1960

Determination of test facilities

BOSTON UNIVERSITY
College of Business Administration

THESIS

Determination of Test Facilities

By

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B. N. S. Dartmouth College 1947
M. S. E. E. Thayer School of Engineering 1948

Submitted in partial fulfillment of
the requirements for the degree of
Master of Business Administration

1960

This thesis was prepared under my supervision and approval is hereby indicated.

Professor of Business Administration

First Reader

This thesis was read by me and is approved.

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INTRODUCTION

The objective of this thesis is to determine the criteria for establishing test facilities when the particular product market is changing to one of diversified nature. The aircraft industry is undergoing this transition to diversification and thereby lends itself to analysis for such criteria.

Manufacturers engaged in the production of equipment for the Aviation Industry are in a transition period with respect to product makeup and ordering quantities therefor. Since the early years of World War II, these manufacturers have been military aviation-oriented. This orientation resulted from large orders for especially selected and qualified products. Production of these products was tied to certain models of military aircraft. Government funding of such equipment continued to rise over the fifteen-year-plus period which followed, and companies became ever limited in flexibility and more entrenched in mass production for Government procurement.

During the latter part of 1957, the Government, after an assessment of expenditure proposals and the makeup of our offensive and defensive weapons, entered into a course of cancellations and stretch-outs of airplane production. Emphasis was swinging toward ballistic missiles and the composition of the aviation market was being oriented to allow room for the rapidly increasing commercial and private airplane business.

Experience has shown a lateness on the part of several companies to effect the transition and to accomodate the changing market, both as to composition and magnitude of the components thereof. These manufacturers have been or will be faced with the effects of program stretch-outs and cancellations for a major portion of their production. Such a situation could cause whole plants or major segments thereof to shut down for lack of quantity orders to which they have become so avidly accustomed.

The test function plays a major role in the production of a given product. All through the manufacturing process inspection or test stations may be required to check the incoming raw material or to check on the correctness of a contributing operation. This is in keeping with the essence of effective quality control which is designed to maintain a continual light check on the manufacturing process to be sure the quality does not change.

The repetitive manufacturing process makes it impractical and nearly impossible to make all products from a given process identical. Some variations are usually allowable and to a degree determined by the customer application. Components and subassemblies must be held within limits which have been established to facilitate assembly,and yet not exceed the variation allowed for the ultimate user. The manufacturing process will many times have facilities, skills, and methods which operate within a narrower range of variation or tolerance to assure meeting that overall variation. This practice is aimed at fewer rejects in later operations. It does entail a higher quality and cost.

Manufacturing must produce the product in the most economical manner and still meet the required quality level. The rise of narrower tolerances during the manufacturing process has been explained. To assure that such a process is in fact held tighter, inspection or test operations are required for the receipt of raw material and for contributing operations. If the product variations are to be controlled, every variable characteristic must be also.

A fundamental approach to inspection is to check every piece or assembly as it is generated. This process culls out all defects within the accuracy limits of the inspection or test. It is still in use for high quality and high cost production, such as diamond cutting and mouting for expensive jewelry, or for equipment for nuclear power plants, and special military applications where extreme reliability is required.

The problems with 100% inspection lie in its cost, or in some instances the fact that it may be destructive. These conditions lead to random sampling*. With the aid of mathematicians a statistical program of sampling has been developed wherein sampling size and number of defects allowable were delineated for the required acceptable levels of quality. The principle objective was that in the long run the sample would be representative of the lot from which it was selected insofar as quality is concerned. A sampling plan does not, of course, find defects in the uninspected portion of the lot. Whenever the sample is truly random and representative of the lot, the plan operates to assure the quality level desired.

The level of savings in cost from using a sampling plan versus a 100% inspection lies in the cost of finding defects later on. These may be found in the manufacturing process and involve spoilage,

*See Appendix I

rework, and manufacturing tie-ups, or in the field where the cost of a customer complaint must be borne as well. For each quality level there is a probable numbers of defects, and when the total cost of correcting this number of defects is less than the cost of having inspected that particular lot 100% originally, the sampling plan at that quality becomes the more economical process.

Effective quality control controls the three variables in the manufacturing process - raw material, machines, and manpower. In this manner the quality variations that occur daily or weekly are around a definite quality level. In addition products exhibit a greater degree of uniformity; complaints, manufacturing losses, and inspection costs are reduced; and the manufacturing process operates smoother.

The subject matter herein, concerns primarily the facilities which test or inspect the completed product. The primary application is in the manufacturing process and constitutes what is called final test and inspection. Similar facilities are also required for product appraisal or evaluation tests where products are retested and inspected. These tests simulate the attitudes of a most critical customer, and exacting compliance to the specifications of the application may be checked. They serve as a check on manufacturing operations and inspection, and can furnish fundamental facts about the design, its life, and characteristics. This approach to super-quality control may shortcut deficiencies which could lead to customer complaints.

In test facilities the conformance of the product to minimum customer guarantees is measured, and managements generally withhold permission to ship the particular product until such conformance has been ascertained. The necessary tests may be elaborate in technology and equipment, require especially trained operators, and much time for completion. To be effective with regard to production economy of time and cost, test facilities must be of the proper type, available at the proper time, and in adequate quantities to meet production requirements. It is essential, therefore, that any determination be based on factors which assure the establishment of the optimum facility for the market, the product, and the particular business conditions which prevail at the time.

A theoretical analysis is presented of the procedures normally followed in the establishment of test facilities for any product, but more particularly one in the aviation equipment market. It is demonstrated that the criteria governing the establishment of such facilities are:

Engineering specifications	Space required
Production quantities	Personnel requirements
Total net cost of facility	Utilities and services
Time available for procurement	

Application of these criteria to the establishment of test facilities will enable managements to obtain a clear concise breakdown of the technical and economical aspects of the plan. Such a breakdown will be of assistance also, in preparing subsequent revisions of the proposals, as each criterion is presented independently of the others and can be modified to meet the particular management objectives for the product plan in light of the prevailing business conditions.

The General Electric Mass-Fuel Flowmeter, as a typical aviation product, both Military and commercial, has been analyzed in the light of such criteria from the viewpoint of its history and its future. Several factors have been found to exert controlling interest in facility establishment with the change in product make-up over the years Different facilities have been established in unique ways to satisfy the particular conditions prevailing at the time. A historical review of conditions such as market forecast, product technology, financial position, and schedules has been made to serve as a basis for examination of errors in approach utilized at the time and to evaluate deviations from budgeted objectives.

With such evidence in hand, a critical evaluation has been made of the years immediately ahead in order to apply the heretofore mentioned criteria. It is anticipated that this approach will result in the establishment of optimum test facilities for the G. E. flowmeter business. The evidence suggests that any manufacturer planning to establish a test facility would do well to evaluate his proposal in light of these criteria. His conditions may require special emphasis on one or more criteria, but in the final analysis the consideration of all will be necessary for the optimum facility.

Little can be found in the literature concerning this problem area. Much information had to be obtained through personal interview, review of official project reports, minutes of meetings, and intensive examination of correspondence.

Insight into some of the problem areas was enhanced by the author's engineering education background and work experiences. Several years as Engineering Leader in test equipment design, and his current position as sales engineer in aircraft flowmeter marketing made for a sharpened curiosity and a familiarity with personnel and product lineages. The active employment of the management training received in the graduate school facilitated the comprehension of the inputs from manufacturing and marketing.

A Glossary of Terms has been included to assist wherever technical terminology may require further explanation.

I

ESTABLISHMENT OF TEST FACILITIES

This section treats of the subject in terms of general applications where any product or type of market could be under considerations. The background, thus obtained, will be reinforced by the case illustrated in later sections where only one product line will be considered and that in detail.

The criteria which appear to be paramount in determining test facilities in the general treatise will be checked against those in the case for a practical verification. To be considered will be product specification, production quantity, facility cost, delivery time, space required, personnel, shop utilities or services, product profitability and cash position.

In order to facilitate the understanding of this problem area an explanation of the functions of a test facility is presented. This is followed by a detailed statement of the origins and purposes of particular design configurations. Finally, a statement of the considerations involved in the actual procurement of the facility is presented.

FUNCTION

The phrase "to test" falls short of even hinting at the magnitude or the complexities involved in stating the function of test facilities. To illustrate this point, the following breakdown as to the types of tests to be performed in a manufacturing plant which supplies military equipment is presented. Each operation may be separate and complete from that required for the other tests.

A. PRODUCTION LINE INSPECTION TESTS - Tests are performed as routine operations to assure general compliance with test specifications. Included may be visual inspection for appearance, operational tests, and safety checks. These tests may be run on a 100% basis or may be part of a sampling plan. As was covered earlier, either method may be used depending upon a cost and product quality analysis. The objective remains at adequate quality for a minimum overall cost.

These tests may be limited in scope and number, but should detect errors due to manufacturing operations or defective materials. As self-checks, they are normally performed by manufacturing personnel at the end of the production line. Products must pass these tests before being shipped.

B. PRODUCT EVALUATION TESTS - Tests are performed to assure compliance with design specifications and/or contractual requirements and, generally, subject the product to performance extremes. Included may be visual super-inspection for appearance and excellance of workmanship, accuracy checks, electrical and mechanical performance characteristics, and proper identification. Random samples are put through such tests by impartial testing groups or outside vendors. These tests are an important part of efforts to assure reliability and substantiate specific product guarantees. Many customers, more especially the Government, require satisfactory performance in such tests before shipments can be made from the particular production batch from which the sample was taken. Several manufacturers follow such a test program on their own to assure high quality and thereby minimize customer complaints. It serves as a check on the manufacturing process and inspection.

