

8. EXERCISE: Minimum Fuel

We have worked out how long it will take us to cover the distance to our destination given the wind conditions of the day. Now we need to work out how much fuel we are going to need for the flight.

Before we work out the beginnings of a fuel plan we should look at some definitions. These are described fully in your textbook, so the following notes are just to refresh your memory:

- **Fuel Flow** is the rate at which fuel flows through the engine at a particular power setting. You may see fuel flows given for cruise power, or holding power.
- **Flight Fuel** is the fuel that will actually flow through the engine while we are enroute to our destination. The amount of fuel will be calculated using a rate calculation, exactly as you worked it in the ground speed exercises. Just replace “nm” with “litres” and replace “kts” with “litres per hour”. You can do the same with gallons and gallons per hour. For example, if you worked out the flight will take you 30 minutes and you burn fuel in cruise at a fuel flow of 30 litres per hour, you will need 15 litres of flight fuel. In other words, you expect 15 litres to go through the engine while flying to your destination.
Should the weather be bad enough that you need to plan for an alternate aerodrome, the flight fuel also includes the flight time to your alternate (see Operational Meteorology).
- **Reserves:** It would be foolhardy to take off with exactly just enough fuel to carry you to your destination, so it is not surprising there are recommendations for how much extra fuel you should carry in case you are delayed or you need more fuel than you planned. Guidelines on reserves are described in CAAP 234-1(1) - Guidelines for Aircraft Fuel Requirements.
 - **Variable Reserve:** this reserve is available for use on any normal flight and the recommendation is to carry a variable reserve of 10% of the amount of flight fuel you expect you will need. This extra reserve is to cover you for unexpected headwinds, minor diversions due to weather or normal ATC delays.
 - **Fixed Reserve:** currently this is considered to be 45 minutes of extra fuel at some fuel flow specified by the operator. In the exam, either the fuel flow to be used when calculating will be given in the question or the fixed reserve will be specified directly. The fixed reserve is an emergency reserve to keep you airborne in case something drastic and unforeseen occurs.

The variable reserve is expected to be burnt during normal flight operations so after a completely normal commercial flight, you should have at least your fixed reserve in the tanks.

The fixed reserve on the other hand should not be touched unless there has been some unexpected problem during the flight.

Interestingly, there is no recommendation that private flights carry a variable reserve according to CAAP 234, and yet, private flights are just as likely to suffer unexpected headwinds and delays as the commercial operators. It would be acceptable then to land with less than a full fixed reserve in the tanks. However, most schools and operators insist on a variable reserve being carried on all flights and this will be specified in the operations manual fuel policy.

- **Allowances:** in addition to reserves, you will be expected to carry fuel to cover start-up and taxi operations, and some operators may even include an approach allowance. Allowances are normally given as a fixed amount of fuel rather than a fuel flow and time interval.

- Holding:** You may have an operational requirement to carry extra fuel due to conditions in the weather forecast (60 minutes for a TEMPO, 30 minutes for an INTER). A full discussion of these is given in the operational meteorology section of the textbook. Some busy airports may also require traffic holding fuel be carried for flights arriving at certain times of day. This must also be included in your flight's fuel plan.

Once you have added together the flight fuel, the reserves, the allowances and any holding, you end up with the Minimum Fuel Required. This is the minimum amount of fuel you must have in the tanks before starting the engines on the ramp.

8.1. Working the Exercise

These problems are presented in a tabular form (see below). You will need to calculate the flight fuel, a variable reserve (if required), the fixed reserve and add in the allowances to come up with the minimum fuel required at start up. Holding is not included in these exercises, but as you now know, in a question where holding was included, it would also need to be added to the grand total. You will also need to be able to work in gallons or litres so this exercise includes practice in converting between the two.

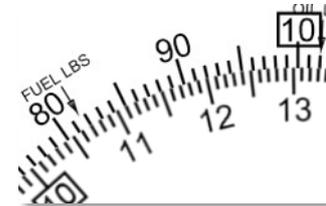
Let's work one problem as an example, then you can have a go yourself.

