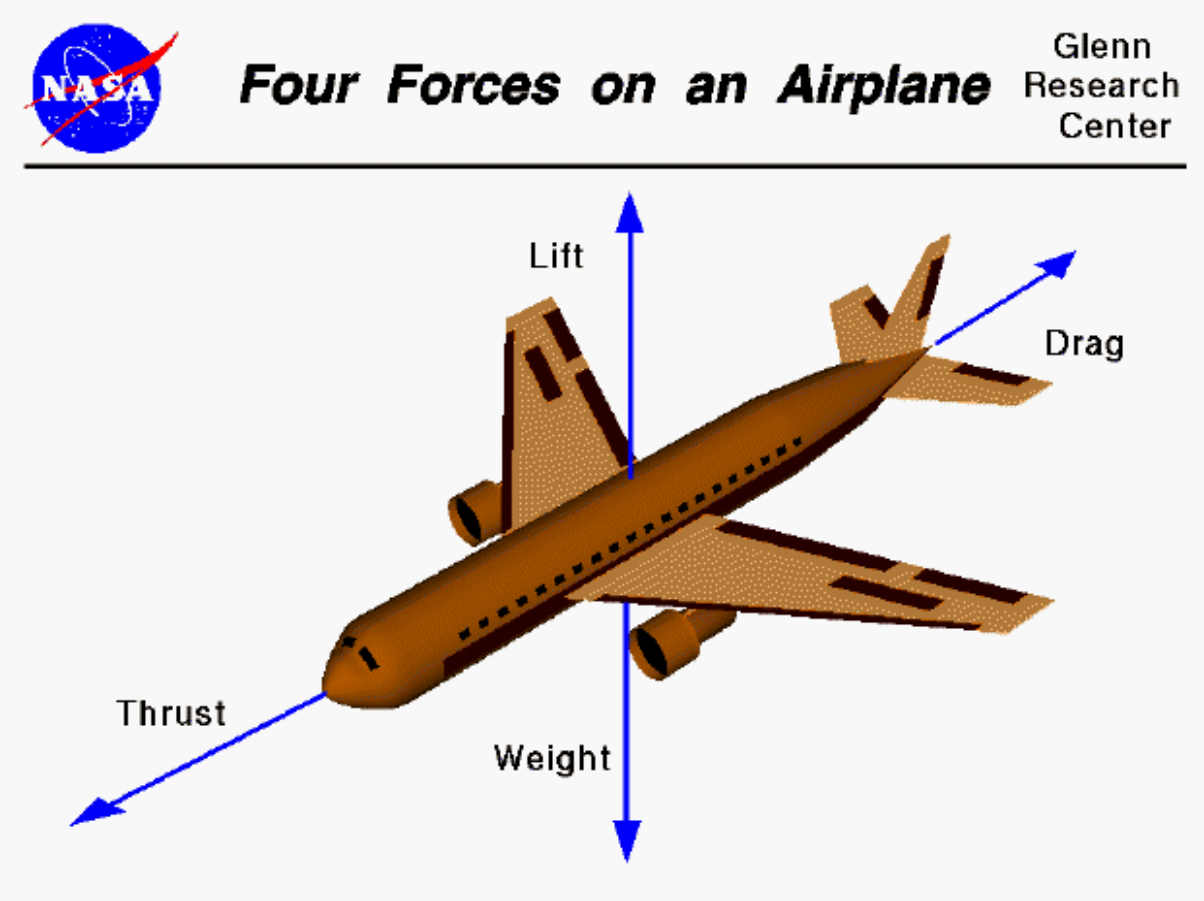
Does an aircraft produce thrust? A Systems and Systems Engineering view

At the INCOSE IS 25 in Ottawa I attended (by accident – see end of post) a very interesting talk on the importance of and testing for hidden belief systems.

Part of the investigation involved providing information to people and asking which bits of that information they used at assess whether or not the requirements "the aircraft must produce xkN of thrust". When asking a question, I prefaced it with a comment like "as an ex-aeroengine designer I have to say an aircraft produces no thrust, the engine does". This was irrelevant to my question but provoked a vigorous (some thought heated) debate after the paper was finished and the break began. That debate got me thinking (as all diverse opinions does – that why I go to conferences. So this post contains my review of the thinking

1) There is a basic systems view that says essentially that the system exhibits both the properties of the whole and the emergence (as a system is more than the sum of its parts. This is basic Systems Thinking, and the point made to me. To illustrate consider the basic view of a standard (commercial) aircraft



This shows the whole – and if you replaced the picture of the aircraft with a black box labelled "AIRCRAFT" it would certainly be clear that there is a thrust force produced by the system we call an aircraft. So, an engine does produce thrust.

2) Note that id we were doing this as a "context diagram" showing the inputs and outputs of the aircraft system there would be more – there would be the exhaust gases (including extra CO2 and H2O produced by the combustion in the engine) which have been accelerated by the (in this illustration) gas turbine (there are other ways of generating thrust!) to which Newton's third law provides the aircraft thrust as a reaction. Additionally, there is the noise the accelerated air produces (as well as noise produced by drag over a/c surfaces).
3) This was also discussed in the (excellent) final keynote speech) where Donela Meadows was quoted as saying a system is a whole and (whilst you need boundaries – see below) "reductionist" separation into parts is dangerous. The moment you create boundaries within the system people start optimising each part. This was referred to as "Boundary Rationality". I have always referred to this as "sub-optimisation" with an idea that an optimised system is necessarily made of "sub-optimised parts" – but a better way of putting it is that it is the systems that defines what the parts need to be, and what "good" is for the part. It is commonly said that the system is greater than the sum of the parts – I don't think that is quite accurate – a system is "different" to the sum of its parts – you can have many systems where what are considered the best parts are put together and the whole is useless (moving out of engineering – consider many sports teams where all stars just can't fit together).
4) My main concern (and the reason I made the comment that an a/c doesn't produce thrust) is that in the practical engineering of an aircraft the input stakeholder needs that are converted into aircraft requirements will not include thrust. Instead, they will be characteristics like range, climb rate, operating altitude (which will come partly from the a/c concept), load, overall a/c noise / emission, unit cost, reliability, safety, maintenance cost, a/c operating cost, turn-round time between flights, ability to load passengers / crew / cargo, etc.

