PARAMETRIC ANALYSIS

Parametric analysis involves using simple relationships between parameters one of which we know and the other we want to know:

Thing we want to know = Fn (thing we know)

All we need is the function Fn. If we have this for all the important system parameters then we can speedily produce preliminary designs for feasibility and preliminary system outline purposes. For this reason they are pretty much essential to the top-down design process.

For example if the function of a spacecraft power system is to provide one kilowatt of power using an array of photovoltaic solar cells. Then we can use the following relationships (where P is power in watts):

Area (m^2) =P / 120 to get the area = 8.3 m^2

Mass (kg) = P / 25 to get the mass = 40 kg

Cost ($) = 2500 . P to get the cost = $ 2.5 million

Thus we can find the main parameters of the solar array in the detail needed for preliminary designs in a few moments.

WHERE DO THEY COME FROM

In theory simple relations can be derived by constructing a mathematical model of the relationship between the two parameters of interest. Sounds good, but it can get very complicated and it a virtual certainty that some real life will get left off making the model optimistic. To do the job well you need a thorough understanding of what you are modelling (including enough to know you are not missing anything important) in which case you probably know more than enough to use the empirical methods.

In practice **Parametric Models** are essentially identical to **Empirical Models.** That is the mathematical relationship is derived by looking at past performance of similar items. The parameters of interest are plotted on a graph and a best fit equation is derived. Sometimes it can be as simple as collecting data from a catalogue, sometimes quite a bit of research is required.

It sounds crude, but the results can be very accurate as they have all the "real life" factors automatically included.

The main problem is you have got to have a good background of relevant data to get the statistics.

LEVELS OF PARAMETRICS

System
Parametrics that predict features of the total system. - In most cases system parametrics do not provide the detail required to properly demonstrate feasibility, but they can be useful as sanity checks on the more detailed work.

They also are limited in their ability to establish the difference between various technical options when the difference are at the subsystem or component level.

Subsystem
Parametrics that predict features of subsystem. - Perhaps the most useful in the initial stages of system design as it enables the big pieces to be roughly put together. When more detailed work is undertaken the overall scheme should hold up.

Equipment
Parametrics that predict features of individual pieces of equipment. This enables quite detailed system design without actually designing specific hardware.

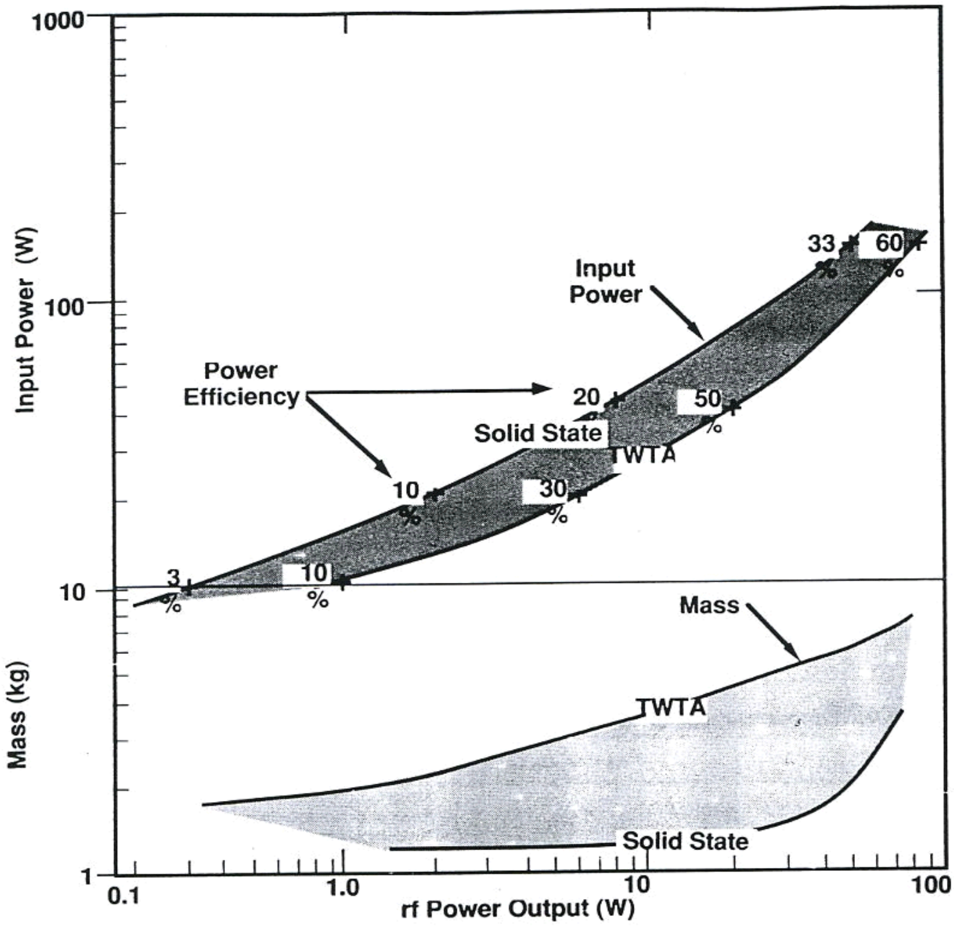
Real life
Normally consideration of concept and preliminary systems designs are a combination of subsystem and equipment level parametrics - where specific "off the shelf hardware" has not been identified.

