where it says "max: _____".

> ### The Main Fuel Valve
>
> - The Main Fuel Valve provides fuel (hydrogen) to both the HPFPT and the HPOTP.
>
> - The Oxidizer Pump Oxidizer Valve only provides oxygen to the HPOTP. This is important to know. If both turbopumps start to slow down the problem is typically a lack of fuel.
>
> - If only one turbopump slows down it could mean that one of the oxidizer valves is closing. This means the turbine is not getting enough oxygen.

Divide the baseline value in column B by the oxidizer turbopump constant. This is the **flow rate** of fuel and oxidizer coming through the valves needed to maintain the RPM rate. The flow rate to maintain rated maximum RPM is _____.
In the row labeled Baseline on your worksheet, enter the flow rate in column **C.**

**Calculating the Flow Rate for the Oxidizer Valve**

If a valve is open all the way, it is open 100%. The oxidizer valve (OPOV) has a constant that relates how much the valve is opened to the resulting flow rate. For the HPOTP's oxidizer valve, this constant is 25 pps (that's 25 pounds per second). If we multiply this constant by how much the valve is opened by the constant, we get a resulting flow rate. Opening the valve completely results in the maximum flow rate for the valve.

To calculate the flow rate, we can use the formula

flow rate = constant $\times$ percent valve is open

or,

$$f_o = c_o \times x_o$$

where

$f_o$ = flow rate of the OPOV

$x_o$ = valve opening

$c_o$ = 25 pps

Note: Be careful with the valve opening value. This value should be between 0 and 1 (0 = 0% and 1 = 100%).  On the SSME Console, values for valve openings are in percents and need to be converted to decimal forms to calculate flow rate.

The flow rate equation should look familiar; it's a linear equation of the form  $y = mx \times b$  where

flow rate is $y$,

25 is the slope, $m$, and

the $y$-intercept $b$ equals 0.

## Working with the HPOTP Worksheet

The maximum oxidizer flow rate for the OPOV is _____.

In the row labeled Baseline on your worksheet, enter the flow rate in column **E.**

## Calculating the Flow Rate for the Main Fuel Valve

If a valve is open all the way it is open 100%. The Main Fuel Valve (MFV) has a constant that relates how much the valve is opened to the resulting flow rate to the HPOTP. This constant is 40 pps (that's 40 pounds per second). If we multiply the constant by how much the valve is opened, we get a resulting flow rate. Opening the valve completely results in the maximum flow rate for the valve.

To calculate the flow rate, we can use the formula

flow rate = constant $\times$ percent valve is open

or,

$$f_h = c_h \times x_h$$

where

$f_h$ = flow rate of the MFV,

$x_h$ = valve opening, and

$c_h$ = 40 pps.

If we look at the flow rate equation in the form $y = mx \times b$:

flow rate is $y$,

78 is the slope, $m$, and

the $y$-intercept b = 0 (no fuel produces 0 rpm).

**Working with the HPOTP Worksheet**

The maximum fuel flow rate for the Main Fuel Valve is _____.

In the row labeled Baseline on your worksheet, enter the maximum flow rate in column **G.**

For the HPOTP's total flow rate, add the flow rates for the two valves.

$f_h + f_h$ = maximum flow rate for both valves

_____ + _____ = _____

In the row labeled Baseline on your worksheet, enter the sum in column **H.**

## HPOTP Worksheet

| Time | RPM<br>min: _____<br>max: _____ | Calculated Flow Rate (RPM/constant) | OPOV (Oxidizer Valve position) | Oxidizer Flow Rate $(x_o \times c_o)$ | MFV (Main Fuel Valve position) | Fuel Flow Rate $(x_h \times c_h)$ | Total Flow Rate (sum of flow rates) |
|---|---|---|---|---|---|---|---|
| Baseline | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |
| | min: _____<br>max:_____ | | | | | | |