C. QUALIFICATION TESTS - Government agencies (including the Military) and customers who, in turn, are subject to government certification, require periodic testing of products to exacting performance and environmental specifications. Qualification tests are usually required with new products, new contracts, or design changes in existing products. These tests usually are an extension of those typically under product evaluation tests and, as such, encompass the environmental exposures of the application. Included are extreme temperature and vibration, humidity, fungus, salt spray, ultra-violet and nuclear radiation effects.

It can be seen from the foregoing definitions that once a customer has included proper Quality Control and Qualification Tests in the contract specifications for the product, he is assured of receiving the same product made to a consistent level of quality by compliance thereto.

DESIGN

The design of a test facility has its beginning in the product specifications which aim at meeting fully the requirements of the application. The engineering function must generate a set of test specifications, fulfillment of which will comply with the customer's product specifications. This test specification defines the types of tests and the conditions under which they are to be performed. Utilizing this test specification the methods planners can proceed to develop a testing operation.

The methods planner has to treat the test or inspection operation in the same aura of importance that he has the other process operations. His breakdown of an operation to produce a part or an assembly involves methods, machines, and manpower. He applies the principles of work simplication to the task under study and utilizes the most efficient manufacturing techniques to effect the required product quality at minimum cost. Test and inspection are functional steps in the manufacturing process and contribute to product quality and cost. They, too, must exhibit the influence of work simplification techniques to minimize costs and contribute to the smoothness of the manufacturing process.

One further input is needed and that is the number of stations required. This depends upon the production rates which evolve from the sales forecast. This evolution is the function of production planning, where production rates are set at optimum to maintain production at a low unit cost and still meet shipping requirements.

The methods planner can proceed to layout the required number of test stations. He can generate an elapsed time for testing of one product from the specification and the setup involved. It may be that a single-station facility will suffice, and that overtime or multishift operation will be used for higher production rates, or he may determine that a more elaborate multi-station facility will result in a lower overall cost.

The methods planners initiate 'requests to quote' for test equipment to satisfy the testing plan. These requests may be placed on an internal company test equipment function or on selected vendors in the particular field. The process of quoting usually involves much of the planner's time to properly define the need. In question may be material limitations, choices of electro-mechanical configurations, and physical size. The final proposal often reflects a compromise of the many potential approaches to the design objectives.

In order to complete the planning of the test operations, the proposals must be analyzed in terms of space requirements, type and number of operators required, auxiliary facilities to implement the procured test equipment, and the cost to effect the installation in its entirety.

One can readily imagine the potential complications in allocating space. With today's technology, space may run from a simple bench test to a completely new and separate plant. Bench tests may involve no more than a bench top area with approved samples for reference against which the production articles are checked. The inspector or tester may be required to use simple measuring instruments or gauges to check dimensions and shapes. Larger facilities may include such items as the automatic automobile engine block inspector which checks all dimensions from machining operations, or the use of acre lots to contain a complete wind tunnel to test airframe resistance to air currents. These complications, and the many gradations, require a critical analysis, as construction costs can be appreciable, and in addition, the mere occupation of factory space involves maintenance and upkeep charges. Any proposal must show the most efficient use of space.

Qualified personnel are seldom readily available. Special training and skills are usually the case with testing assignments. The operation may be run on a single or a multi-shift basis. Procurement of qualified personnel, who will work under the particular working hours and conditions, may well involve lengthy lead times.

Many opportunities exist for a job to be downgraded by using automaticity or subdividing the task. All efforts in these directions lead to the use of lessor skilled operators, and thereby utilize a more easily obtainable group of operators. The planner must reconcile over-all costs with the problem of obtaining adequately trained personnel in order to effect the lowest product cost to satisfy the job requirements. It may result that a better skilled operator can do the job quicker and with less facility cost, than in a proposal where lessor skills require more elaborate and costly equipment.

Auxiliary facilities may well run the same gamut as space requirements. Heat, power, light, air, and water may only be the beginning. As with space, above, the technological conditions required could be an insurmountable obstacle to the establishment of the facility. Recent examples of the potential complications were: the sinking of artesian wells and the diverting of the municipal water lines, both in-side and outside of the plant proper, in order to obtain an adequate supply of cooling water for a constant temperature oil supply in a large hydraulic test stand; and the building of a six-compressor power plant to supply enough high pressure air to test pneumatic starters and super-chargers for aircraft engines.

The first illustration was not foreseen as a problem area until the warm weather began and the existing plant air conditioning systems exhausted most of the incoming water supply lines. The latter illus-tration was foreseen and adequately planned. The magnitude of the undertaking can be appreciated when one realizes that an entirely new building was required, and that the engines to drive the air compressors were each the size of that on a naval destroyer. This multimillion dollar facility is definitely an extreme example. The lesson is that facilities cannot be treated lightly and as a matter of course. Most plants have heat, light, power, etc., but are they of the proper type, and available at the proper place and time in the required quantities? The planner must make his study a complete one.

In the final analysis, the cost of the facility determines its future. Management may question the status as to expense or capitalization; the cash position with respect to income and expenditures; and the cost of alternatives, such as subcontracting the entire testing operation. The answers to each point or issue either re-enforces the proposal or detracts from its merits. The essential elements are that the enterprise must show a return on investment commensurate with that earned by similar ventures, and it must show an adequate annual earning rate as a percentage of sales billed.

The issue of expense write-off or capitalization is usually dictated by the limits allowed under the tax statutes. If all projects could be expensed, the net earnings, and taxes thereon, could be held to a minimum. Only recently, a new interpretation has allowed special electronic test equipment to be regrouped, and written off as expense, if it fell within certain defense contract categories. Otherwise, this equipment has to be amortized over a three-year life.

The particular financial conditions of the period may dictate approval or not on the basis of cash position. If the facility represents a severe drain on cash, the company might be forced to undertake short term financing until the cash situation can be recouped, or if this is not seen as advisable from a cost or policy viewpoint, the facility may have to be deferred. Much of this depends on the earning rate of the product.

Management generally desires to know the cost of alternatives to such a proposal for facilities. A subcontracting of the operation can be extremely profitable if a suitable vendor is available and already in operation with the required task. The savings in startup expenditure must be balanced against the interruption in the production process and the loss of control over one operation. It is to be remembered that all costs must be on an out-of-pocket basis to be equivalent. Internal costs can often be distorted through the addition of non-applicable mark-ups and overhead percentages.

In summary each of these financial areas contributes to management evidence that the expenditures as proposed are justified by the product income over the foreseeable life of the product line.

It can be deduced from the foregoing that much forecasting, planning, engineering, and financial analyzing must be performed before a request for appropriation is in proper form for management analysis.

PROCUREMENT

Once management has approved the appropriation and the funds are available, the procurement of the necessary equipment, services, and manpower can commence. Regardles of physical size or cost, the same people or functions become involved in specification clarification and deviations, installation problems and the many miscellaneous details. With larger projects, the degree of complexity may become greater, and the problem frequency generally runs higher. Under these conditions the role of project coordinator, whether it is the product engineer or the methods planner, must be exercised more actively and effectively to assure timely and economical completion of the test facilities.

A typical procedure might involve a coordination and scheduling meeting where each contributing function is assigned its particular task and an integrated schedule is established to meet the production requirements for the product line. The procurement paperwork can be generated based on the engineering specifications and the requirements for the manufacturing process as established by the methods planner. For an outside-the-company procurement this paperwork constitutes the basis of the purchase order.

Once the buyer has placed the order, any problems which arise with the vendor require immediate and effective action on the part of the engineer, planner, and buyer, so as not to delay shipment or cause unnecessary changes in the equipment as ordered. In dealing with a vendor, contracted agreements govern the procurement. It can be easily seen that changes may lead to a renegotiated instrument. It is wise to work out all details thoroughly before requesting any change, and thereby, minimize negotiations, delays, and the associated paper work attendant upon a changed contract.

When the equipment is to be procured from an internal function, many of the rigid contractural rules are eliminated and changes can be more readily incorporated. Again, it must be noted that changes to the design of the facility can involve extra cost and extend the delivery date.

While in the normal process of procurement the decision, as to whether the equipment or facility should be built internally or bought from a vendor, would have been made before seeking management approval, the choice may have to be reviewed before placing the order. In building through the company's own facilities the equipment can be especially tailored to the application. The construction generally employs engineers, designers, and construction personnel who are already on the payroll. Each new project may tend to increase their utilization. This type of procurement can provide the most economical package in specialized equipment. As has been mentioned, the processing of necessary changes after the order has been placed can result in fewer complications than when dealing with an outside vendor. There is also the benefit of having better control over quality of the workmanship, and if needed, over the delivery schedule.

In contrast is the standardized type of equipment which is nearly, if not in fact, off-the-shelf. Here a vendor has already completed the engineering, drafting, and construction of the equipment. The purchaser pays a minimum for engineering and tooling, saves in delivery time that amount normally to be spent for those functions. The purchaser must decide on what special requirements of his application he can compromise, and thus be in a position to use a standard article. This may not be possible, and herein lies one main factor which makes test equipment and facilities specialized and expensive.

Engineering and planning do not always have adequate lead time for providing test facilities. This forces compromises in design, manufacturing efficiency, or in cost in order to meet the product production date. In addition, when the invariable problems arise, the vendor and purchaser have to effect a solution under the heat of a tight delivery.

It should be the objective of every engineer, planner, or manager to facilitate the progress of the design, approval, and procurement of a test facility. A seldom realized objective should be to allow the vendor to deliver in accordance with his normal process time. Costs may be held to a minimum and quality can be maintained.