Gallons x 3.8 = Litres, Litres ÷ 3.8 = gallons Express Gallons to 1 decimal place. Round litres to the nearest whole litre.						Fuel Required at Start up		Flight Fuel	
No.	Cruise Fuel Flow	15% Variable Reserve?	Fixed Reserve 45 min @ cruise	Start up/Taxi Allowance	EET	gallons	litres	gallons	litres
1	46 lph	Yes		11 litres	111 min				

The first value we need to calculate is our flight fuel. We are working in litres and burning fuel in cruise at 46 litres per hour. The estimated enroute time (EET) is 111 minutes. 111 minutes is nearly 2 hours, so the answer must be a little less than 90 litres...



First we set up for the fuel flow: 46 litres per hour means we need to set 46 over 60 on the flight computer. We want to know the number of litres burnt in 111 minutes so the next step is to find 111 minutes on the inner scale and read the litres off the outer scale - **85** litres.



About 85 litres can be expected to run through the engines just during the enroute segment. We can now create our fuel plan and work out the minimum fuel required in the tanks at start up.

This question requires a variable reserve which is 10% of the flight fuel to be carried:

$$10\% \times 85 \text{ litres} = 8.5 \text{ litres (make it 8 litres).}$$

TIP: A quick way to calculate the flight fuel + variable reserve is to multiply the flight fuel by 1.1 – see the textbook for why this works.

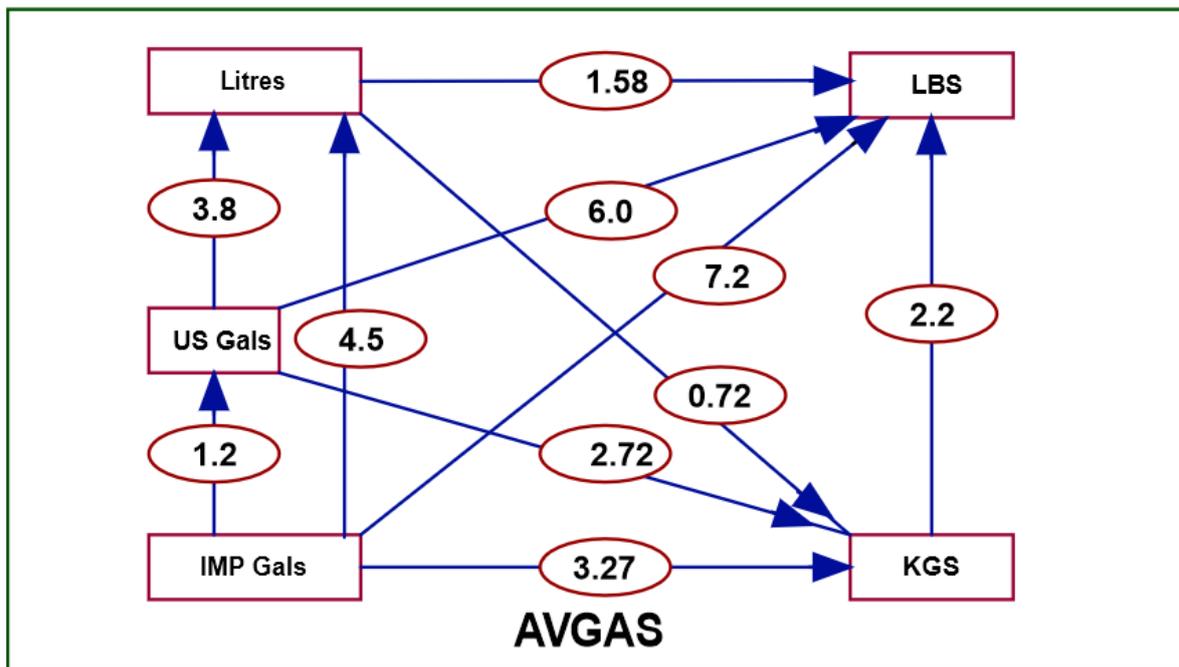
The fixed reserve is 45 minutes @ 46 litres per hour. The flight computer is probably still set for this rate so we read off about 34.5 litres as a fixed reserve. We will round this to 35 litres. There is no holding fuel and an 11 litres start-up/taxi allowance required. This gives us a total of 139 litres.

