QUALITY AND VERIFICATION

Definition – **Quality** **(reminder)**

The **quality** of a product is the property it possesses when it complies with the requirement specification.

Definition – **Verification** **(new)**

Is the demonstration of a system's quality, i.e. the process of verifying the system meets the requirements laid down for it.

Historical note: The old (and perfectly adequate) word for this was "testing" but this apparently is no longer "politically correct" as it implies some uncertainty in the outcome. I still use the word "testing" and have no problem if you do.

VERIFICATION AND VALIDATION

Verification is the process of ensuring what is designed and built meets the requirement specification. But what if there is a fault in the requirement specification - that is the event where a product meets the specification but does not meet the Purpose or objectives.

The process of proving something made to the requirement specification will meet the Purpose (i.e. do the job the customer wants) is called **Validation.**

At the highest system level (the whole aircraft etc.) the Validation is an integral part of the concept definition phase (Phase A in NASA/ESA speak). In theory it should cover checking mission models, and all the other analysis which tum the Purpose into the requirement specification.

In practice the term is used to refer to the comparison of the operational system with its objectives so it is often shown as the last development activity - taking place in the operations phase (e.g. the V diagram). But of course by then it's a bit late for the system being validated and is mostly done for the lessons to be learnt on later projects.

So Validation can be thought of as being both a concept definition and an operations activity.

At lower levels (Sub-system and Unit) there is a different approach being introduced. Manufacturers of such units will be responding to requirement specifications and will be treating the unit or subsystem as a system in its own right.

The argument goes that in this case the Validation of the requirements can be undertaken

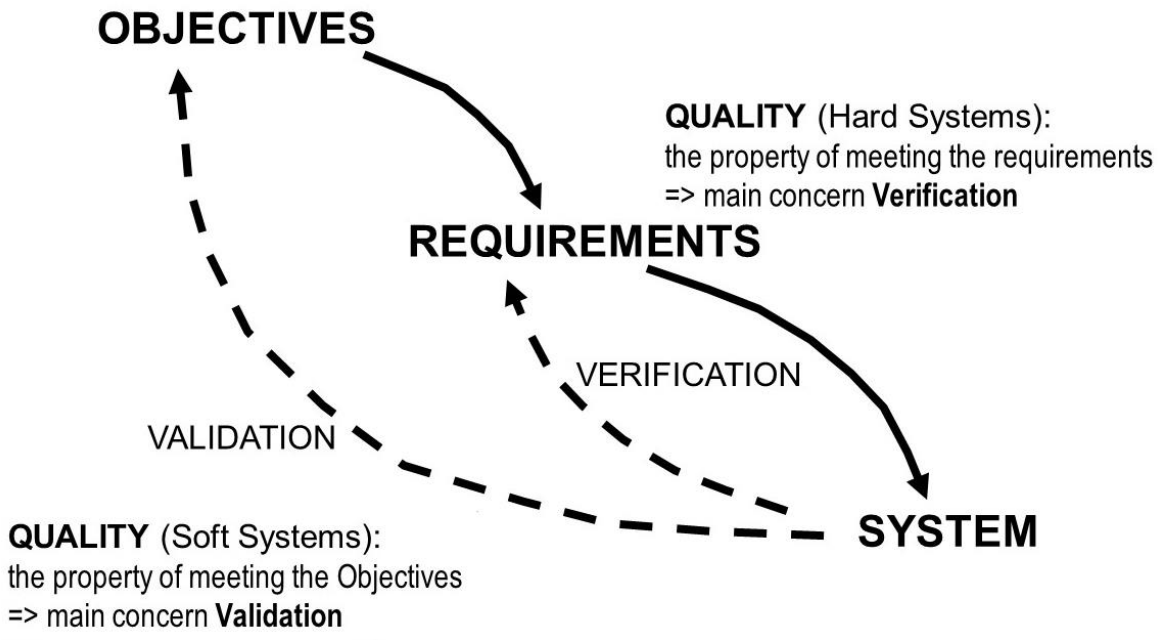
during design and build phases and therefore correct the requirement specification and the subsequent design before the unit is delivered. So formal procedures can be introduced to check possible solutions not only against the specification but also against the objectives.

It was to improve the Validation of requirements in this context that Boeing introduced the integral commentary in the requirement specification (which we follow in the assessed project).

IN SUMMARY

Verification is about comparing what is built with the Requirement Specification.