Management would do well to remember the importance of allowing adequate lead time for establishing a facility. Problems invariably arise, and when purchaser and vendor can work out details without the heat of a short delivery procurement, both benefit.

The order should be placed as soon as the design criteria are frozen and the expenditure has been approved. Every attempt should be made to assure that this date is consistent with the vendors normal delivery schedules. Thus ordered, costs and delivery time may be held to a minimum.

II

DETERMINATION OF TEST FACILITIES FOR A MASS PRODUCTION MARKET

GENERAL ELECTRIC MASS-FUEL FLOWMETERS

MARKET RESEARCH

Toward the end of the 1940's, the U. S. A. F. enlisted the assistance of industry to develop a fuel-flow measurement system for jet engines. This system had to be accurate at all flow rates from 0 to 12,000 PPH to within ± 2% of the particular flow rate being measured. This meant that at a normal cruise rate of 2500 PPH the system could indicate no higher than 2550, or lower than 2450 PPH. Such a system would be an essential part of efficient fuel management.

Fuel quantity gauges (similar in function to that in an automobile) were inadequate as a primary measurement because they measured only volume of fuel remaining, and then at a ± 20% accuracy.

Jet-engine trust (power output) is proportional to the mass rate of fuel-flow, or pounds per hour, a fact which limited the success of existing volumetric and variable orifice designs. The transmitter, or primary sensor, in these models responds to volume rate or gallons per unit of time. These models are fundamentally sensitive to density (mass per unit volume) variations which occur with temperature changes at different altitudes during flight.

The primary Air Force application was the then-entering-production B47 high-speed six-engine jet bomber, which could fly at altitudes of 40,000 feet with - 65° temperature. This market was estimated to be 5000 units per year based on individual engine instrumentation, including spares.

General Electric activity was directed toward a density-compensated variable-orifice flowmetering system. This approach attempted to eliminate the density variation effects by compensation techniques. Progress was slow. A sudden engineering breakthrough produced a working model exhibiting the momentum principle. For the first time, a true mass-flow sensor had been developed.* A constant frequency power supply and a self-synchronous indicator completed the system. In January 1951, the Air Force initiated procurement of development systems for actual flight installations.

The following sales forecast was established shortly thereafter to support the request for development authorization. This forecast was extraordinary in the sense that G-E was a sole source supplier, and in such a monopoly position could use the plane production figures for the forecast of the system production.

Shipments of Flowmeter Systems

(Units)

	Transmitters	Indicators	Power Supplies
1953	4,500	4,500	1,500
1954	11,600	11,600	3,900
1955	11,600	11,600	3,900

One year later, this forecast was revised to reflect the latest expected plane production figures. This revision was the essence of the business supplement to the formal production authorization prepared at that time.

*See Appendix II, III, IV

Shipments of Flowmeter Systems

(Units)

	Transmitters	Indicators	Power Supplies
1953	3,700	3,700	1,200
1954	16,000	16,000	5,400
1955	16,000	16,000	5,400

The authorization was submitted to the Executive Office for approval with the following note attached.

> The completion of this project will clearly establish General Electric as the leading manufacturer of aircraft flowmeters and will broaden the base of our aircraft instrument operations through participation in a new measurement field.
>
> I. F. Kinnard, Manager of Engineering
> Instrument Department, General Electric Co.
> March 1952

TEST FACILITY DESIGN

Test specifications were prepared by engineering based on requirements set forth in the controlling military specifications. The flow range was established as 0-12,000 PPH. The flowmeter transmitter was to be accurate to within ± 1% of point over the full flow-range and had to be free from position errors. Also included in the specification were sub-assembly and component tests which aimed at minimizing problems in testing the fully assembled product.

These sub-assembly and component tests were part of quality control. Incoming raw materials and vendor parts were inspected. Spring material was tested on a force-deflection fixture and was hardness tested on a commercial hardness gauge. Motors were tested for starting and running electrical and mechanical characteristics. Magnets were strength tested in their sub-assemblies. Finally, the complete turbine sub-assembly was calibrated and balanced in a bench test prior to assembly into the transmitter housing for final test.

Analysis of the sales forecast revealed that production had to be ultimately geared to produce 300 plus units per week. This rate according to the testing schedule of the methods planners, would utilize more than 300 hours of test facility time each week. Consequently, when the optimum space required for a test stand was determined, it was found that the proposed floor space would accommodate four stands. For ultimate production, these stands would have to be operated on a two-shift basis.

After effecting a floor plan and a production flow chart, a smooth-flowing assembly line was generated. This was accomplished in spite of the complexities of four large test stands in the test operation.

PRODUCT EVALUATION FACILITY

The Instrument Department Testing Laboratory had, over the years, acquired a reputation for performing accurate unbiased tests. This position was only naturally extended to cover flowmeter testing. The problem was to establish an adequate facility for such tests. The existing development and design test stands used by engineering were found to be limited in both capacity and function.

In order to prepare for expansion, a new facility was designed for 25,000 PPH full scale. Included in the facility were high and low temperature fuel conditioners as well as ambient temperature chambers. This facility would serve engineering in the development of new higher flow-rate flowmeters as well as allow experimentation under different temperature conditions.

A vibration facility was to be established with a portable flowstand. This facility would only be used 50% of the time, and the shaker-table could be used for other types of tests, or other products. Special qualification tests such as fungus resistance, radio noise, and explosion-proof were not provided for with separate facilities. It was found to be more economical to sub-contract such work to one of the competent vending laboratories in the particular fields.

The new flow facility would be required to handle up to three units a week (1 per 100 units shipped) for Military Specification Sampling Plan tests. This load could be handled with two testers on a one-shift basis with a small percentage of time available for engineering evaluations previously mentioned. Of course, overtime and extra shifts could be programmed, if needed, for such activities.

PROCUREMENT

COST

Preliminary cost estimates had been developed by the Test Equipment Unit and these were the budgetary figures used in initial planning. Once specifications were firm, and location and quantities established for the planned production, formal bids were entertained for the facilities.

A review of the proposals received showed the internal bid to have been lowest. This was made more favorable in view of the overhead write-offs which were an integral part of the bid price. In effect, the out-of-pocket cost was extremely low for the Test Equipment Unit proposal compared to that of the vendors proposing.

INCOME

The inventiveness and technical ingenuity behind this product placed the Company effectively in a non-competitive market. Adequate mark-ups were included in the planned selling price, so as to write off the costs of facilities within the life span of contracts then in prospect. Legally, write-offs were limited by the Federal Income Tax regulations applicable thereto and were in the three year category.

ORDERS

Procurement had been initiated for the first 5000 units by the Air Force. This market was forecast at that time to be much broader and deeper than at any previous review.

GENERAL

It had been determined that duplicate facilities were not readily available elsewhere for Sampling Plan and Qualification Tests. The only adequately equipped facility was at the Air Force Development Center in Wright Field, Ohio. The prospect of conducting different tests at different vendors' laboratories according to the availability of facilities, was rejected as excessively expensive and time consuming.

Spare capacity in the laboratory facility could be made available for the engineering development tests of new designs, techniques, and product applications.

INSTALLATION

Management approved of the project after short review and analysis. The Manufacturing and the Laboratory facilities were both operative in the early part of 1953. The design and construction were the responsibility of the Test Equipment Unit and they solicited the guidance and counsel of the G. E. River Works Plant Engineering Unit, as well as the vendors of the many pumps, valves, etc., required.

The Laboratory facility as established could handle flow rates up to 25,000 PPH at temperatures down to -65°F and up to +100°F as well as at standard conditions. Calibration was determined by use of a built-in weigh tank which allowed basic weight and time standardization. Readout was accomplished through tapered tube Flowrators which were maintained in calibration by the weigh tank method on a routine schedule.

The manufacturing stands had the tapered tube Flowrators for rate indication and utilized a pneumatic-hydraulic system of valves for automatic flow control.* Calibration was maintained through frequent checks with transfer standards which were calibrated and periodically checked on the laboratory facility.

EVALUATION OF FACILITIES AS ESTABLISHED

In retrospect, the facilities heretofore discussed were properly determined and fully utilized for the purpose intended. Specific periods of overload did occur and the factory accommodated by working, first, six days and, then, with the addition of a partial third shift. The laboratory felt such binds more severely as the qualified ranks for testers were thin. Consequently, loads had to be absorbed by six-day weeks, and finally, two-shift operation. In one extreme condition, work had to be scheduled for two twelve-hour shifts for continuous operation.

High quality design and construction resulted in few production shutdowns and minimized major maintenance programs. The only changes to be effected in the first five years were to eliminate the pneumatic-hydraulic flow control valves because the dynamics of the system made for oscillations, and the substitution of in-line standards in place of the tapered-tube flowrators. This speeded the test operation and allowed the operators to read similar instruments, a technique which minimized errors in data recording.

Manufacturing placed orders in 1956 for automatic flow recording equipment. The long processing time precluded its installation until early 1958.

By that time, the Military had effected the newsworthy cutbacks in procurement, and diversification had made great inroads in this product line. Consequently, this mass production read-out technique has been side-lined, perhaps forever.

The manufacturing stands handled all flow rates up to 17,500 PPH, and an uprating wasn't required until 1958. At that time, only new pumps and pressure valve readjustments were required to change to 25,000 PPH and accommodate new models of 18,000 and 24,000 PPH ratings.