Flight Fuel	85
Variable Reserve	8
Subtotal:	93
Fixed Reserve	35
Holding	-
Allowances	11
Total:	139

We can then convert the answers into gallons (using the constants found in ERSA GEN-CON) to complete the table:

No.	Cruise Fuel Flow	10% Variable Reserve?	Fixed Reserve	Fuel Required at Start up				Flight Fuel	
				Start up / Taxi Allowance	EET	gallons	litres	gallons	litres
1	46 lph	Yes	35 Litres	11 litres	111 min	36.5	139	22.4	85

For your reference, here is the chart of conversion constants from ERSA GEN-CON.



- To convert: **multiply** by the factor in the "balloon" when moving in the direction of the arrow, or **divide** by that factor if converting in the opposite direction.
- Fuel SG (0.8 AVTUR and 0.72 AVGAS) is based on ISA temperature at MSL. Therefore, fuel weights will be approximate for other than 15DEG Celsius.

Extract from ERSA GEN-CON-2

Now it is your turn. Have a go at the following exercises.

EXERCISES: Minimum Fuel

Gallons x 3.8 = Litres Litres ÷ 3.8 = gallons

Express Gallons to 1 decimal place. Round litres to the nearest whole litre.

No.	Cruise Fuel Flow	10% Variable Reserve?	Fixed Reserve 45 min @ cruise	Start up/Taxi Allowance	EET	Fuel Required at Start up		Flight Fuel	
						gallons	litres	gallons	litres
1	9.2 gph	Yes		2 gal	167 min				
2	38 lph	No		11 litres	111 min				
3	12.7 gph	Yes		3 gal	189 min				
4	33 lph	Yes		8 litres	55 min				
5	41 lph	No		11 litres	118 min				
6	12.2 gph	No		3 gal	114 min				
7	8.9 gph	No		2 gal	92 min				
8	12.5 gph	Yes		3 gal	164 min				
9	48 lph	Yes		11 litres	116 min				
10	10.1 gph	No		3 gal	103 min				
11	38 lph	Yes		11 litres	209 min				
12	14 gph	No		4 gal	92 min				
13	51 lph	No		11 litres	90 min				
14	38 lph	No		11 litres	57 min				
15	11.4 gph	Yes		3 gal	198 min				
16	12.8 gph	Yes		3 gal	122 min				
17	12.3 gph	No		3 gal	93 min				
18	52 lph	No		11 litres	207 min				
19	40 lph	Yes		11 litres	87 min				
20	45 lph	Yes		11 litres	121 min				

9. EXERCISE: Safe Endurance

In the previous section, we looked at finding out how much fuel we needed in the tanks before taking off for a known flight. In this section we approach fuel planning from the other direction: if I know how much fuel is in the tanks, how much of that is available as flight fuel and how long will it last.

How long the available flight fuel will last while still keeping all our reserves and applicable allowances and holding intact, is known as the **Safe Endurance**.

9.1. Working the Exercise

We are going to reuse the fuel plan from the previous section, but this time we fill it in from the bottom, at the total in the tanks and working backwards until all we have left is the flight fuel available. A rate calculation will then tell us how long that flight fuel will last at cruise power settings.

Let's take a sample problem and work through it:

Fuel on Board At Start-up	Cruise Fuel Flow	Holding Fuel Flow	10% Variable Reserve?	Fixed Reserve 45 min @ holding	Holding (@ holding FF)	Start up/Taxi Allowance	Safe Endurance (minutes)
124 litres	39 lph	27 lph	Yes		15 min	11 litres	

Firstly, we fill in our fuel plan, starting at the bottom and working backwards, removing fuel which needs to be kept aside for reserves and allowances etc. Enter the total on board at start-up in the Total section, then put in the allowances of 11 litres in the Allowances box.

We need to carry 15 minutes holding at the holding fuel flow of 27 lph. A rate calculation gives an answer of 6.75 or roughly 7 litres of holding fuel required.

Next, we need to keep a fixed reserve of 45 minutes at 27 lph, which works out to be 29.25 (rounded to 29) litres.

Subtracting the holding, allowances and fixed reserve from the total of 124, leaves us with 77 litres of fuel.

