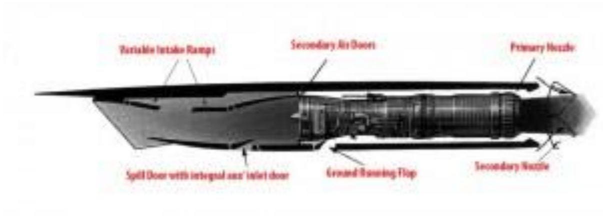
THE CONCORDE POWERPLANT:
Part 1:
We are going to start our journey into the Concorde powerplant, and we are going to take a long, slow look at the whole thing, this includes the variable geometry intake, the engine itself, the reheat/afterburning system as well as the primary and secondary nozzles.

Let’s begin our journey. The diagram here shows the powerplant itself in its simplest form:



THE INTAKE:
No jet engine will accept supersonic air, so if we are doing Mach 2, something has to be done about slowing down the air. This in itself is easy, the engine itself ‘decides’ the actual entry Mach number (you can’t ‘force in’ supersonic to a jet engine compressor) but unless it is done ‘right’ you lose enormous amounts of total (head) pressure, corresponding loss of thrust. The variable geometry intake on Concorde achieves an unprecedented pressure recovery of 94%, as we GENTLY go through the workings of the intake we will explain how this is all done and inject a few simple numbers. For now we will say that Concorde uses a series of shockwaves (we’ll look at what these are later too) to slow the air down to subsonic speed. In fact in about 14’ of intake the air loses around 1,000 MPH of airspeed, while the ‘static’ (that is if you like the ‘free’ outside) air pressure increases by 600%!!. (As well as, as we’ve just seen, recovering 94% of the total pressure).

THE ENGINE:
The Rolls-Royce Olympus 593 Mk 610 installed in Concorde STILL remains the most efficient jet engine in the world at Mach 2, as far as thermal efficiency is concerned. This is due to the design of the engine itself of course, but mainly down to the intake, and to a lesser extent the individual nozzle designs. We’ll be having a fairly decent look in the following week(s) and the wonders of this amazing engine will be explained. (As efficient as the OLY 593 is at Mach 2 and about, at slower speeds it uses fuel like it’s going out of fashion, hence the need for a minimum of low speed flying with Concorde).

THE PRIMARY NOZZLE:
The control for this nozzle was ‘lifted’ from the ill-fated BAC TSR2 supersonic bomber. The nozzle fulfils two separate functions:
ONE: To enable the two rotating spools of the engine to run at independent speeds, enabling peak efficiency due to running as close as possible to their individual ‘surge boundaries’ and also being able to run at a fairly constant TET (Turbine Inlet Temperature) for just about the entire flight regime.
TWO: To act as a conventional ‘reheat’ nozzle, where when the reheat flame lights, the increasing pressure would tend to ‘choke’ the flow through the engine if there was not a variable nozzle to ‘chase off’ the rising pressure.
The detailed operation of the nozzle will be covered as we go through our powerplant study, but the really ‘clever’ part about the design was that it didn’t care what mode it was operating in, the control was identical, a really classic design.

THE SECONDARY NOZZLE:
This fulfils the dual function of thrust reverser and variable nozzle to minimise loss of thrust due to the ‘flaring’ of the exhaust plume due to the very high ratio of pressure in the exhaust gas and the outside air at high speeds and high altitude as well as minimising low speed losses..
We will be going into all of this and far more in detail as we progress, just a quick mention now of some of the minor things in the diagram.
THE AUXILIARY INLET VANE is built into the hydraulically actuated intake spill door, and is opened by the difference in pressure between the inside of the intake and outside. It will open fully at low speeds (sucked in if you like) to allow extra air to enter the engine (the intake is a little ‘choked’ at high power and low

speed). As intake pressure starts to increase with rising airspeed the vane progressively closes, and by Mach 0.93 there is sufficient pressure within the intake to close the vane fully.