The laboratory stands were inadequate within a year, for new engineering designs required 45,000 PPH. This change was made and the system performed well until 1958, when a new pump (connected in parallel with the existing model), and larger pump inlet piping to minimize pressure drop, had to be installed. A new flowrator with 150,000 PPH capability was installed to handle the new flowrates. Prototypes have since been tested at 75,000 PPH.

III

EXPANSION OF MARKET DUE TO NEW APPLICATIONS

IN-FLIGHT REFUELING

In an effort to extend the effective range of its long range bombers the Air Force developed the technique of in-flight refueling in the early 1950's. This technique involved a bomber making a rendezvous with a high speed jet tanker. The fuel was transferred through a probe which trailed the rear of the tanker. The measurement problem involved the actual rate of transfer and the integration thereof, or total fuel transferred.

The pipe size ran to four and one-half inches or three times the diameters experienced heretofore. Flow rates were expected to be in the range of from 60,000 to 600,000 PPH. To better orient magnitudes, this latter flow passes enough fuel in one minute to drive an automobile around the earth at the equator.

Manufacturing facilities were non-existent for flowmeters in these flow ranges. The Air Force thereupon decided to fund the design and construction of two 1,000,000 PPH flowstands with the appropriate accessories and readout equipment. One stand was established for production, and the other qualification and sampling plan tests. Special tanks for fuels of different specific gravities were installed and calibration was planned to be performed against a working standard transmitter. These working standards were planned to be periodically recalibrated at the WADC facility at Wright-Patterson Center in Ohio.

At the time of facility planning the total market was estimated at 700 systems to be procured over three to four years. The success of this refueling technique coupled with the broadening of the application has since caused production estimates to be several times revised. Including 1959, over 3,000 units have been shipped. The current reemphasis on the importance of manned bombers dictates maintenance of production rates for several years to come.

This facility has indeed served well the intended purposes. The second stand has served for several engineering experiments for military and commercial applications. The recently introduced Industrial Gas Flowmeter had its beginnings in just such liquid flow experiments.

45,000 PPH PROTOTYPE TRANSMITTER

In 1955 procurement was negotiated with a prime contractor for eight plane sets of flowmeters and indicators. Analysis of the prospects for a market revealed that for several years only limited quantities would be required. In the long run, however, this plane could represent a sizeable market.

A further note of indefiniteness was injected by the equipment being furnished by the prime contractor, and not the government. There was evidence that the contractor, in addition, had financial interests in a competitor.

The decision was made to perform all flow tests and calibration checks on the Laboratory facility. All such operations and necessary adjustments were performed by planning men and laboratory technicians.

Lower paid Manufacturing testers could not be used in the Laboratory facility due to union regulations. Moreover, operations would not be planned and methodized. It was felt that the planning men and the technicians would have the ability and ingenuity to solve the ever present problems.

By paying a higher unit cost and saving on the facilities management deemed the total project cost to be the optimum. They would appear to have been justified, for through 1959, no production orders have been in prospect for equipment in this flow range.

LOW RANGE-HIGH ACCURACY SYSTEMS- 1959

The application of small jet engines to utility transports dictated the need for accurate flow measurements with cruise rates held to 0.5%. Existing manufacturing facilities with calibration by transfer standards accumulated probable testing tolerances which were excessive for such tight cruise control. The only known technique was to revert to a direct weight-time calibration.*

The market was canvassed and a specialty vendor was located who could supply a self-contained weigh tank and weigh stand facility. Equipment could be delivered in less time and at a lower cost than internal units could propose.

The flexibility of the design of the purchased stand led to procurement of a similar model with high and low temperature test capabilities for the Testing Laboratory. This made for the closest reconciliation of calibration between the Manufacturing and the Laboratory facilities. The Laboratory facility in toto was made more flexible. Extreme accuracy was now possible in the flow ranges 0-5,000, 0-15,000, 0-50,000 and 0-100,000 PPH.*

SUBMINIATURE SYSTEM

The results of a marketing breakthrough to the jet-driven helicoptor and the small executive aircraft market led to the design in 1959 of a subminiature system with flow ranges of 0-1200, 0-1800, and 0-2500 PPH.

*See Appendix VI

These systems are being readily handled using the purchased facilities in operation with the low range systems. Of the models currently in production, these systems have the greatest potential market. In two or three years the production rates are expected to rise to the point where separate facilities will be required for this system.

*See Appendix VII

IV

EFFECTS OF FURTHER DIVERSIFICATION

Mass flowmeters were quickly adopted by the commercial transport manufacturers and users for jet engine applications. In the commercial aviation industry efficient fuel management has always been essential. The mass flowmeter enabled the various flights to be programmed and operated under the required speed and altitude conditions with optimum fuel consumption.

The problems with test facilities were initiated by the many models to be made for the many engines. Most of these applications required different flow ranges and different indicator presentations. The flow ranges were covered by changes in flow stands, while the indicator presentations involved several different types of electronic test equipment.

The following examples illustrate the utilization of existing facilities (by modifications) where possible. This increased the flexibility of the facilities, but because of the several models using each facility, no one model could be tested at a high production rate. This was the status of the flowmeter facilities at the time this thesis was written.

The consideration for future applications illustrates two flow ranges which because of production rates or technological reasons show signs of outgrowing the existing facilities. The high range has already been provided for by orders for new facilities. Close following by the product planning function will be in order to enable the low ranges to be covered in time with the proper facilities.

Commercial Applications

PROP-JET TRANSPORTS

In 1957 the 12,000 PPH transmitter was redesigned to operate with 3,000 PPH full scale. This resulted in an extremely low pressure drop transmitter which could serve the low flow prop-jet market.

With the military 12,000 PPH system procurement falling off and the prospects for the prop-jet market very encouraging, one of the factory stands was converted to the new range and configuration. All nominal 1% transmitters in the range up to 3,000 PPH were to be tested on this stand.

TURBO-JET TRANSPORTS

During 1958 the fruits of major marketing and engineering efforts were borne as General Electric Mass Fuel-Flowmeters were specified on the Boeing 707, Douglas DC-8, and Convair 600 and 880. The 0-15,000 PPH flow range allowed these systems to be tested on the stands originally set up for the 12,000 PPH military versions. Modifications were minor and involved only piping adapters and mounting brackets with pressure adjustments on the pumping system.

The long range airliners had a need for a fuel consumed system of extreme accuracy. The importance of accuracy reserve means six extra paying passengers. The transmitters for these systems were tested on the 0-5,000 PPH weight tank facility which was purchased complete and had full flow rate of 15,000 PPH.

The fuel consumed systems increased the value of the unit sale per plane. All of the previously mentioned systems were exclusively of flow rate variety. On long range flights efficient fuel management requires carrying only that amount of fuel needed plus legal spare requirements. All extra fuel serves to displace paying passengers or cargo.

The rate system allows effective power setting on the engines, but they have allowable tolerances for accuracy variations. In a long flight these errors could add and cause aircraft to refuel premeturely (if possible) or crash out of fuel.

The addition of the fuel consumed indication provides an accurate total of fuel consumed in pounds. The crew merely subtract this figure from the fuel quantity on board at the start of the flight and they have an accurate measure of fuel remaining. Periodic monitoring of this data will assist in programming engine consumption and make for effective fuel management.

This commercial venture has exceeded most of the marketing forecasts in terms of net sales billed. The market has recently been seen to have real depth on a retrofit basis.

<u>Considerations for Future Requirements</u>

<u>MILITARY</u>

At the present the military market can be forecasted only with a great deal of speculation. The product planners and market research units will have to watch the changing emphasis from manned space vehicles to missiles and back to manned aircraft again.

The best estimates at this time foresee requirements, in the 0-60,000 and 0-100,000 PPH flow range for the manned interceptor and bomber programs. Looking ahead to these requirements two self-contained weigh-tank flowstands are being programmed for purchase this year. One will be used in the Laboratory and one in the Factory. These will satisfy the increased accuracy requirements being incorporated in new military specifications and will be economical on a first cost consideration.

Missiles represent a field of technology of their own. The fuel to be measured usually is a cryogenic. The measurements are only for tests and are not operational. The momentum principle will work on low temperature cryogenics, if the materials utilized can keep pace with the technology. Present activity in this area is limited to the academic.

COMMERCIAL

The airtransport business is constantly striving for lower costs for operations and more passengers. Fuel management systems will be ever directed at higher accuracies, and flowmeter tests will have to run on a weight-time basis, for fuel consumed systems at least.

Changes for the immediate future involve an uprating of systems to 20,000 PPH. This will fit systems to the new engines which have higher thrust ratings. The airlines forced this uprating to allow take-offs from shorter runways. The 10,000 foot length now required means many desirable cities cannot be serviced by jet airliners. This new rating would appear to be maximum for many years. Higher fuel consumption engines will mean displacement of passengers in order to carry the extra fuel. This is not an objective of the airlines.

The prop-jet business appears to be one of great growth potential. The prop-jets are faster and smoother flying and can carry bigger payloads than their reciprocating engine predecessors. Already conversions are being designed around existing reciprocating engine aircraft. In these conversions prop-jet engines in their new smaller pods will be attached to the wings. Each engine will be flowmetered as with a new aircraft. This market will require a substantial increase in production for this type system.

Marketing studies are underway to check the program for new engines for jet transports. It has been apparent that more economical engines are a requirement for such operations. Several manufacturers are introducing what are variations of a fan engine. These are designs to give more thrust from less fuel by bypassed air being directed into the engine exhaust.

Such a study shows that the 20,000 PPH system will not entirely displace the 15,000 PPH market. This lower range will be a maximum for fan engines. Product planners are continuing their research to tie down the flow rates and the required indications such as fuel consumed or rate which will be required.