The question requires a variable reserve, so the 77 litres represents the flight fuel available for the flight plus the 10% of variable reserve. In other words, 77 litres is 10% of the flight fuel (100% + 10%). To find the flight fuel we have available, we need to divide 77 by 1.1 to give 69 litres. *(Check your textbook if you do not follow the calculation).*

The flight fuel is 69 litres and the variable reserve is therefore 8 litres. At the cruise fuel flow of 39 lph, 69 litres will last about 106 minutes.

The aircraft can be started, taxied to the runway (burning the start-up taxi allowances) and then flown for 106 minutes. That will still leave enough fuel in the tanks to cover the variable and fixed reserves plus the 15 minutes holding fuel.

Now it is your turn...

Flight Fuel	69
Variable Reserve	8
Subtotal:	77
Fixed Reserve	29
Holding	7
Allowances	11
Total	124



EXERCISES: Safe Endurance

Gallons x 3.8 = Litres, Litres ÷ 3.8 = gallons.

Express Gallons to 1 decimal place. Round litres to the nearest litre.

No.	Fuel on Board At Start-up	Cruise Fuel Flow	Holding Fuel Flow	10% Variable Reserve?	Fixed Reserve 45 min @ holding	Holding (@ holding FF)	Start up/Taxi Allowance	Safe Endurance (minutes)
1	146 litres	39 lph	27 lph	Yes		60 min	11 litres	
2	36.1 gal	9 gph	6.3 gph	Yes		None	2 gal	
3	85 litres	52 lph	36 lph	No		None	11 litres	
4	179 litres	43 lph	30 lph	No		30 min	11 litres	
5	41.9 gal	8.7 gph	6.1 gph	Yes		60 min	2 gal	
6	30.7 gal	8.7 gph	6.1 gph	Yes		None	2 gal	
7	46.1 gal	11.6 gph	8.1 gph	Yes		60 min	3 gal	
8	86 litres	36 lph	25 lph	Yes		60 min	8 litres	
9	96 litres	32 lph	22 lph	No		None	8 litres	
10	32.3 gal	8.8 gph	6.2 gph	No		60 min	2 gal	
11	105 litres	37 lph	26 lph	Yes		60 min	8 litres	
12	33.5 gal	8.1 gph	5.7 gph	No		60 min	2 gal	
13	95 litres	39 lph	27 lph	No		None	11 litres	
14	127 litres	48 lph	33 lph	Yes		None	11 litres	
15	264 litres	51 lph	36 lph	Yes		60 min	11 litres	
16	53 gal	10.2 gph	7.1 gph	Yes		60 min	3 gal	
17	17 gal	8.6 gph	6 gph	No		None	2 gal	
18	44.4 gal	10.4 gph	7.3 gph	Yes		None	3 gal	
19	190 litres	50 lph	35 lph	No		None	11 litres	
20	50.8 gal	12.2 gph	8.5 gph	No		60 min	3 gal	

EXERCISES: Minimum Fuel – ANSWERS

Gallons x 3.8 = Litres

Litres ÷ 3.8 = gallons

Express Gallons to 1 decimal place. Round litres to the nearest whole litre.