   The balance between thrust and drag, the amount of lift required (both to stay flying or cruise, and to climb) balanced with the weight of the loaded a/c and the drag of the overall aircraft – and so the thrust requirements are derived from the design of the aircraft. Recognise that there are concepts like a glider that do not have any means of or need to generate thrust.

   Typically, a major sub-system of the aircraft is an engine (or set of engines) which generate thrust (and require some other part of the aircraft to provide fuel). Note that the engines also provide some other useful inputs to the aircraft, including possibly mechanical, hydraulic and / or electrical power (although there may also be a separate Auxiliary Power Generator) and provision of pressurised cabin air.

Key point – the thrust demand for the aircraft is derived from analysis of an aircraft system architecture and provided as a need to the engine (thrust / power providing subsystem

5) Going back to the problem of sub-optimisation. Typically (but not always) the engine provision is by another company than that designing the overall aircraft. Where an organization makes the whole system and the sub-systems it can be hard to coordinate the necessary iteration between system and sub-system – but that is immensely harder with different companies (and hence different business requirements). It is hard to iterate between two companies (IP and business confidentiality etc) and even harder to iterate across a contact. I often wonder how different modern a/c would look if the engines were simply another "division" inside the aircraft company
6) The issue raised in the exercise in the paper that sparked this of raised an interesting and subtle issue. There is of course, once the sub-system architecture is determined, a thrust related requirement on the aircraft. It has to be correctly install the engine and get the thrust going in the right direction. I see this as turning the "scalar" thrust generated by the engine into a "vector" of it in the right direction (but see point 8 below on vectoring options). The exercise described asked for review of whether the requirements "The a/c shall produce x kN of thrust" using information like an engine test report and installation drawings. Two sets of installation drawings shown – one with engine (conventionally / correctly) point rearwards, and one with the engines pointing into the fuselage (90 degrees to normal). So the aircraft requirement is to correctly install the engines to make use of the thrust produced by the engines, balancing the thrust force (the engine provides) with the other forces (lift, weight and drag) provided by the other parts of the aircraft, or the aircraft as a whole
7) As an aside – we do not have to assume the solution is always an engine producing thrust. I have mentioned the idea of a glider, but there are other options (some not always practical)
    a. Stored compressed air release to provide a force to react against
    b. The engine acts as power source to drive a propellor – in many cases propellor may be seen as part of engine – but not always – consider a helicopter rotor
    c. The engine acts as an electrical power source, and the electricity used to drive an electric motor to drive a propellor.
    d. As a variant of c) there is no engine but stored power in batteries driving the propellor
8) Once I started thinking about the basic thrust and the installation turning that thrust into a "vector" (i.e. the thrust in a specific direction) I started thinking about vectored thrust – there are numerous variations

a. A Helicopter vectors the thrust by changing the tilt of the rotor (not propellor) blades – and so providing both lift and thrust (and some drag)
b. The classic STOVL a/c (Harrier / AV8B) uses vectoring nozzle on the engine, and the vectoring is controlled by the engine. The same principle (in a very different engine arrangement) is in the F-35B short take off and vertical landing (STOVL) variant of the F-35 Lighting 2. It has a three-bearing main engine exhaust (changing direction of "normal" main thrust, and LiftFan (driven in STOVL operation by shaft from main engine providing vertical thrust, and two roll posts in wing) providing stability control
c. The Bell-Boeing V-22 Osprey is a helicopter variant where the orientation of the engines and propellors combined is changed to alter the direction of thrust (allowing VTOL, climb and cruise
d. There have even been variants where the engines remain in fixed position relative to the wing – but the whole wing is moved. In the Canadian National Aviation Museum (which I visited immediately after the International Symposium) there is a Canadair Cl-84 Dynavert which was a prototype (flew successfully but never ordered into production had a wing that could be tilted through 100°!

9) A general comment on the usefulness of different viewpoints and opinions. I hope in this note I have shown that the statement "an aircraft produces thrust" is both correct (as the thrust needs to be seen as a part of the whole) and incorrect as the thrust in a "conventional" a/c is generated by the engine (the aircraft design giving the context and the requirements derived from that design). If we all agreed with everything everyone said the IS would be dull and not worth going to. This "discussion" with someone who I really respect led me to reflect and improve my systems thinking about aircraft / engines – and remind myself (although I hope I don't need too much reminding) that when we partition a system into parts to engineer it, we introduce a significant risk as we will consider the parts in isolation and lost the view of the whole
10) Finally – a comment on random serendipity. This was one of the most stimulating parts of the IS for me. But when I came to write my notes, I saw that in my original plan I had intended to attend a different lecture, and had gone into this lecture totally by mistake (rushing as I moved between session tracks I misread the room number I was going to!). So moving off the planned path can be where most learning is achieved