V

CRITERIA WHICH DETERMINE TEST FACILITIES

In this study of establishing test facilities for a product market change to one of diversification, certain criteria have been shown to be of paramount importance. In any given example, conditions may elevate in importance one or more of these criteria, but, usually, attention must be paid to all, if the optimum facility is to be established.

A diversified market requires many models and variations of models in the product line. It is not generally expected to produce many high volume lines. This picture of generally low volume models requires extra effort from market research, sales, engineering, planning, manufacturing, and management in overseeing all. A gross error in judgment by any of these functions could lead to an ill-planned, costly, and less-than-utilitarian facility.

The important criteria to be evaluated in establishing the optimum test facility have been found to be:

- Engineering Specifications
- Production Quantities
- Total Facility Cost
- Time Available for Procurement
- Space Required
- Personnel Requirements
- Utilities and Services

Any appropriation request which reflects study of these criteria, and a proposal based on the integration of the results thereof, will enable management to arrive more quickly and easily at approval of the request.

Should management desire clarification of one or more of these criteria, the explanation can be readily effected as the criteria are nearly independent and each can be handled as if it were. Resubmittal thereby involves only a minor rewrite in order to secure acceptance and approval of the proposal. The clarity and thoroughness of such an approach presents management with the important facts in a format which can be readily understood and appraised.

The importance of these criteria can be seen from the following analysis.

ENGINEERING SPECIFICATIONS

These are the nucleus for all proposals to establish test facilities. For these specifications state the performance required of the product in order to meet fully the customer's application. Certain tests are required by the engineering function to assure compliance of the design and the manufacturing operations to the customer's requirements.

Using these specifications, the methods planner can proceed to develop a testing operation. He can integrate the test facility into the assembly line or provide for tests to be performed elsewhere. Vending test companies can be utilized whenever tests can be run cheaper, or, if the facility is unique and difficult to duplicate economically, on time, and within the manufacturing area.

If the company is to have its own facility, the methods planner can request preliminary designs and proposals from external and internal suppliers. The specification then becomes the primary article in any contracts for procurement which follow.

In the G. E. flowmeter case, the importance of specifications could readily be seen. This product line is one of high technical content and high accuracy is required under extremes of ambient conditions. A simple recirculating loop type flowstand with working standards for flow control was found to be adequate for the nominal 1% accuracy class transmitters. When the low-range 1/2% accuracy transmitter was entering production, the tests had to be conducted on a direct weight-time basis. This required the methods planner to procure a standard vendor packaged flowstand with a built-in weight tank.

The physical size of any flowstand is determined by the flow range of the model under consideration. Pipe sizes, bends, valves, pumps and accessories all increase in size with flow rate. For the smooth flow conditions necessary for testing straight smooth lengths of pipe are required. These too, similarly increase with flow rate. It was shown that the flow facility occupied a space 6' x 8' x8', while the in-flight refueling flowmeter facility involved a new building 80' x 80' to handle flows up to 1,000,000 PPH and the necessary accessories.

Accessories for performing tests under environmental conditions can affect the physical size, cost, and delivery of any facility under procurement. The flowstand procured for the Testing Laboratory was required to provide fuel temperatures from -65°F to +100°F to within ±2°F. This requirement changed the standard design by the addition of heat exchangers, temperature regulators, and complete insulation. The package became too large for the standard cabinet for this flow range and a larger version had to be used. Fortunately, the space previously allocated for the facility was just large enough for the increased size.

It is important, therefore, that engineering specifications be realistically and accurately prepared. The success of any establishment may be no more than the thoroughness and diligence exhibited by the engineers and employed by the methods planner.

PRODUCTION QUANTITIES

Production quantities and the rate at which these quantities are to be produced is a major part of the justification for establishing a test facility. The net impact is, of course, biased by the profitability of the product in these quantities and rates.

The methods planner has to integrate the test operation into the product manufacturing cycle. If the specifications require routine tests with little in the way of equipment, and quantities and profits have been forecasted as high, the job is simplified. The planner can usually establish the necessary facility. The problem areas encompass products with low production rates and high facility cost.

Under these conditions, the planner has to reconcile the costs of establishing a full facility with operating with a hand-made type of set-up, or sub-contracting the test operation to an outside vendor. The latter two approaches result in low investment, but incur high unit cost. With special set-ups or subcontracting, there is also the real problem of an interrupted production flow and extended schedules as the product leaves the direct control of the product manufacturing unit for test. The economics of the different approaches determine the best approach, when schedules can be worked out.

The 45,000 PPH prototype flowmeter program illustrates the success potential of utilizing effectively a make-shift set-up. As was stated heretofore, this product had a limited market for several years to come.*

The system was set up to be tested in the testing laboratory by technicians. While the unit cost ran high, the total prototype program reflected overall economy of operation with respect to testing.

This criterian pin-points the importance of the analysis of the market. The test facility may be established or not depending on the production quantity and rate forecasted. Accuracy becomes extremely important under these conditions, and the market analyst should act accordingly.

The methods planner works from the forecast or the subsequent sales budget quantities in establishing the test operation. His investigation of the avenues available must be thorough. Only when all of the production details are presented, can management properly evaluate the proposal to establish a test facility.

TOTAL COST

Total cost becomes of importance when considered in light of return on investment and cash flow during the procurement period. Return on investment is generally one of the major measures of accountability in judging the performance of management. Management analyzes the return on investment and general profitability considerations in weighing the total cost. The procurement period may come at a time of stringent

*This forecast was correct, as five years passed before the application required significant production quantities.

financial conditions and cash position may represent a real bind. The total cost, while not a complete deterrent, may force a delay in part of the procurement until conditions change and cash flow becomes more favorable.

The in-flight refueling flowmeter system represented a poor return on investment picture, and yet the need for the product was real. Negotiations were undertaken with the Air Force and resulted in government funding of the facility consisting of two 1,000,000 PPH flowstands. In retrospect, the market forecast based on Air Force data was far too low in light of actual usage in subsequent years. If such a total quantity could have been foreseen, the return on investment picture would have been different, and G. E. might have established this special high flow test facility with its own funds. This would have allowed freer use of the facilities, and avoided government restrictions on funded equipment.

The importance of the market forecast has been stated. The other contributing functions, such as engineering with its design alternatives, the methods planner with the various ways of doing an operation, and finally, the financial representatives, who must realistically and accurately provide the cost data, all need to be thorough in their analysis and strive constantly to keep costs at a minimum by choosing the optimum solution to the problem of providing test facilities.

TIME AVAILABLE FOR PROCUREMENT

The nearness of the date for operation becomes significant in considering flexibility of the facility design and, in some cases, total cost. Generally, the approach of the methods planner is to seek the optimum design for the product entering production in light of other production, both current and forecasted. If he can foresee requirements for a similar model and if he can, with a minor design change, make provision for this model, he may provide for these future requirements as long as his primary product will leave spare capacity. This would be incorporating flexibility. A high volume item seldom leaves idle capacity, and such a facility is usually highly specialized.

The problem of incorporating flexibility, regardless of foreseeable need, is the added cost and time for the facility to be established. The specialized facility to handle the specifications of one product will usually result in short delivery and low cost.

The decision to build or buy can be influenced by the time for procurement. If the facility has already been designed by either vendor, delivery should be shorter and perhaps at a lower cost for that vendor. This assumes that the manufacturing cycles are roughly equivalent.

The shortest delivery is usually for the purchase of an off-the-shelf item. Such a procurement involves a compromise of desires and needs. It is a rare coincidence, and a fortunate one, when the exact facility needed is of the off-the-shelf variety. Where time is of the essence, compromises are the norm for all details except that of specification. The product must be tested to assure compliance with the customer's needs.

The G. E. low range program was undertaken with extremely tight schedules. It was fortunate that a test stand vendor had a standard model, which met specifications, and could be procured to meet product schedules. This was the first stand purchased from an outside vendor.

The testing laboratory had additional requirements for high and low temperature testing. This requirement made the vendors stand a special. Delivery was almost twice as long, the cabinet became larger, and the cost went up appreciably.

In both cases, the internal test equipment unit had the problem of designing from the bottom up, andincorporating the special weight tank for the high accuracy requirements. This project would have run too long and cost too much for the product production program.

CONCLUSION

It has been demonstrated that several criteria exist for the establishment of test facilities for a transition to a diversified market. These have been found to be: Engineering Specifications, Production Quantities, Total Facility Cost, and Time Available for Procurement.

Of secondary importance, generally, but still vital to the consideration, are Space Required, Personnel, and Utilities and Services. Their impact can be found intertwined with one or more of those listed as being of paramount importance.

The author realizes that these criteria also prevail for any test facility. The importance of each is not always a constant with different products, markets, or business conditions. In a market which is tending toward diversification where several models, sizes, principles of operation, and specification can exist, a proposal for establishing a test facility requires a critical evaluation in light of each of these factors.

Managements are better able to analyze a proposal for a facility if it includes such a critical evaluation. They can then integrate the venture into the business plan, and more readily effect approval or offer alternatives suggested by their viewpoint.

It appears that the criteria generated in this thesis would be applicable to many facilities in a manufacturing process. Several processes, such as chemical treating, metal-working and machining, temperature processing, and finishing of wood, cloth, metal, or plastics, are suggested as requiring potentially complex and elaborate engineering, planning, financing, and operation. Managements in businesses involving establishment of such facilities would be better able to plan, if the facilities were evaluated in light of the suggested criteria.