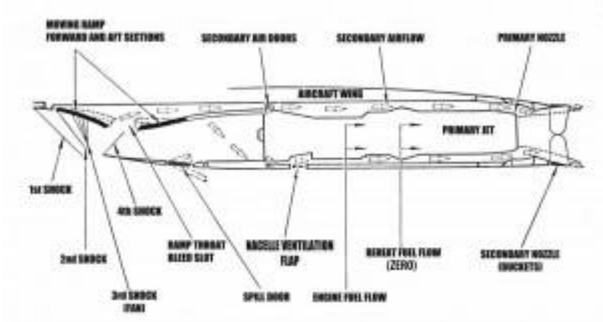
THE SECONDARY AIR DOORS

They isolate the air that passes over the intake ramps, into the engine bay and around the primary nozzle into the annulus (the outer bit) of the secondary nozzle. Again, at very low speeds and high power the pressure in the intake is very low, and so the electrically driven doors remain closed to prevent exhaust being re-ingested into the intake. Above Mach 0.26/173 Knots (around 200 MPH) engines 1, 2 & 3 doors open automatically but engine 4's door opening is delayed until 220 Knots (253 MPH) for reasons that will be explained later on.

Ground Running Flap is spring loaded open to permit extra airflow into the nacelle, and in the usual fashion progressively closes as airspeed rises and pressure inside the nacelle increases, being fully closed by about Mach 0.6.

Part 2:

This diagram again shows the whole powerplant from front to back, but at Mach 2 cruise, and illustrates pretty well what's going on in there:



The INTAKE RAMPS can be seen lowered (to around 50% of travel, the exact amount depending on Mach Number and on outside air temperature and varies constantly throughout supersonic cruise) and has caused a series of SHOCKWAVES to form. (Again for now, don't worry too much about what shockwaves are etc.). Ideally the shock system is 'focused' very slightly forward of the lower lip of the intake, although the illustration here is pretty simplified. But what we CAN say for now is that the air progressively slows down and is 'pre-compressed' as it passes through every shock, and by the time the air has reached the 'narrowest' part of the intake, around the rear intake ramp, it is JUST subsonic. As the now subsonic air travels downstream towards the engine, due to the divergent (tapering outward) nature of the intake duct it tends to slow down even further and pre-compress even more. (Remember in our first explanation yesterday we talked about recovering about 94% of the total pressure, this is the pressure you feel when you put your hand out of a car window while you are driving fast) but INCREASE the static (free air) pressure by some 600%). All of this process slashes losses and gives the core engine FAR less work to do.

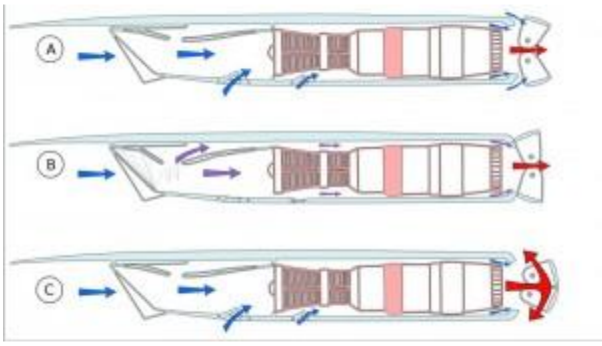
The SPILL DOOR in the floor of the intake is shown fully shut, and in fact only ever opens when power is reduced at top of descent, or in the extremely unlikely case of an engine being shut down. The integral AUXILIARY INLET VANE that we looked at in the first diagram is held firmly shut by differential air pressure.

It can be clearly seen from this diagram just how the intake airflow splits, most of the air flowing toward the engine but air bypassed over the REAR RAMP has quite an interesting path. Some of this air flows through the top SECONDARY AIR DOORS which are of course fully open and the remainder around the cavity within the inake wall through the lower doors. (Some of the diagrams do not show this clearly at all, but this is pivotal to the operation of the intake). Our air carries on flowing around the outside of the engine, which as you can see is adding no REHEAT fuel, the afterburner being switched off at Mach 1.7.

The PRIMARY NOZZLE is almost wide open and the SECONDARY NOZZLE is wide open, and what happens now is really quite neat. The 14:1 pressure ratio of the high exhaust gas pressure and the very low outside air pressure would flare like a fir tree if we did not do something about it, wasting huge amounts of engine thrust. What our intake bleed air does for us is to give the exhaust a nice gentle cushion to expand against, and large amounts of thrust are generated against the divergent (opening out) walls of the secondary nozzle.