SOME SPACE EXAMPLES

(from Wertz and Larson “Space system Design and Analysis”)

At the top are examples of graphical parametrics that in this case give power and mass estimates for two types of power amplifier used in satellite communications. Note one type (solid state) uses more power but weighs less than the other (Travelling Wave Tube Amplifiers) the parametric allows the designer to do a trade off to establish the best systems level option.

The table at the bottom is as simple as it gets: if you have a function (in this case they are related to attitude control) then here are estimates of mass and power values that go with that function.



Satellite Transmitter Power and Mass Versus rf Power Output. The curves derive from actual flight hardware. The data is relatively independent of output frequency.

Weight and Power of Components in a Guidance, Navigation, and Control Subsystem. Note $T \equiv$ Torque in N·m, and $H \equiv$ angular momentum in N·m·s.

Component	Weight (kg)	Power (W)
Earth sensor	2 to 3.5	2 to 10
Sun sensor	0.2 to 1	0 to 0.2
Magnetometer	0.2 to 1.5	0.2 to 1
Gyroscope	0.8 to 3.5	5 to 20
Star sensor	5 to 50	2 to 20
Processors	5 to 25	5 to 25
Reaction wheels	$2 + 0.4 \times H$ $H < 10$ $5 + 0.1 \times H$ $10 < H < 100$	10 to 20 at constant speed; 500 to 1000 W/(N•m) when torquing
Control moment gyros	$35 + 0.05 \times H$ $100 < H < 2500$	15 to 30 W standby; 0.02 to 0.2 W/(N•m) when torquing
Actuators (single axis)	$4 + 0.03 \times T$	1–5 W/(N•m)

DANGERS OF USING PARAMETRICS

Extrapolation outside their range

Whether a statistical or an analytical parametric it will not be over an infinite range. While interpolation between data points and within the range covered by the data. But take great care should be taken when moving outside the range for which data was available.

Technical base

A statistical parametric will refer to a particular technology base. It is important to determine that the technology assumed in the system design is the same as the technology base in the parametric. Sometime sophisticated parametrics have a family of curves related to different technology assumptions.

Remember in some fields technology can move very rapidly.

Impact of New Technology

A related problem and the worst limitation of using parametrics. A statistically derived parametric will of course relate to the level of technology and methods of design and construction used in the examples used to derive the relation. Often in a new system (or simply a new approach) it is the new technology that is the key feature and this will have to be evaluated by other means.

COST PARAMETRICS

A lot of effort has gone into the creation of cost parametrics that enable a good estimate of cost to be derived early in the project.

The parametrics are called Cost Estimating Relations (CERs).