APPENDIX

TYPICAL SAMPLING TABLE

Lot Size	First Sample n_1	Second Sample n_2	Acceptable Quality Level															
			1/4%		1/2%		1%		2%		3%		5%		10%		20%	
			c_1	c_2	c_1	c_2	c_1	c_2	c_1	c_2	c_1	c_2	c_1	c_2	c_1	c_2	c_1	c_2
Less than 15	*	3	x		x		x		x		↓		*	0	*	0	*	1
15-24	*	5	x		x		x		↓		↓		*	0	*	1	*	2
25-39	5	10	x		x		↓		↓		↓		0	1	1	2	2	5
40-64	7	14	x		↓		↓		↓		0	1	0	2	1	4	3	6
65-109	10	20	↓		↓		↓		0	1	0	1	0	3	2	5	4	8
110-179	15	30	↓		↓		0	1	0	1	0	2	1	3	3	6	5	13
180-299	25	50	↓		0	1	0	1	1	2	1	3	2	6	5	10	8	21
300-499	35	70	↓		0	1	0	2	1	3	2	4	3	7	6	14	11	28
500-799	50	100	0	1	0	2	1	3	2	4	3	5	4	10	8	20	14	37
800-1299	75	150	0	1	1	2	2	4	3	5	4	8	6	14	11	28	20	54
1300-3199	100	200	0	2	1	3	2	6	3	8	5	11	8	19	14	37	↑	
3200-7999	150	300	1	3	2	4	3	9	5	13	7	18	11	28	20	54	↑	
8000-21999	200	400	1	4	2	7	4	11	6	16	9	24	14	37	↑		↑	
22000-109999	300	600	2	5	3	8	5	13	8	25	12	35	20	54	↑		↑	
110000 --	500	1000	3	7	4	13	7	23	14	40	20	54	↑		↑		↑	
Approx. Lot Tol. % Def.			1.5%		2.5%		4%		5%		7%		11%		20%		35%	

(*) Go at once to combined first and second sample size.
(x) Inspect each unit of lot involved.
(↓) Use sample size in first row below where acceptance numbers are shown for Acceptable Quality Level involved.
(↑) Use sample size in first row above where acceptance numbers are shown.

1. Procedure:
   a. Select first sample (n_1) indicated in table for lot size involved.
   b. Determine in the first sample the number of units d_1 which contain defects:
      (1) If d_1 does not exceed c_1, accept the lot.
      (2) If d_1 exceeds c_2, reject or 100% inspect the lot.
      (3) If d_1 exceeds c_1, but not c_2, select a second sample (n_2) of size indicated in the table. Determine in second sample the number of units d_2 which contain defects. Then if $d_1 + d_2$ does not exceed c_2, accept the lot. Otherwise reject or 100% inspect the balance of the lot.
2. The Lot Tolerance % Defective is the poorest quality of an individual lot that will ordinarily be accepted under the sampling plan.

FIGURE I

II HOW THE G-E MASS FLOWMETER OPERATES

Reference Figure II

Elements of the transmitter which is located in the fuel line to the engine include flow-sensing means, synchronous drive motor, restraining spring, and a transducer that converts mechanical rotation to an electrical position signal.

Angular momentum proportional to line frequency is imparted to each unit mass of fuel. By recovering this angular momentum, a mechanical torque is developed which is proportional to the product of mass flow rate and applied frequency. This torque is converted to an electrical position signal which is suitable for accurate transmission to the remote indicator.

The flow-sensing means is comprised of two similar rotors placed coaxially end-to-end with small axial spacing. The upstream and downstream rotors are referred to as the "impeller" and "turbine" respectively. Each rotor is comprised of a pair of concentric cylinders with radial vanes dividing the angular space between them into a number of identical flow passages. They are enclosed in a common cylinder housing in which radial clearances are small enough to prevent appreciable fuel flow around the rotors.

The impeller is driven by a synchronous motor through a magnetic coupling and gear train at angular velocity directly proportional to applied frequency. Each unit mass of fuel in transit emerges from the impeller flow-passages with the angular velocity of the impeller.

By virtue of this angular velocity, each unit mass of fuel enters the turbine flow-passages with angular momentum proportional to impeller speed, but independent of flow rate, fuel density and viscosity, and other ambient conditions. All the angular momentum imparted to the fuel by the impeller is recovered by the turbine so that, in accordance with Newton's law, the fuel exerts on the turbine a torque directly proportional to the product of mass-flow rate and applied frequency.

The turbine is restrained by a spring to deflect through an angle proportional to the torque exerted upon it by the fuel. This motion is converted directly and accurately to an electrical signal that is transmitted to the indicator. The indicator is usually mounted on the pilot's instrument panel along with the other engine instrumentation.

It has been said that a pilot depends on the flowmeter system as an automobile driver depends on his speedometer to program his drive. The driver knows he can go so far with his tank of gas at a given speed; so does the pilot know his endurance at given flowmeter settings.

