1 Test facility specification, system integration and project organization

Introduction

An engine test facility is a complex of machinery, instrumentation and support services, housed in a building adapted or built for its purpose. For such a facility to function correctly and cost-effectively, its many parts must be matched to each other while meeting the operational requirements of the user and being compliant with various regulations.

Engine and vehicle developers now need to measure improvements in engine performance that are frequently so small as to require the best available instrumentation in order for fine comparative changes in performance to be observed. This level of measurement requires that instrumentation is integrated within the total facility such that their performance and data are not compromised by the environment in which they operate and services to which they are connected.

Engine test facilities vary considerably in power rating and performance; in addition there are many cells designed for specialist interests, such as production test or study of engine noise, lubrication oils or exhaust emissions.

The common product of all these cells is data that will be used to identify, modify, homologate or develop performance criteria of all or part of the tested engine. All post-test work will rely on the relevance and veracity of the test data, which in turn will rely on the instrumentation chosen to produce it and the system within which the instruments work.

To build or substantially modify, a modern engine test facility requires coordination of a wide range of specialized engineering skills; many technical managers have found it to be an unexpectedly complex task.

The skills required for the task of putting together test cell systems from their many component parts have given rise, particularly in the USA, to a specialized industrial role known as system integration. In this industrial model, a company or more rarely a consultant, having one of the core skills required, takes contractual responsibility for the integration of all of the test facility components from various sources. Commonly, the integrator role has been carried out by the supplier of test cell control systems and the role has been restricted to the integration of the dynamometer and control room instrumentation.
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In Europe, the model is somewhat different because of the long-term development of a dynamometry industry that has gave rise to a very few large test plant contracting companies.

However, the concept of systems integrator is useful to define that role, within a project, that takes the responsibility for the final functionality of a test facility; so the term will be used, where appropriate, in the following text.

This chapter covers the vital importance of good user specification and the various organizational structures required to complete a successful test facility project.

Test facility specification

Without a clear and unambiguous specification no complex project should be allowed to proceed.

This book suggests the use of three levels of specification:

1. Operational specification: describing ‘what it is for’, created by the user prior to any contract to design or build a test facility.
2. Functional specification: describing ‘what it consists of and where it goes’, created either by the user group having the necessary skills, as part of a feasibility study by a third party, or by the main contractor as part of the first phase of a contract.
3. Detailed functional specification: describing ‘how it all works’ created by the project design authority within the supply contract.

Creation of an operational specification

This chapter will tend to concentrate on the operational specification which is a user-generated document, leaving some aspects of the more detailed levels of functional specification to subsequent chapters covering the design process. The operational specification should contain a clear description of the task for which the facility is being created. It need not specify in detail the instruments required, nor does it have to be based on a particular site. The operational specification is produced by the end user; its first role will normally be to support the application for budgetary support and outline planning; subsequently, it remains the core document on which all other detailed specifications are based. It is sensible to include a brief description of envisaged facility acceptance tests within the document since there is no better means of developing and communicating the user’s requirement than to describe the results to be expected from described work tasks.

- It is always sound policy to find out what is available on the market at an early stage, and to reconsider carefully any part of the specification that makes demands that exceed what is commonly offered.
- A general cost consciousness at this stage can have a permanent effect on capital and subsequent running costs.
Because of the range of skills required in the design and commissioning of a ‘green field’ test laboratory it is remarkably difficult to produce a succinct specification that is entirely satisfactory, or even mutually comprehensible, to all specialist participants. The difficulty is compounded by the need for some of the building design details that determine the final shape, such as roof penetrations or floor loadings, to be determined before the detailed design of internal plant has been finalized. It is appropriate that the operational specification document contains statements concerning the general ‘look and feel’ and any such pre-existing conditions or imposed restrictions that may impact on the facility layout. It should list any prescribed or existing equipment that has to be integrated, the level of staffing and any special industrial standards the facility is required to meet. In summary, it should at least address the following questions:

- What are the primary and secondary purposes for which the facility is intended and can these functions be condensed into a sensible set of acceptance procedures to prove the purposes may be achieved?
- What is the realistic range of units under test (UUT)?
- How are test data (the product of the facility) to be displayed, distributed stored and post-processed?
- What possible extension of specification or further purposes should be provided for in the initial design and to what extent would such ‘future proofing’ distort the project phase costs?
- May there be a future requirement to install additional equipment and how will this affect space requirement?
- Where will the UUT be prepared for test?
- How often will the UUT be changed and what arrangements be made for transport into and from the cells?
- How many different fuels are required and must arrangements be made for quantities of special or reference fuels?
- What up-rating, if any, will be required of the site electrical supply and distribution system?
- To what degree must engine vibration and exhaust noise be attenuated within the building and at the property border?
- Have all local regulations (fire, safety, environment, working practices, etc.) been studied and considered within the specification?

**Feasibility studies and outline planning permission**

The work required to produce a site-specific operational specification, or statement of intent, may produce a number of alternative layouts each with possible first-cost or operational problems. In all cases an environmental impact report should be produced covering both the facility’s impact of its surroundings and, in the case of low emission measuring laboratories, the locality’s impact on the facility.
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Complex technocommercial investigatory work may be needed so a feasibility study might be considered, covering the total planned facility or that part that gives rise to doubt or the subject of radically differing strategies. In the USA, this type of work is often referred to as a proof design contract.

The secret of success of such studies is the correct definition of the required ‘deliverable’ which must answer the technical and budgetary dilemmas, give clear and costed recommendations and, so far as is possible, be supplier neutral. The final text should be capable of easy incorporation into the Operation and Functional Specification documents.

A feasibility study will invariably be concerned with a specific site and, providing appropriate expertise is used, should prove supportive to gaining budgetary and outline planning permission; to that end, it should include within its content a site layout drawing and graphical representation of the final building works.

Benchmarking

Cross-referencing with other test facilities or test procedures is always useful when specifying your own. Benchmarking is merely a modern term for an activity that has been practised by makers of products intended for sale, probably ever since the first maker of flint axes went into business: it is the act of comparing your product with competing products and your production and testing methods with those of your competitors. The difference today is that it is now highly formalized and practised without compunction. Once it is on the market any vehicle or component thereof can be bought and tested by the manufacturer’s competitors, with a view to taking over and copying any features that are clearly in advance of the competitor’s own products. There are test facilities built and run specifically for benchmarking.

This evidently increases the importance of patent cover, of preventing the transfer of confidential information by disaffected employees and of maintaining confidentiality during the development process; such concerns need to have preventative measures built into the specification of the facility rather than added as an afterthought.

Safety regulations and planning permits covering test cells

Feasibility not only concerns the technical and commercial viability, but also whether one will be allowed to create the new or altered test laboratory; therefore, the responsible person should consider discussion at an early stage with the following agencies:

- local planning authority;
- local petroleum officer and fire department;
- local environmental officer;
- building insurers;
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- local electrical supply authority;
- site utility providers.

Note the use of the word ‘local’. There are very few regulations specifically mentioning engine test cells, much of the European legislation is generic and frequently has unintended consequences for the automotive test industry. Most legislation is interpreted locally and the nature of that interpretation will depend on the industrial experience of the officials concerned, which can be highly variable. There is always a danger that inexperienced officials will over-react to applications for engine test facilities and impose unrealistic restraints on the design. It may be found useful to keep in mind one basic rule that has had to be restated over many years:

An engine test cell, using liquid fuels, is a ‘zone 2’ hazard containment box. It is not possible to make its interior inherently safe since the test engine worked to the extremes of its performance, is not inherently safe; therefore the cell’s function is to contain and minimise the hazards and to inhibit human access when they are present. (see Chapter 4, Test cell and control room design: an overall view).