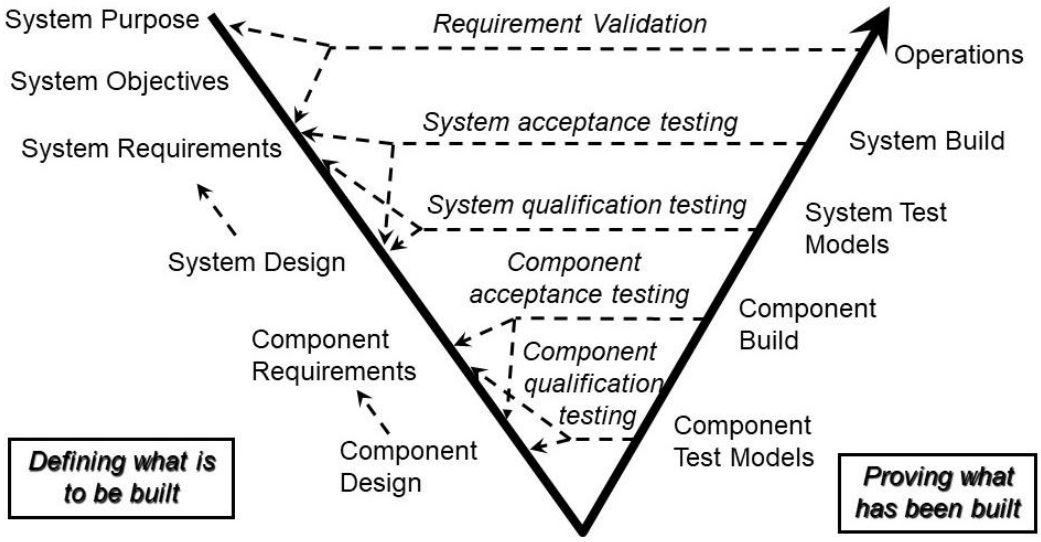
Validation is about comparing what is built with the Purpose.



THE V DIAGRAM

(V for Verification and Validation)

A currently trendy way to visualize the quality process in a systems engineering environment!



TWO MAIN CATEGORIES OF VERIFICATION

1) QUALIFICATION

Verification of the system design by analysis, modelling, component testing, prototype testing, comparison with similar designs etc... This leads to **"Qualification"** of the system design.

"Qualification" proves that, if built as designed, the system will meet the specification. Qualification should be established at the **Critical Design Review** prior to starting production.

2) ACCEPTANCE

Verification of the system construction - proving that each individual system meets the specification - Either by proving it meets the design (inspection) and/or by directly proving it meets the specification (acceptance testing). This leads to **"Acceptance"** of the actual system by the customer often called "Buy Off". This is done at the **Delivery Review Board.**

Acceptance testing has an additional legal implication as they are normally agreed with the customer at contract start. Failure to meet these tests will certainly lead to extra expense to correct the problem and can lead to the customer refusing to buy off of the product.

PLEASE MAKE SURE YOU LEARN THE DIFFERENCE BETWEEN THESE TWO!

PRODUCT ASSURANCE

"Product Assurance" (PA to close friends) (or "Quality Control", or "Quality Assurance") is the process by which the "Quality" of a product is achieved.

> "The Product Assurance (PA) system ensures that failure, hazard, and degradation aspects of the design and software are properly considered"
>
> *T.Meaker - ESA PA Department In "Spacecraft Systems Engineering" by Fortescue and Stark*

PA Activity that is normally conducted by a separate department with a special reporting path to senior management (*). This Department covers reliability, safety (normally) and verification.

> "PA has developed from fundamentally an 'inspection' function to a sophisticated and respected total engineering science."
>
> *T. Meaker - ESA PA Department in "Spacecraft Systems Engineering" by Fortescue and Stark*

* Cynical Note: Great play is often made by companies of the fact their quality organisation reports directly to the Managing Director and bypasses many levels of management. In practice this normally means the quality guys get isolated, as the Managing Director never has time to deal with them at the detailed required to make them effective and they have no working middle management path like everybody else.

VERIFICATION PLAN.

Verification doesn't just happen. Part of the system design phase activity is the production of a plan (or several plans) that shows how both Qualification and Acceptance of the system will be achieved. It used to be called "the Test Plan", nowadays the grander "Verification Plan" is more often used.

This plan forms part of the system definition and is approved by the customer.

In theory (and, in well run programmes, in practice) every requirement in the system Requirement Specification is considered and the method by which system Compliance with that requirement is going to be demonstrated is defined.

Note 1: If the product is a subsystem the same logic applies to the subsystem requirement specification

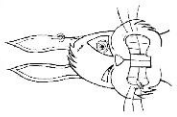
Note 2: The onus on the Requirement Specification is to specify things that can be verified. Also if different ways of specifying a requirement exist, the best way is normally the one that is easiest to verify.

EXAMPLES

Examples of how tests are used to achieve Qualification and Acceptance against specific requirements.