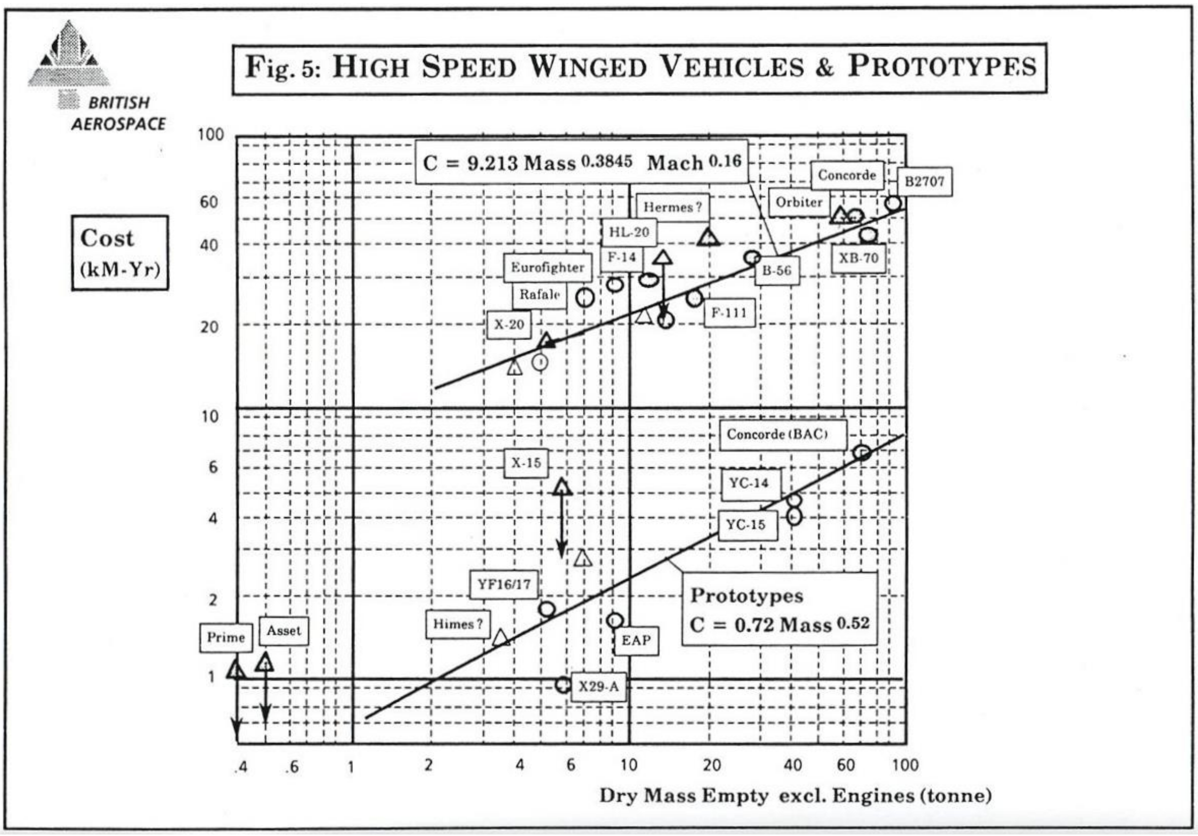
The basic equation for a CER is:

$$\text{COST} = \text{Fixed Constant} + \text{Factor Constant} \times \text{Tech. Factor} \times \text{Parameter}^{\text{Exponent}}$$

where - The Fixed constant, Factor constants and the Exponent are obtained statistically. Not all cost model have a fixed constant (which implies you pay even if you get nothing). - The Tech. factor is a correction for such things as technical complexity, (ir is not always relevant) - The Parameter is the thing used to scale the item to be costed - most commonly mass

Normally each item will have two cost parametrics - one for development and one for production.

While the CERs are often either company confidential or are expensive packages of computer programmes and training some books do give the game away for example with spacecraft a complete cost model (and lots of good discussion) can be found in Wertz and Larson “Space mission Analysis and Design”: it pays to seeks out such books in your subject area.



An example of a system level cost parametric for high speed aircraft.
(Note the label prototype is wrong these are actually system demonstrators)

WHAT LEVEL TO COST?

Cost Parametrics exist at all levels - system, subsystem, and equipment.

Equipment level is normally too detailed for requirement generation and system design phases (but can be used for special detailed examinations of specific areas). The real use for these is as a sanity (and rip-off) check on prices coming in on subsystem and equipment bids the in detailed design phase.

Opinions differ on the use of System level and Subsystem level costings during early studies.

System proponents of this level of parametric argue if you base the costing on subsystem level parametrics then anything you have left off will not get costed. Since that is most likely to happen in the expensive but light avionics, or engine areas, this could lead to major cost error. System level parametrics are less sensitive to these errors. Also System level parametrics covers "real world" factors like mistakes, project slips etc.