Most of the operational processes carried out within a typical automotive test cell are generally no more hazardous than those hazards experienced by garage mechanics, motorists or racing pit-staff in real life. The major difference is that in the cell the running engine is stationary in a space that is different from that for which it was designed and therefore humans may be able to gain close and potentially dangerous access to it.

It is more sensible to interlock the cell doors to prevent access to an engine running above ‘idle’ state, than to attempt to make the rotating elements ‘safe’ by the use of close fitting guarding that will inhibit operations and fall into operational disuse.

The authors of the high level operational specification need not concern themselves with some of such details, but simply state that industrial best practice and compliance with current legislation is required. The arbitrary imposition of existing operational practices on a new test facility should be avoided at the final functional specification stage until confirmed as appropriate, since they may restrict the inherent benefits of the technological developments available.

One of the restraints commonly imposed on the facility buildings concerns the number and nature of chimney stacks or ventilation ducts. This is often a cause of tension between the architect, planning authority and facility designers. With some ingenuity these essential items can be disguised, but the resulting designs will inevitably require more space than the basic vertical inlet and outlet ducts. Similarly, noise break-out via such ducting may be reduced to the background at the facility border but the space required for attenuation will complicate the plant room layout (see Chapter 3, Vibration and noise).

Note that the use of gaseous fuels will impose special restrictions on the design of test facilities and, if included in the operational specification, the relevant authorities and specialist contractors must be involved from the planning stage. Modifications may include blast pressure relief panels in the cell structure and exhaust ducting, which need to be included from design inception.
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Specification for a control and data acquisition system

The choice of test automation supplier need not be part of the operation specification but, since it will form part of the functional specification, and since the choice of test cell software may be the singularly most important technocommercial decision in placing a contract for a modern test facility, it would seem sensible to consider the factors that should be addressed in making that choice. The test cell automation software lies at the core of the facility operation therefore its supplier will take an important role within the final system integration. The choice therefore is not simply one of a software suite but of a key support role in the design and ongoing development of the new facility.

Laboratories where the systems are to be fully computerized should consider

• the local capability of each software/hardware supplier;
• the installed base of each possible supplier, relevant to the industrial sector;
• level of operator training and support required for each of the short-listed systems;
• compatibility of the control system with any intended, third party hardware;
• modularity or upgradeability of both hardware and software;
• requirements to use pre-existing data or to export data from the new facility to existing databases;
• ease of creating test sequences;
• ease of channel calibration and configuration;
• flexibility of data display and post-processing options.

A methodical approach allows for a ‘scoring matrix’ to be drawn up whereby competing systems may be objectively judged.

Anyone charged with producing specifications is well advised to carefully consider the role of the test cell operators. Significant upgrades in test control and data handling will totally change the working environment of the cell operator. There are many cases of systems being imposed on users which never reach their full potential because of inadequacy of training or inappropriate specification of the system.

Use of supplier’s specifications

It is all too easy for us to be influenced by headline speed and accuracy numbers in the specification sheets for computerized systems. The effective time constants of many engine test processes are not limited by the data handling rates of the computer system, but rather of the physical process being measured and controlled. Thus the speed at which a dynamometer can make a change in torque absorption is governed more by the rate of magnetic flux generation in its coils, or the rate at which it can change the mass of water in its internals, rather than the speed at which its control algorithm is being recalculated. The skill in using such information is to identify the numbers that are relevant to task for which the item is required.

Faster is not necessarily better and it is often more expensive.
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Functional specifications: some common difficulties

Building on the operational specification, which describes what the facility has to do, the functional specification describes how the facility is to perform its defined tasks and what it will contain. If the functional specification is to be used as the basis for competitive tendering then it should avoid being unnecessarily prescriptive. Overprescriptive specifications, or those including sections that are technically incompetent, are problems to specialist contractors. The first type may prevent better or more cost-effective solutions being quoted, while the later mean that a company who, through lack of experience, claims compliance wins the contract, then inevitably fails to meet the customer’s expectations.