No.	Cruise Fuel Flow	10% Variable Reserve?	Fixed Reserve 45 min @ cruise	Start up/Taxi Allowance	EET	Fuel Required at Start up		Flight Fuel	
						gallons	litres	gallons	litres
1	9.2 gph	Yes	7 gal	2 gal	167 min	37.2 gal	142 litres	25.6 gal	97 litres
2	38 lph	No	30 litres	11 litres	111 min	29.5 gal	111 litres	18.5 gal	70 litres
3	12.7 gph	Yes	10 gal	3 gal	189 min	57 gal	215 litres	40 gal	151 litres
4	33 lph	Yes	27 litres	8 litres	55 min	17.9 gal	68 litres	8.1 gal	30 litres
5	41 lph	No	30 litres	11 litres	118 min	32 gal	122 litres	21 gal	81 litres
6	12.2 gph	No	9 gal	3 gal	114 min	35.2 gal	132 litres	23.2 gal	87 litres
7	8.9 gph	No	7 gal	2 gal	92 min	22.6 gal	87 litres	13.6 gal	52 litres
8	12.5 gph	Yes	9 gal	3 gal	164 min	49.6 gal	189 litres	34.2 gal	131 litres
9	48 lph	Yes	34 litres	11 litres	116 min	38.8 gal	147 litres	24.4 gal	93 litres
10	10.1 gph	No	8 gal	3 gal	103 min	28.3 gal	106 litres	17.3 gal	65 litres
11	38 lph	Yes	30 litres	11 litres	209 min	49.3 gal	186 litres	34.8 gal	132 litres
12	14 gph	No	11 gal	4 gal	92 min	36.5 gal	138 litres	21.5 gal	81 litres
13	51 lph	No	38 litres	11 litres	90 min	33.3 gal	126 litres	20.3 gal	77 litres
14	38 lph	No	30 litres	11 litres	57 min	20.5 gal	77 litres	9.5 gal	36 litres
15	11.4 gph	Yes	9 gal	3 gal	198 min	53.4 gal	201 litres	37.6 gal	142 litres
16	12.8 gph	Yes	10 gal	3 gal	122 min	41.6 gal	159 litres	26 gal	100 litres
17	12.3 gph	No	9 gal	3 gal	93 min	31.1 gal	118 litres	19.1 gal	73 litres
18	52 lph	No	38 litres	11 litres	207 min	60.6 gal	228 litres	47.6 gal	179 litres
19	40 lph	Yes	30 litres	11 litres	87 min	27.9 gal	105 litres	15.4 gal	58 litres
20	45 lph	Yes	34 litres	11 litres	121 min	38.4 gal	145 litres	24 gal	91 litres

EXERCISES: Safe Endurance – ANSWERS

Gallons x 3.8 = Litres, Litres ÷ 3.8 = gallons.

Express Gallons to 1 decimal place. Round litres to the nearest litre.

No.	Fuel on Board At Start-up	Cruise Fuel Flow	Holding Fuel Flow	10% Variable Reserve?	Fixed Reserve 45 min @ holding	Holding (@ holding FF)	Start up/Taxi Allowance	Safe Endurance (minutes)
1	146 litres	39 lph	27 lph	Yes	20 litres	39 litres	11 litres	123 min
2	36.1 gal	9 gph	6.3 gph	Yes	4.7 gal	None	2 gal	178 min
3	85 litres	52 lph	36 lph	No	27 litres	None	11 litres	54 min
4	179 litres	43 lph	30 lph	No	22 litres	22 litres	11 litres	183 min
5	41.9 gal	8.7 gph	6.1 gph	Yes	4.6 gal	6.1 gal	2 gal	183 min
6	30.7 gal	8.7 gph	6.1 gph	Yes	4.6 gal	None	2 gal	151 min
7	46.1 gal	11.6 gph	8.1 gph	Yes	6.1 gal	8.1 gal	3 gal	136 min
8	86 litres	36 lph	25 lph	Yes	19 litres	36 litres	8 litres	51 min
9	96 litres	32 lph	22 lph	No	17 litres	None	8 litres	134 min
10	32.3 gal	8.8 gph	6.2 gph	No	4.7 gal	6.2 gal	2 gal	132 min
11	105 litres	37 lph	26 lph	Yes	20 litres	37 litres	8 litres	74 min
12	33.5 gal	8.1 gph	5.7 gph	No	4.3 gal	5.7 gal	2 gal	159 min
13	95 litres	39 lph	27 lph	No	20 litres	None	11 litres	98 min
14	127 litres	48 lph	33 lph	Yes	25 litres	None	11 litres	104 min
15	264 litres	51 lph	36 lph	Yes	27 litres	51 litres	11 litres	204 min
16	53 gal	10.2 gph	7.1 gph	Yes	5.3 gal	7.1 gal	3 gal	201 min
17	17 gal	8.6 gph	6 gph	No	4.5 gal	None	2 gal	73 min
18	44.4 gal	10.4 gph	7.3 gph	Yes	5.5 gal	None	3 gal	188 min
19	190 litres	50 lph	35 lph	No	26 litres	None	11 litres	183 min
20	50.8 gal	12.2 gph	8.5 gph	No	6.4 gal	8.5 gal	3 gal	162 min