Requirement	- The spacecraft shall be launched on XXX-Launch system (implies a vibration environment)
Qualification	- Structure Model vibration tested to Ultimate loads. - Prototype Equipments tested to Ultimate loads. - Prototype Model vibration testing to Ultimate loads
Acceptance	- Vibration testing to Proof loads of entire spacecraft.
Requirement:	- The system shall not weigh greater than XXX kg.
Qualification:	- Often by analysis only - unless a prototype has been constructed.
Acceptance:	- Weighing built product.
Requirement:	- The RF power shall be greater than XXX Watts.
Qualification:	- Testing of breadboard on RF range or in an anechoic chamber.
Acceptance:	- Testing the system on RF range or in an anechoic chamber.
Requirement:	- The Spacecraft shall have a Delta Velocity capability of XXX m/sec.
Qualification:	- By analysis of propulsion system and component qualification.
Acceptance:	- Component testing and inspection of completed propulsion system.

THIS IS NOT AN EXAMPLE OF THE LAYOUT OF A VERIFICATION PLAN NOR THE LEVEL OF DETAIL THAT SHOULD BE IN IT.



REAL WORLD PAPER WORK

As always industries (and companies) differ in the way they handle the later stages but a "Full Monty" approach would be:

After the plan a series of Test Specifications are produced to define in more detail what is required from the test. This can be done either late in System Design or early in detailed design.

Once the thing to be tested is designed a Test Procedure would be written to answer each test specification. This document contains the sort of material that you would include in the Method, Apparatus and Procedure sections of a lab report. The point here is that you get all this approved before you conduct the test. This should be done late in the detailed design phase and be approved by the CDR (Critical Design Review).

Once the unit/subsystem/system has been made (so we are in Build Phase) it is tested to the approved test procedure and a Test Report is written. This is like the results and conclusions part of a lab report. It would normally then be included as part of the documentation supporting the Delivery Review.

QUALIFICATION - Analysis and Modelling

Qualification can be argued on the basis of analysis and mathematical models showing the designs characteristics (we will explore various aspects of modelling later in the course). This implies that you have a great degree of confidence in your understanding of the system - which is not always the case.

This method of Qualification is normally only used when qualification testing on real hardware has verified the model being used. It can then be used to qualify variations from the basic design such as upgrades or special additions.

This sort of approach can lead to attempts to qualify designs by reference to previous designs + modelling. This approach is OK if everybody keeps a cool head. However in the excitement of the massive cost savings this approach normally achieves there is a danger of taking it too far. - Caution advised.

Examples:

- Mass properties qualified by a mass budget based on mass estimates based on drawings.
- Propellant budgets based on qualified engine performance and system modelling.
- Structure modifications based on a Finite Element model already checked against testing.
- Control system response based on Dynamic Modelling.

QUALIFICATION - Components

Components that are used in systems are usually themselves designed (or sold if already designed) against Requirement Specifications and have to be qualified to that document. The same basic principles apply as to the systems itself.

The use of highly tested and proven parts in a system or subsystem can lead to an alternative route to qualification. In this case qualification is argued on the basis all the component parts have been individually qualified so the system is qualified. This only really makes sense on very simple systems where the lack of complexity means no interaction can occurs which interferes with the component level qualification.

It is not normally a method by itself; more often the component qualification status is used to argue a reduction, rather than a complete elimination, of the system qualification.

QUALIFIED PARTS AND MATERIALS LISTS

In space engineering commonly used parts are tested for suitability for use in space as a background activity and not for specific systems and then included on publicly available lists. These are held by ESA (ESTEC Holland) and Goddard Spaceflight

Centre. They list components that have passed a generic qualification test program for use on spacecraft. This list is normally further refined into a **Preferred Parts List** from which a design engineer will select components.

A spacecraft design must then produce a **Declared Parts List** (i.e. list of every part on the spacecraft). Showing that either the part is on the **Preferred Parts List** or that qualification has been achieved by another route.

A similar standard qualification process exists for basic materials leading to a **Preferred Materials List** and, as with parts, during the design and production a record is made of all materials used called a **Declared Materials List.**

QUALIFICATION – Testing

Ideally the main qualification testing should be on a completed system - the prototype.

Prototype testing
A universal approach for aircraft. Special dedicated systems are produced to the manufacturing drawings (but not necessarily on production tooling) for testing purposes.

Testing covers the complete design range (not the specified operational range). For example for a structure the loads applied will be ultimate and not limit.

Protoflight Testing
An alternative only used by the spacecraft community. With spacecraft engineering approaches becoming more standardised and better understood it was judged possible (in 1970's) to avoid the expense of a prototype which often raised the total production run from two to three (i.e. 50% more production costs).