Overprescription may range from ill matching of instrumentation to unrealistically wide range of operation of subsystems.

A classic problem in facility specification concerns the range of engines that can be tested in one test cell using common equipment and a single shaft system. Clearly there is a great cost advantage for the whole production range of a manufacturer’s engines to be tested in one cell. However, the detailed design problems and subsequent maintenance implications that such a specification may impose can be far greater than the cost of creating two or more cells that are optimized for narrower ranges of engines. Not only is this a problem inherent in the ‘turn-down’ ratio of fluid services and instruments having to measure the performance of a range of engines from, say 500 to 60 kW, but the range of vibratory models produced may defy the capability of any one shaft system to handle.

This issue of dealing with a range of vibratory models may require that cells be dedicated to particular types or that alternative shaft systems are provided for particular engine types. Errors in this part of the specification and the subsequent design strategy are often expensive to resolve after commissioning. Not even the most demanding customer can break the laws of physics with impunity. Before and during the specification and planning stage of any test facility, all participating parties should keep in mind the vital question, By what cost- and time-effective means do we prove that this complex facility meets the requirement and specification of the user?

It is never too early to consider the form and content of acceptance tests, since from them the designer can infer much of the detailed functional specification. Failure to incorporate these into contract specifications from the start leads to delays and disputes at the end.

Interpretation of specifications

Employment of contractors with the relevant industrial experience is the best safeguard against overblown contingencies or significant omissions in quotations arising from user-generated specifications.
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Provided with a well written operational and functional specification any competent subcontractor experienced in the engine or vehicle test industry should be able to provide a detailed specification and quote for their module or service within the total project. Subcontractors who do not have experience in the industry will not be able to appreciate the special, sometimes subtle, requirements imposed upon their designs by the transient conditions, operational practices and possible system interactions inherent in the industry.

In the absence of a full appreciation of the project based on previous experience they will search the specification for ‘hooks’ on which to hang their standard products or designs, and quote accordingly. This is particularly true of air or fluid conditioning plant where the bare parameters of temperature range and heat load can lead the inexperienced to equate test cell conditioning with that of a chilled warehouse. An escorted visit to an existing test facility should be the absolute minimum experience for subcontractors quoting for systems such as chilled water, electrical installation and HVAC.

General project organization

In all but the smallest test facility projects, there will be three generic types of contractor with whom the customer’s project manager has to deal. They are

- civil contractor;
- building services contractors;
- test instrumentation contractor.

How the customer decides to deal with these three industrial groups and integrate their work will depend on the availability of in-house skills and the skills and experience of any preferred contractors.

The normal variations in project organization, in ascending order of customer involvement in the process are

- A consortium working within a design and build or ‘turnkey’* contract based on the customer’s operational specification and working to the detailed functional specification and fixed price produced by the consortium.
- Guaranteed maximum price (GMP) contracts where a complex project management system, having a ‘open’ cost accounting system, is set up with the mutual intent to keep the project within a mutually agreed maximum value. This requires joint project team cohesion of a high order.  

*The term Turnkey is now widely misused. The original turnkey contract was one carried out to an agreed specification by a contractor taking total responsibility for the site and all associated works with virtually no involvement by the end user until the keys were handed over so that acceptance tests can be performed.
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- A customer-appointed main contractor employing supplier chain and working to customer’s functional specification.
- A customer appointed civil contractor followed by services and system integrator contractor each appointing specialist subcontractors, working with customer’s functional specification and under the customer’s project management and budgetary control.
- A customer controlled series of subcontract chains working to the customer’s detailed functional specification, project engineering, site and project management.

Whichever model is chosen the two vital roles of project manager and design authority (systems integrator) have to be clear to all and provided with the financial and contractual authority to carry out their allotted roles. It should be noted that in the UK, all but the smallest contracts involving construction or modification of test facilities will fall under the control of a specific section of health and safety legislation known as Construction Design and Management Regulations 1994 (CDM) regulations which require nomination of these and other project roles.