This is a really nice (and very old) Rolls-Royce illustration of the engine and nozzle. All that intake air we were talking about flows AROUND the engine and primary nozzle (you can see the nozzle jacks at the rear of the engine) and into the secondary nozzle annulus. (The secondary nozzle is shown here at the supersonic position here too):

Part 3:
The diagram below shows the powerplants in their three different phases, those being : TAKE-OFF (A), SUPERSONIC CRUISE (B) and REVERSE THRUST ON LANDING (C), so let’s look at them all in turn:



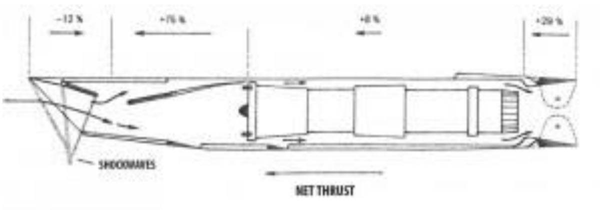
TAKE-OFF:
As the SECONDARY AIR DOORS are all shut, the engine bay is isolated from the intake airflow, and so ALL of the intake air flows into the engine. We can also see that the intake ramps are fully raised and also the AUXILIARY INLET VANE which is part of the SPILL DOOR assembly is ‘sucked’ in, to admit extra airflow into the engine. Airflow is admitted into the engine bay via the sprung loaded open GROUND RUNNING FLAP. For the first time we’ll have a look at what is going on in the land of the SECONDARY NOZZLE (You will notice that the PRIMARY NOZZLE is wide open, which equates to REHEAT operating). We have a problem in the SECONDARY NOZZLE area known as ‘base drag’. (Nothing to do with military guys dressing up as women!!). The problem is we have this EXTREMELY high pressure exhaust flowing out of the nozzle at very high velocity and the engine bay has very little internal airflow, and so this region of low pressure air tends to get quite literally ’dragged along’ by the high speed stuff, which is slowed down in the process and loses huge amounts of thrust. To completely eliminate the problem we have the openings at the top and bottom of the nozzle, and free-flowing outside air is drawn in as shown to fill the low pressure void, and also helps reduce the colossal noise out there.

SUPERSONIC CRUISE:
As we can see, the ramps have automatically lowered to their cruise position (it all starts at Mach 1.28) and the shock system is established. The MACH NUMBER of the air has reduced from MACH 2 to MACH 0.49 at the face of the engine compressor. The SECONDARY AIR DOORS are now open, permitting intake bypass air to flow into the engine bay via the SECONDARY AIR DOORS which are, as of course EVERYBODY now know, fully open. (This diagram, like several others is a little misleading, as it shows the air to the lower doors apparently coming from inside the intake, but as we saw previously, this air flows around the intake behind the walls to these doors). As we can see all of the other doors and flaps are now shut, and this air flows into the ANNULUS of the nozzle, to provide the air cushion for the exhaust to expand against. Again, the PRIMARY NOZZLE is pretty much wide open.

REVERSE THRUST:
We have landed and the SECONDARY NOZZLE buckets have closed up to the reverse position. Notice here that the SECONDARY AIR DOORS, AUXILIARY INLET VANE and GROUND RUNNING FLAP are all open again. One aspect of this diagram that is wrong is that the PRIMARY NOZZLE is shown open,

whereas in reality it closes to a minimum position once the buckets have closed up. But we'll look at that later on, this really still is a nice diagram I think to put everything together.

Part 4:
THE MAIN THRUST OF IT ALL:



This diagram, which is the last of the 'whole powerplant' series shows the division of the thrust forces actually propelling our aircraft along at Mach 2. The poor old engine itself produces just 8% of the net thrust, and the convergent/divergent primary and secondary nozzle combo produces a highly credible 29%, largely due to the intake bleed air cushion aided nozzle design controlling the expansion of the exhaust gas as it leaves the nozzle.

The most incredible figure of all comes from the intake, and once we've digested the figures we will see JUST why the intake is the most critical part of the whole powerplant. First of all we have the 'negative thrust', caused by the aerodynamic drag of the forward part of the intake, this being an equivalent 'loss' of 12%. HOWEVER, and we'll explain all this in more detail later on, the 'positive' thrust coming from the intake (assuming it is operating correctly, with the shockwaves in the correct positions) is 75%.

Therefore the net thrust from the intake assembly is 63%!! Yes, SIXTY THREE PERCENT OF THE FORCES PROPELLING THE AIRCRAFT ARE PRODUCED BY A BOX BOLTED ON THE FRONT OF THE ENGINE. The design of the intake therefore is the one reason greater than any other that Concorde is able to do something that NO other aircraft before or since has been able to do, cruise at Mach 2 and above without the use of reheat/afterburning.