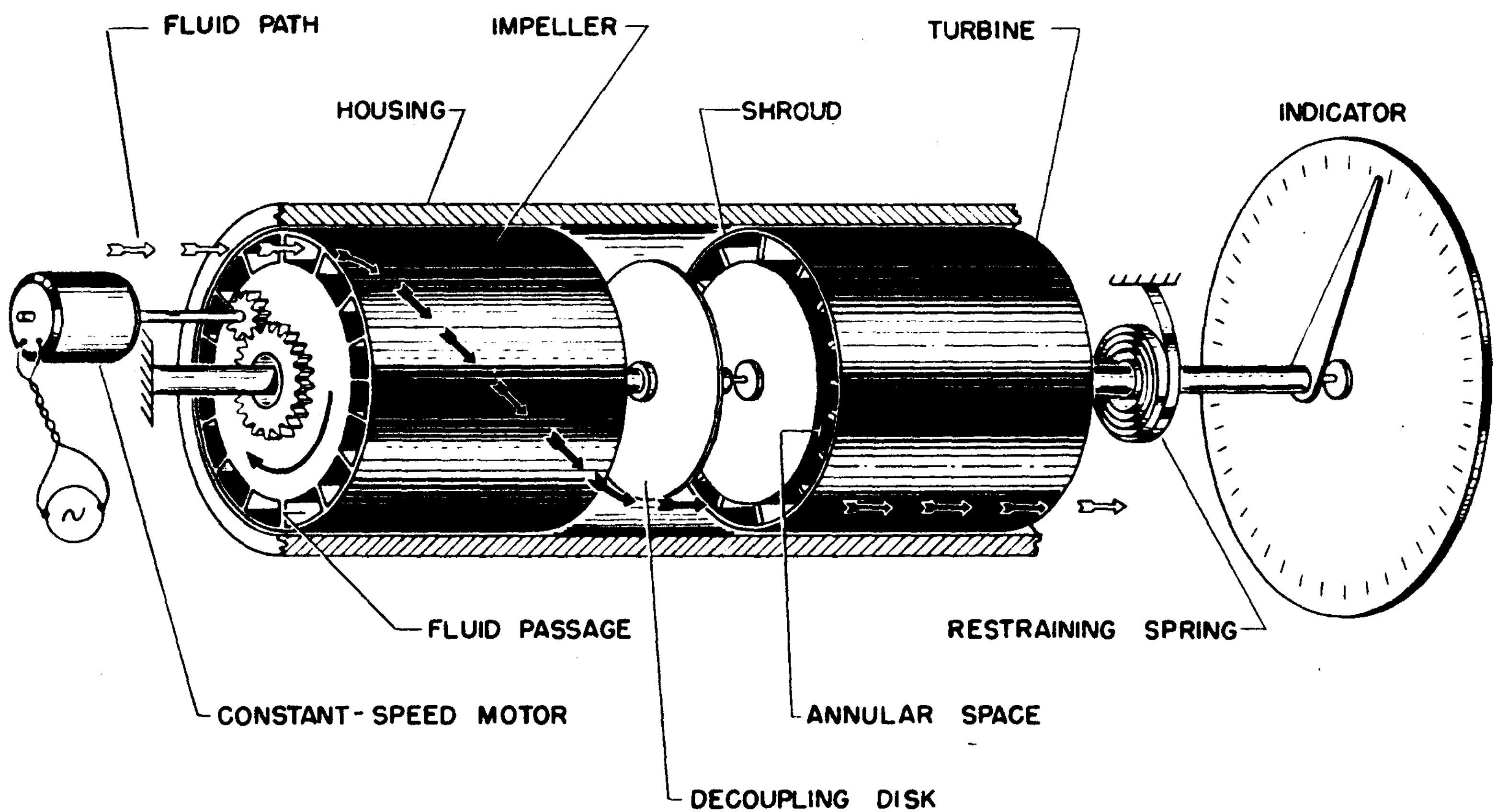


FIGURE II

C-2058450

III FLOWMETER ERRORS DUE TO DENSITY CHANGES

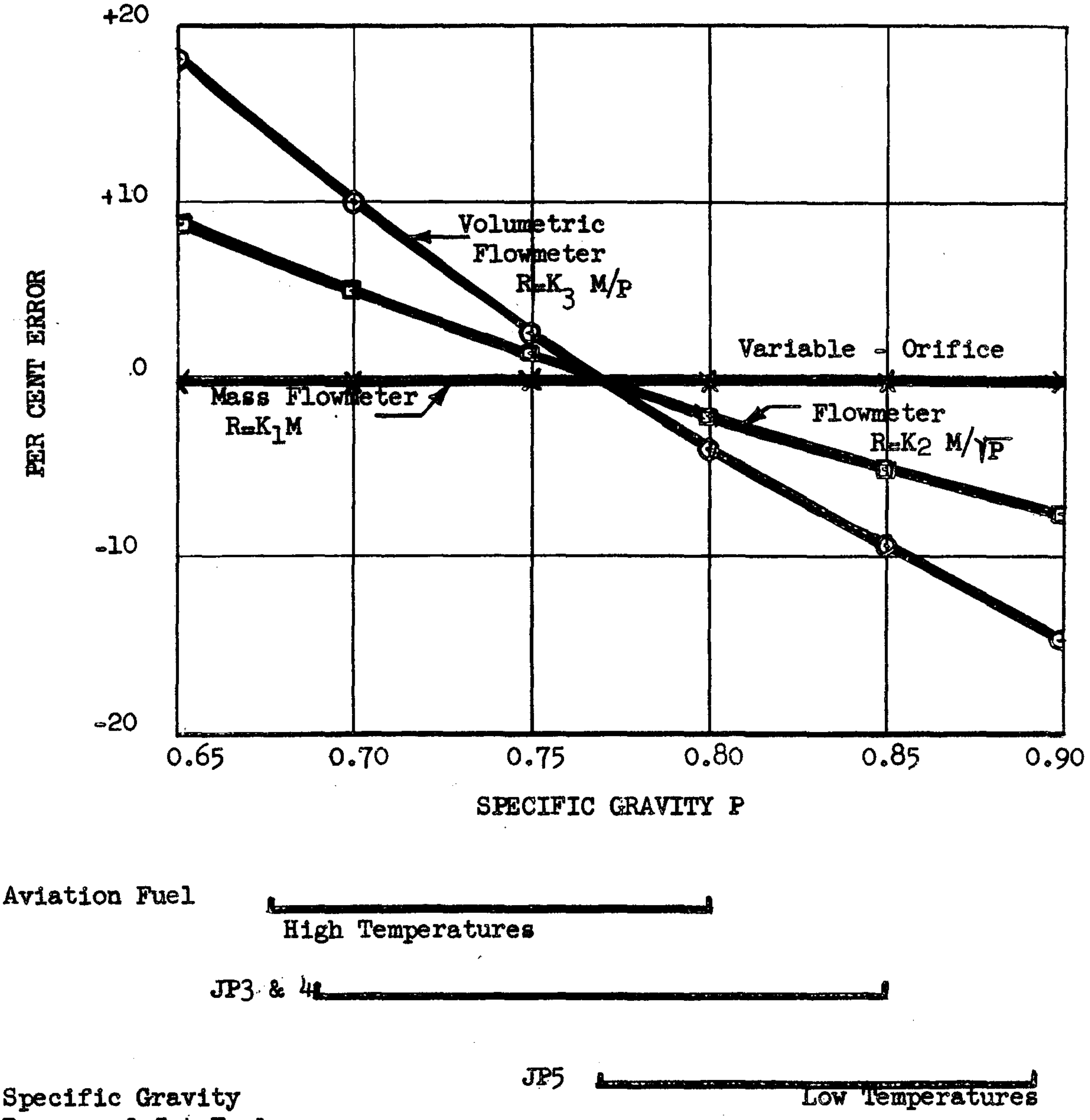
Reference Figure III

Here is illustrated one of the primary benefits to be obtained from the use of a mass fuel-flowmeter. Petroleum fuels have different specific gravities or weight divided by volume, and of equal importance have a broad range of values within themselves due to variations in distillation or from temperature changes.

The chart shows the great errors to be experienced with volumetric flowmeters which respond to mass divided by specific gravity, or variable orifice flowmeters which respond to mass divided by the square root of the specific gravity.

The mass flowmeter has zero error due to changes in specific gravity and is responsive only to changes in flow rate. This is of extreme importance for several reasons. First, jet engine output is proportional to the heat energy of the fuel used. For jet fuels it has been proven that this heat energy is proportional to the mass of the fuel. Thus, by controlling the mass rate of fuel-flow the engine output is controlled and engines can be operated at their most efficient settings.

FUNDAMENTAL RESPONSE CURVE
OF
VARIOUS FLOWMETERS CALIBRATED
TO MEASURE MASS RATE OF FLOW



Specific Gravity
Ranges of Jet Fuels
With Temperature

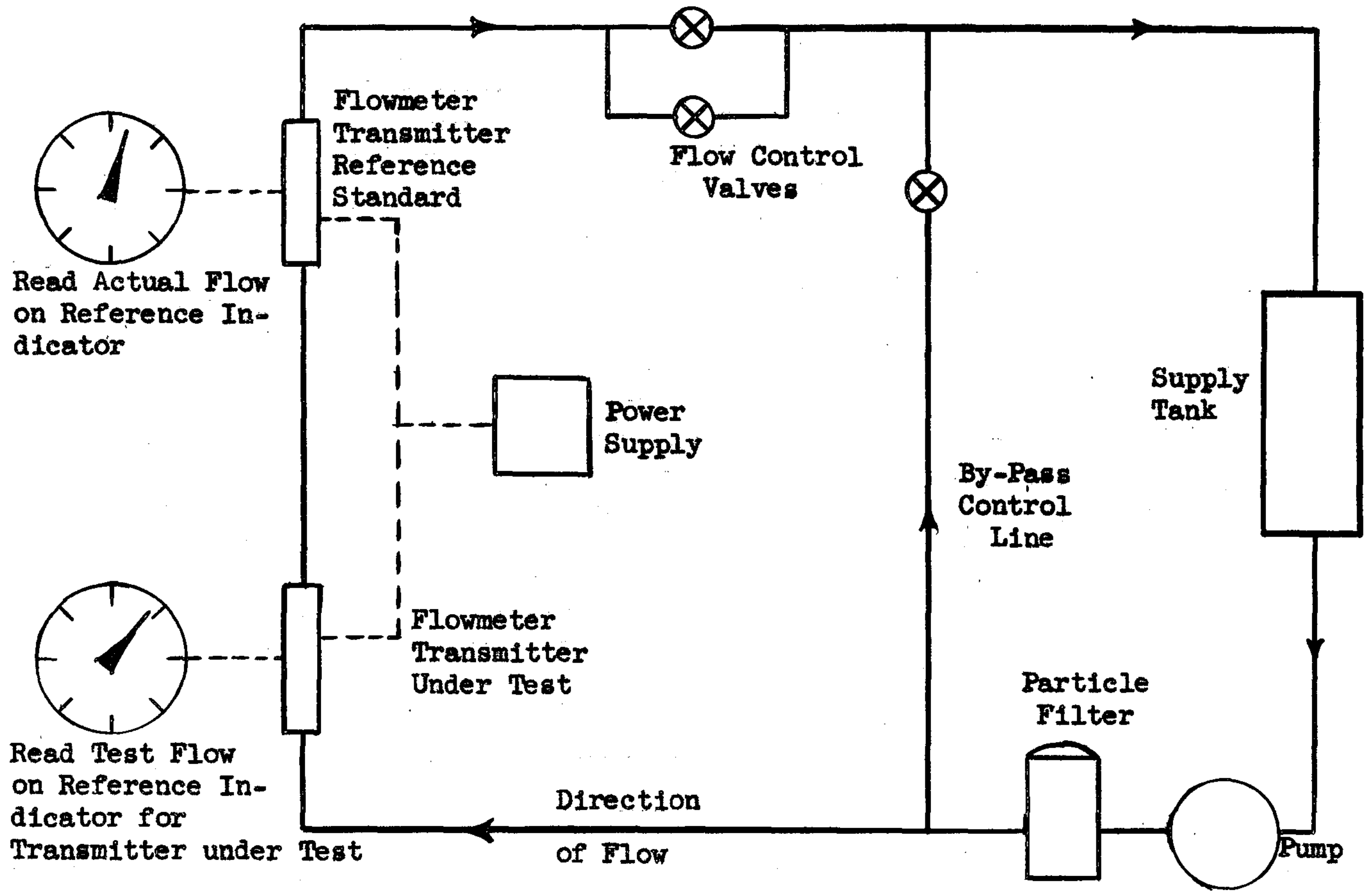
FIGURE III

IV RECIRCULATING LOOP MASS-FLOW STAND

Reference Figure IV

This is a schematic representation of a fundamental recirculating flow stand. The fuel is pumped, filtered, and regulated in flow rate as it passes from the tank through the test and reference transmitters to the supply tank. Both transmitters, thereby, measure the same flow at the same time.

A common power supply for the electricals is shown, along with the master indicators used to indicate the outputs of the transmitters. Flow is held on the reference system and adjusted by the flow control valves. The output of the test transmitter, as read on the master indicator, is compared with the flowrate held on the reference indicator, and the difference represents the error for that flow rate. Thus, the test transmitter can be calibrated point by point over the operating range.



SCHEMATIC DIAGRAM OF MASS-FLOW STAND

FIGURE IV

V 12,000 PPH TEST STAND FOR MANUFACTURING FACILITY

Reference Figure V

This stand was one of the first stands established for Manufacturing to use for production. The two test transmitters are at the right in a swivel mount that allows for testing in any position. The operator is holding the calibration flow point by use of a Flowrator, which is a flowmeter consisting of a vertical glass tube the internal bore of which increases in diameter with height. In this tapered bore floats a truncated plug which has a perfectly round horizontal edge. As fuel flows upward through the tube the float assumes a height which is proportional to the flowrate in gallons per hour. It must be corrected to indicate mass flow rate in pounds per hour. On the table are the two master indicators upon which the test transmitter output is indicated.