Project roles and management

The key role of the client, or user, is to invest great care and effort into the creation of a good operational and functional specification. Once permission to proceed has been given, based on this specification, and the main contractor has been appointed, the day to day role of the client user group should, ideally, reduce to that of attendance at review meetings and being ‘on-call’.

Nothing is more guaranteed to cause project delays and cost escalation than ill-considered or informal changes of detail by the client’s representatives. Whatever the project model, the project management system should have a formal system of notification of change and an empowered group within both the customer’s and contractor’s organization to deal with such changes quickly. The type of form shown in Fig. 1.1 allows individual requests for project change to be recorded and the implications of the change to be discussed and quantified. Change can have negative or positive effect on project costs and can be requested by both the client and contractor; with the right working relationship in a joint project team, change notes can be the mechanism by which cost- or time-saving alterations can be raised during the course of work.

All projects have to operate within the three restraints of time, cost and quality (content) (figure 1.2). The relative importance of these three criteria has to be understood by the client and project manager. The model is different for each client and each project and however much a client may protest that all three criteria have equal weighting and are fixed; if change is introduced, one has to be a variable.
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<table>
<thead>
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<th>Variation No:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project name:</td>
<td>Project No:</td>
</tr>
</tbody>
</table>

Details of proposed change:  
(include any reference to supporting documentation)

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<thead>
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<th>Requirement (tick and initial as required)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Design authority required design change</td>
<td></td>
</tr>
<tr>
<td>Customer instruction:</td>
<td></td>
</tr>
<tr>
<td>Customer request:</td>
<td></td>
</tr>
<tr>
<td>Contractor request:</td>
<td></td>
</tr>
<tr>
<td>Urgent quotation required:</td>
<td></td>
</tr>
<tr>
<td>Customer agreed to proceed at risk:</td>
<td></td>
</tr>
<tr>
<td>Work to cease until variation agreed:</td>
<td></td>
</tr>
<tr>
<td>Requested to review scope of supply:</td>
<td></td>
</tr>
<tr>
<td>Other (specify):</td>
<td></td>
</tr>
</tbody>
</table>

Contractor representative
Name
Email/Phone No.
Authorized

Customer representative
Name
Email/Phone No.
Authorized

Actions:
Sales quote submitted: (date and initial)  
Authorized for action: (date and initial)  
Implemented: (date and initial)

Figure 1.1 A sample contract variation record sheet

If one of the points of the triangle is moved there is a consequential change in one or both of the others and that the later in the program the change is required, the greater the consequential effect.

One oft-repeated error, which is forced by time pressure on the overall programme, is to deliver instrumentation and other equipment into a facility building before internal environmental conditions are suitable. It is always better to deliver such plant late and into a suitable environment, then make up time by increasing installation man hours, than it is to have incompatible trades working in the same building space and suffering the almost inevitable damage to the test equipment.
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Figure 1.2 Project constraints: in real life, if two are fixed the third will be variable

Key project management tools

The techniques of project management are outside the remit of this book but some important tools and skills that any project manager in charge of an automotive test facility are suggested.

Communications and responsibility matrix

Any multicontractor and multidisciplinary project creates a complex network of communications. These networks between suppliers, contractors and personnel within the customer’s organization may pre-exist or be created during the course of the project; the danger is that informal communications may give rise to unauthorized variations in project content or timing. Good project management is only possible with a disciplined communication system and this should be designed into and maintained during the project. The arrival of email as the standard communication method has increased the need for communication discipline and introduced the need, within project teams, of creating standardized, computer-based filing systems.

If competent staff are available to create and maintain a project specific intranet website then the project manager has a good means of maintaining control over formal communications. Such a network can give access permission, such as ‘read only’, ‘submit’ and ‘modify’, as appropriate to individuals’ roles to all of the groups and nominated staff having any commercial or technical interest in the project.