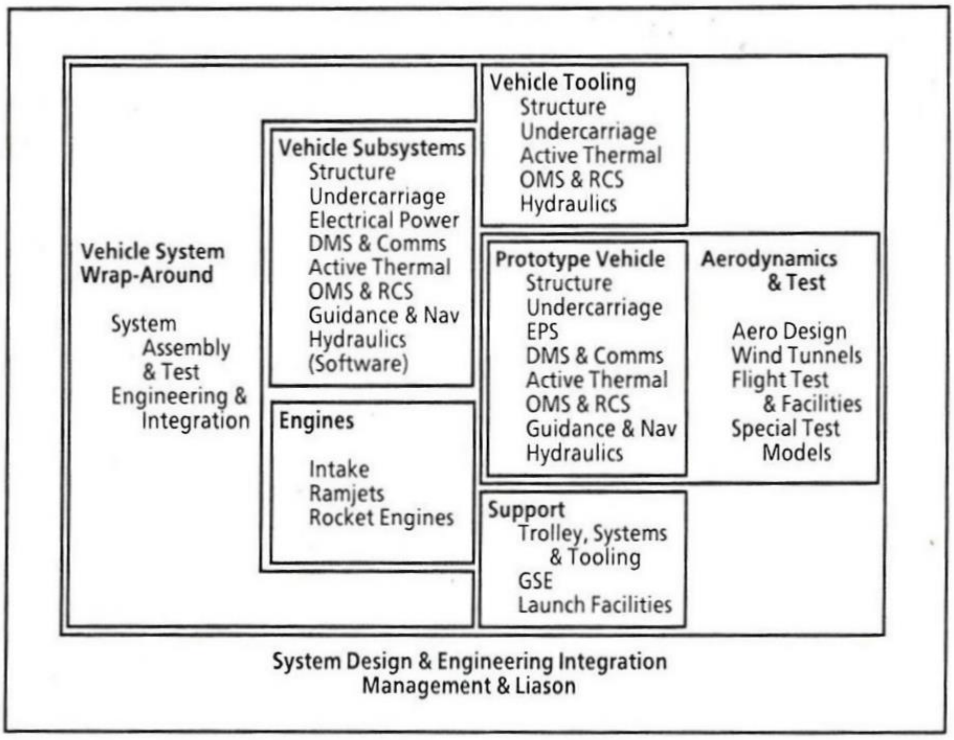
Subsystem proponents argue that if you use system costs you do not account for any changes in the technology, innovative system design etc. In fact there is no way to cost improvements - often the very thing you want to base your new system feasibility on.

Hempsell's opinion. Subsystem is the best route and the one I use but I then use the system level models as a “sanity check”.

SPECIAL FEATURES OF SUBSYSTEM LEVEL COST MODELS

Wrap-Arounds

Unlike budgets of mass, power etc where summing all the equipment values gives you the system total, with cost budgets subsystems and system have costs associated with them which must be added to the total produced by the equipment. These factors are called Wrap-Arounds. - They are normally a factor based on the total equipment or subsystem cost. Typically an additional 10%.



An example of the structure of a subsystem cost model with wrap-arounds.

What to Do About Margins

In early phases your best mass (or power etc.) estimates are likely to be light. But the Cost Parametric is based on actual real final build values. Therefore you are in danger of the estimate being under.

However your margins to cover this are hopefully larger than needed and the final mass will be lower on successful completion of the project. Also margins are not necessarily used where they are first allocated.

So do you cost the margins or not. No-one seems to agree. What I do (using my complex breakdown of margins) is cost my equipment and subsystem level margins but not the system level margins.

HOW TO DEAL WITH INFLATION

Technical parametrics deal in fixed quantities. However money suffers from inflation and is therefore not fixed in time.

Constant Year Money

The more traditional method. The parametrics are worked out for a currency (normally USA Dollars) for a given year. Inflation tables can then be used to move the currency to the year you are interested in.

Problem - What is inflation? It is not a single figure. What is actually needed is real inflation within the industry to which the parametric applies (not normally an available figure) most Governments give out suitable tables (including projections for the future) which are normally the best you can get. What is needed is wage cost/Factory gate inflation after productivity is accounted for.

Note: It is very important in costing to tag currency to years. "It cost a million dollars" is almost meaningless; "It cost a million dollars in $2020' is very useful.

Man-Years

Gaining wide acceptance within the Space cost estimating community based on work by D.E.Koelle. It produces costing in Man-years of effort (sometimes called a Koelle Man-Year).

The Man-year is derived from looking at the total directly accountable people working on the project and dividing by the cost. Thus it not only includes direct booking charges (labour wages + overheads+ profits) but also travel, materials etc.