The Flowrators were found to be too slow for the higher production rates which soon followed. They were replaced by a reference transmitter which was installed in the flow line behind the stand and its output was read on one master indicator for holding flow points. The other master indicator could then be switched to indicate the output of either test transmitter. This design is an elaboration of that shown in the schematic (Figure IV) which is fundamental to all design.

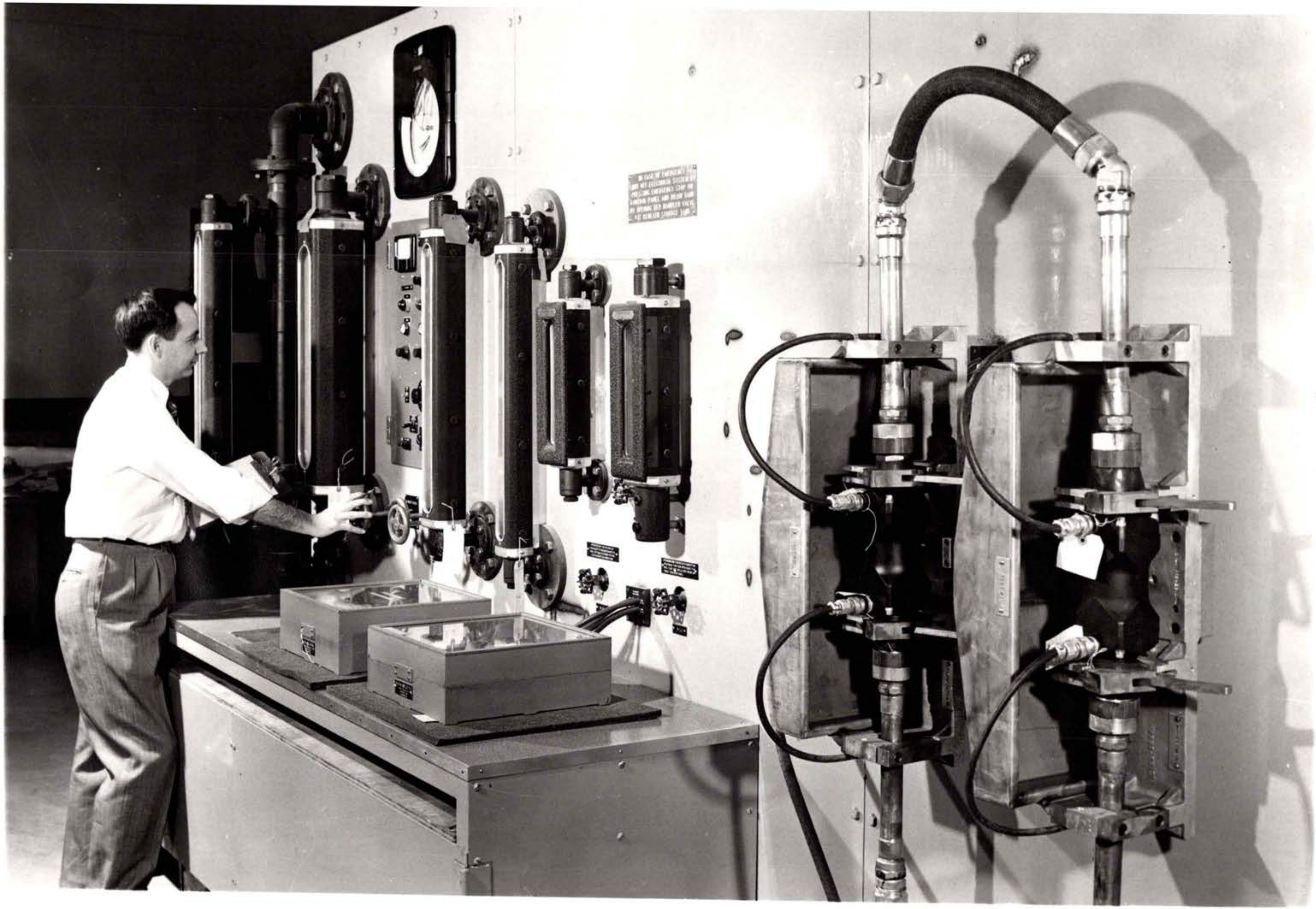


FIGURE V

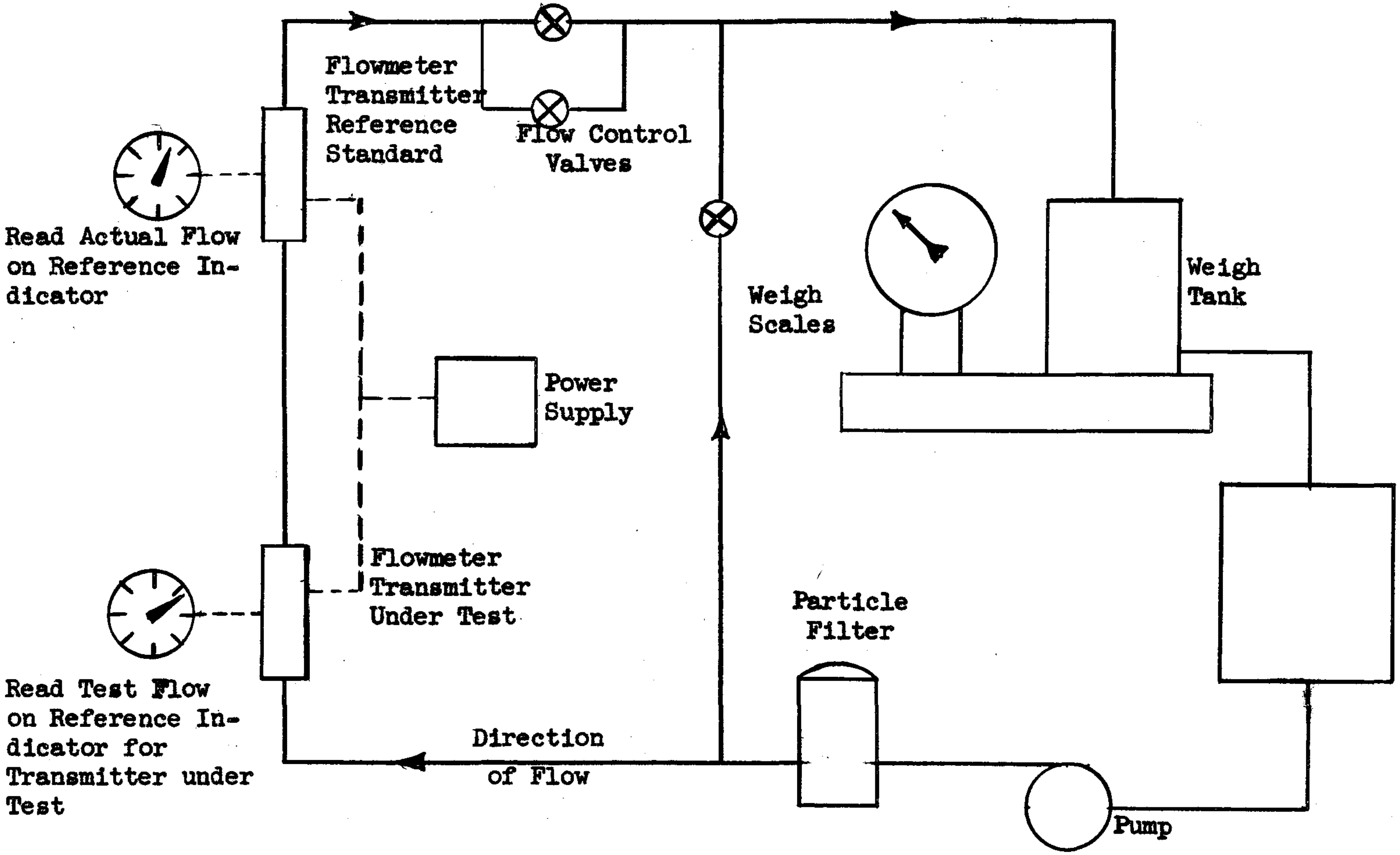
2806 093 TEST STAND FOR G-E TYPE TJ-50 FLOWMETER TRANSMITTER.
E369.4 4-16-53

VI RECIRCULATING LOOP FLOW STAND WITH WEIGH SCALES

Reference Figure VI

This recirculating loop has incorporated a weigh tank for self-calibration. As necessary, the fuel being circulated can be collected in the weigh tank and the time for a given weight to accumulate is measured. A simple calculation gives flow rate in pounds per hour.

Weight and time are the primary standards for calibrating any system for mass flow rate. The technique described is too slow except for the most accurate requirements. It is normally used for standardizing in the laboratories, and not for production. The reference transmitters mentioned in Figures 4 and 5 would be calibrated on a stand such as this before being used in a recirculating loop type of stand.



SCHEMATIC DIAGRAM OF MASS-FLOW STAND WITH WEIGH SCALES

FIGURE VI

VII 15,000 PPH COX FLOW STAND

Reference Figure VII

This stand was purchased when the need arose for a high accuracy facility which could be quickly procured. This stand was a standard model of Cox Instruments Company and was self-calibrating through the use of a built-in weigh stand. For high accuracy testing each product could be tested against this weigh stand.

The principle of the weigh stand is to measure the time required to collect a certain weight of fuel. By easy calculation the flow rate could be determined in pounds per hour.

The particular model shown was the special version made for use with wide temperature ranges. Because of this requirement, the vendor had to redesign the basic model. This led to a larger cabinet to house the temperature controllers and necessary insulation. The stand has been successfully used in the Testing Laboratory for both standardizing and special product calibration.

"CCX FLOWSTAND 15,000 PPH"
FIGURE VII

80186-1