The creation of a responsibility matrix is most useful when it covers the important minutiae of project work, that is, not only who supplies a given module but who, insures, delivers, off-loads, connects and commissions the module.
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Use of ‘master drawing’ in project control

The use of a facility layout or schematic drawing graphically showing facility modules that can be used by all tendering contractors and continually updated by the main contractor or design authority, can be a vital tool in any multidisciplinary project where there may be little detailed appreciation between specialized contractors for the spatial requirements of each other.

Constant, vigilant site management is required during the final building ‘fit out’ phase of an automotive test facility if clashes over space allocation are to be avoided, but good preparation and contractor briefing can reduce the inherent problem. If the systems integrator or main contractor takes ownership of project floor layout plans and these plans are used at every subcontractor meeting, kept up to date to record the layout of all services and major modules then most of the space utilization, service route and building penetration problems will be resolved before work commences. Where possible and appropriate, contractors method statements should use the common ‘table top’ project plans to show the area of their own installation in relation to the building and installations of others.

Project timing chart

Most staff involved with a project will recognize a classic Gantt chart; not all will understand their role or the interactions of their tasks within that plan. It is the task of the project manager to ensure that each contractor and all key personnel work within the project plan structure. This is not served by sending an electronic version of a large and complex Gantt chart, but by early contract briefing and preinstallation progress meetings.

There are some key events in every project that are absolutely time critical and these have to be given special attention by both client and project manager. Consider, for example, the arrival of a chassis dynamometer and the site implications:

- One or more large trucks will have to arrive on the client’s site, in the correct order, and require suitable site access for manoeuvring.
- The chassis dynamometer will require a large crane to off-load. The crane’s arrival and site positioning will have to be coordinated within an hour of the trucks’ arrival.
- Access into the chassis dynamometer pit area will have to be kept clear for special heavy handling equipment until the unit is installed, the access thereafter will be closed up by deliberately delayed building work.
- Other contractors will have to be kept out of the effected work and access areas, as will client’s and contractor’s vehicles and equipment.

Preparation for such an event takes detailed planning, good communications and authoritative management. The non, or late arrival of one of the key players because ‘they did not understand the importance’ clearly causes acute problems in the
example above, but the same ignorance of programmed roles causes delays and overspends that are less obvious throughout any project where detailed planning and communications are left to take care of themselves.

**A note on documentation**

Test cells and control room electrical systems are, in the nature of things, subject to detailed modification during the build and commissioning process. The documentation, representing the ‘as-commissioned’ state of the facility, must be of a high standard and easily accessible to maintenance staff and contractors. The form and due delivery of documentation should be specified within the functional specification and form part of the acceptance criteria. Subsequent responsibility for keeping records and schematics up to date within the operator’s organization must be clearly defined and controlled.

**Summary**

Like all complex industrial projects, the creation, or significant modification, of an engine test laboratory should start by the creation of an operational specification involving all those departments and individuals having a legitimate interest. The specification of the engine testing tasks and definition of suitable acceptance tests are essential prerequisites of such a project.

The roles of system integrator, design authority and project manager must be well defined and empowered. Specifically, ensure that the design authority for systems integration is explicitly given to a party technically competent and contractually empowered to carry it out.

There are at least three levels of specification that should be considered and it is essential to invest time in their preparation if a successful project is to be achieved. Paper is cheaper to change than concrete.

The project management techniques required are those of any multidisciplinary laboratory construction but require knowledge of the core testing process so that the many subtasks are integrated appropriately.

The statement made early in this chapter, ‘Without a clear and unambiguous specification no complex project should be allowed to proceed’, seems self-evident; yet many companies, within and outside our industry, continue either to allocate the task inappropriately or underestimate its importance and subject it to post-order change. The consequence is that project times are extended by an iterative quotation period and from the point at which the users realize that their (unstated or misunderstood) expectations are not being met, usually during commissioning.