Once the cost in man-years has been found tables can be used to convert that into year and currency (e.g. the value for 1993 in dollars is 200,000 per Man-year)

At the moment it is just a more convenient and fundamental unit. But it is hope in future that national productivities could be included in the conversion tables making for more accurate cost estimates based on where the item is actually built. At the moment the Tables cover USA and Europe and there is no detectable difference between them.

PRODUCTION - THE LEARNING CURVE

Normally the production cost parametric gives an estimate for the First Unit. If more than one unit is built then the cost per unit is reduced due to:

- - not making the mistakes again i.e. real learning;
- - investment in tooling and automation;
- - reductions in set up time;
- - bulk buying and other scale economies ;

The mathematical relation that describes the change in cost is called the **learning curve,** established by T.P.Wright ("Factors Affecting the Cost of Airplanes" Journal of Aeronautical Science 1936).

The learning curve is described by the equation.

$$\text{Production Cost of N units} = \text{Theoretical Cost of First Unit} \times N^{\left(1-\frac{\ln(100\% \ / \ S\%)}{\ln(2)}\right)}$$

Where S is learning curve slope and is the percentage reduction cumulative average cost when the production run is doubled.

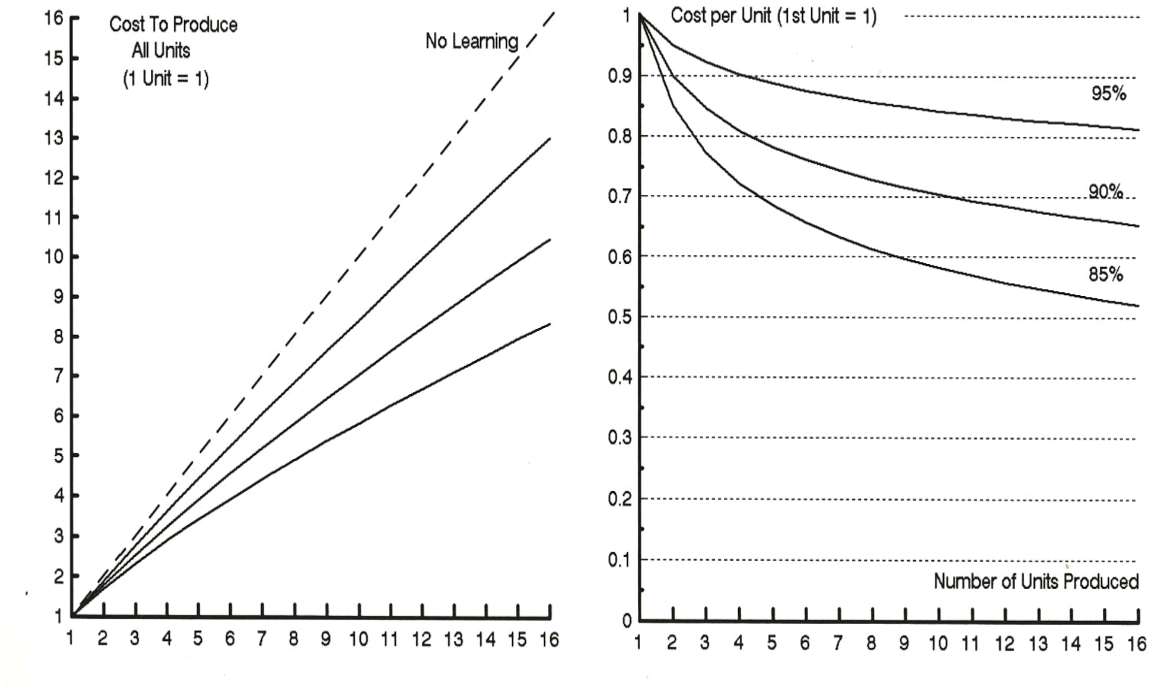
S is commonly recommended to lie between 85 % and 95 % and Wong (in Wertz and Larson) suggests for aerospace:

less than 10 units	95 %
10 to 50 units	90%
Over 50 units	85%

And you won't come to too much harm with that advice.

SOME LEARNING CURVES

For total production cost and average cost per unit.



LIFECYCLE COSTING

Much of the concentration of costing activities is on the price, and from that the cost to the customer to buy the system **- The Acquisition Cost**

But the real trade off criteria for the best route to proceed should be the total cost of ownership - that is acquisition, running, decommission; i.e. **The Lifecycle Cost**.

The use of parametrics for lifecycle costing is less well established, and more complex as the cost of such items as reliability, insurance etc. come into play.