The philosophy involves testing the first spacecraft to levels above acceptance testing (that should never put the system outside its operational range) but below typical prototype levels which reach the design limits. The spacecraft then are designed to survive the protoflight tests + a full mission. Then after the protoflight tests the spacecraft is then flown operationally.

QUALIFICATION - Model Philosophy

Other physical test models that can be used as part of Qualification:

Breadboards - for electrical circuits (also elegant breadboards).
Iron Birds - A complete electrical system on a gash structure (aircraft).
Engineering Models - Like flight but no inspection and some compromises.
Structure Models - Flight structure with dummy units, for structure testing.
Thermal Models - Flight structure and thermal finishes + dummies and heaters.

The cruder models (like Breadboards) and those without proper inspection (like Engineering Models) obviously have less potential to aid qualification than virtual prototypes like a Structure Model

The verification Plan will contain a "Model Philosophy" outlining which models are to be part of the qualification process (other models may still be built) . With aircraft (and cars etc.) The investment in test models is low compared with the total production cost and separate models may be constructed. Spacecraft often make one model suffice - upgrading it and changing it for different tests.

PROCUREMENT STANDARDS AND SPECIFICATIONS

To help the process of Verification (and particularly acceptance) there are standard specification from various bodies (normally Government).

Examples of standards bodies (British Standards Institute) BSI - American Standards Institute - USA Dept of Defense (DOD-SPECS), International Standards Organization (ISO) – European Standards (EN).

Mostly these define the qualification and acceptance testing and inspection required for a product and in the commercial marketplace that often leads to a standards logo being placed on the product. Such (normally national) logos are rarer now due to products being designed for the global marketplace.

There has recently been a perception (particularly within the USA DOD) that the use of customer standards like DOD-SPECS may over do the verification and be less efficient for government procurement than letting the supplier define the most appropriate verification process. This debate may lead to a relaxation in the use of procurement standards and specifications in military purchases.

ACCEPTANCE

There are three main ways in which a product can be verified for acceptance.

Inspection.

The classic quality technique. All parts when made are compared to the parts drawing and every measurement checked - again every assembly operation is checked against the assembly drawing. These inspections are conducted by inspectors (who are never the person who does the work) the results are recorded in a Build Log.

Batch Testing

For components when many are made in a single batch (i.e. it can be assumed every component is identical) a few are taken for testing. Batch testing is normally

to ultimate levels and tested components are not then used. It is not possible to batch test complete systems as they are never made in one consistent operation.

Acceptance Testing

As we have already seen this approach tests to levels that cover the operating range i.e. to values in the Requirement Specification but in theory not beyond it (but see next overhead).

Most common in acceptance testing is comprehensive testing showing that the complete system meets the specification on delivery. An example would be pre-delivery test flights on aircraft. But sometimes the acceptance testing duration is prolonged to "Burn In" the component to sort out the infant mortality due to wear in. This is most often used with electronic component testing.

DESIGN FOR ACCEPTANCE

So far in these lectures we have laid emphasis on designing a product to meet the Requirements defined in the Requirement Specification - a key principle in top down system design. However Acceptance Testing can introduce a complication. Many Acceptance Tests - push the system a little beyond the system requirement to ensure there can be no question about whether the requirement has been met (the same philosophy as the Baker's dozen = 13).

The problem comes when the result of a test is damage or undue stress to the system. Clearly it is not desirable to break the system that is to be used operationally while proving it meets the requirements. So in practice the design of the system is to the Acceptance Test levels and not the specified requirements levels.

While this does lead to over-design it is often the only practical way to ensure it is possible to prove the system's quality.

Examples: Structures are designed with RFs against proof loads not limit loads.
Engines are designed and tested to over 100% rated thrust

Note: This constraint does not in theory apply to qualification testing because damaging a qualification model can be acceptable. In practice the need to do further test on the same model means qualification loads are often also considered during design.

ASIDE - TOTAL QUALITY

A favourite concept of the moment.

"Quality" of a production process is normally judged by the quality of the product coming out of the factory gates.

"Total Quality" splits up the inside of the production process and looks at the quality each element in an industrial plant. The aim is to treat every output with the process as if it is going to an external customer (in system terms the same quality systems used on system interfaces are applied to internal interfaces.) Then once this is established a process of continuing quality and production improvements is implemented. It ends up more complicated in practice.

Generally a good idea if you already have a healthy organisation wishing to improve. However Total Quality has a history of being tried on companies that are already going down the tubes. In these instances it is used as a desperate last measure and actually normally hastens the inevitable demise.

I am not sure "Total Quality" has to be combined with "systems engineering" but it often is. Although I am not going to cover it further it avoids confusion if you know what it is.