

Measurement Uncertainty Applied to Cost-Effective Testing

RATIONALE

The purpose of this revision is to align the methodology, nomenclature, and terminology with AIR1678 Revision B.

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1. SCOPE

The report shows how the methodology of measurement uncertainty can usefully be applied to test programs in order to optimize resources and save money. In doing so, it stresses the importance of integrating the generation of the Defined Measurement Process into more conventional project management techniques to create a Test Plan that allows accurate estimation of resources and trouble-free execution of the actual test. Finally, the report describes the need for post-test review and the importance of recycling lessons learned for the next project.

1.1 Introduction

Uncertainty analysis is a practical, scientific tool that is used to estimate the uncertainty of test measurements and of test results determined from the measurements. Prior to actually running a test, the methodology of uncertainty analysis allows the experimenter to learn much about the potential accuracy of a test result and to assess the relative effects of various error sources on the total test uncertainty. After data is obtained in the test, uncertainty analysis is used to quantify the goodness of the experimental results. There has been an increase in the awareness of uncertainty analysis over the past several years, and some of the key sources of information on it are given in References 2.1.1.1, 2.1.2.1, 2.2.1, and 2.2.2.

Unfortunately, the planning, design, and execution of testing programs is still too frequently carried out without reference at the planning stage to the detailed needs of the recipient/end-user of the test results and consequently without proper regard to the required uncertainty of the test measurements. A common scenario is that a test is planned within budgeted costs and timescales, utilizing facilities which are not optimal to the testing program but which are either already available or are readily accessible at reasonable cost. If the assessment of the uncertainty of the results takes place after the testing has been completed, then there is a risk that the accuracies actually obtained fail to meet the desired, sometimes contractual, requirements.

Obviously, cost-effectiveness in the use of testing resources is vitally important within both industrial and academic environments, and the scenario described above is based upon this necessity for economy. Finding that test results are too uncertain to be used effectively is not cost effective. However, the application of measurement uncertainty methodologies to the planning of the test program can benefit not only the final accuracy of the test but also the cost effectiveness of its execution. The action of defining the measurement processes, including the detailed breakdown of calibration hierarchies and elemental error sources, ensures that the test that is performed actually provides the required level of measurement uncertainty. It is not cost-effective to obtain a greater accuracy than is required. In this way, the use of expensive laboratory or industrial scale testing facilities may be optimized and real savings made.

The purpose of this report is to present a clearly defined approach to the application of uncertainty methodology to the planning and conduct of cost effective test programs. The report is written for the aero engine-testing environment, and in particular for the determination of in-flight thrust. However, the approach described in the report can be applied to almost any experimental setting and is recommended to all who undertake testing programs with cost constraints.

The report begins by defining the basic requirements for a preliminary test plan from which estimates of resources, timescales, etc. may be drawn. It emphasizes the need to address the actual needs of the "customer" (whoever that may be) at the initial stages of planning. The required uncertainty of the test results must be established through expert dialogue between the supplier/test engineer and the customer/user. At this stage in the test program, an initial uncertainty analysis is performed using knowledge of the probable instrumentation uncertainties and experience of similar testing work. This initial uncertainty analysis helps to identify potential problems and to verify that the test has some reasonable probability of meeting the required uncertainty for the test results.

Potential problems with both human and material resources, schedules, and other major test issues are identified in this initial phase of the test program. The preliminary test plan section of the report stipulates the need to recognize the limitations, risks, and the importance of a clear definition of program accuracy requirements.

The report continues with the description of the development of the Defined Measurement Process (DMP) in detail. The DMP is comprised of three parts:

- Definition of the measurement chain, including details of the type and number of instruments to be used and their calibration requirements.
- An elemental uncertainty analysis, in which all possible sources of both systematic and random error are defined and estimates are made of the uncertainties associated with each error source.
- A results uncertainty analysis, where the effects of propagation of the elemental uncertainties into the results are assessed.

Using this procedure, an estimate of the uncertainty of the final results is obtained and can therefore be compared to the original requirement. Where there is a discrepancy, in the sense that the uncertainty is either greater or smaller than what is demanded, the test plan can be modified, the DMP revised, and a new uncertainty estimate made. The uncertainty analysis gives significant guidance on where the problems are and what needs to be corrected. By iteration of these processes, the test plan can be optimized prior to or during the initiation of any actual testing work. This optimized plan may then be reviewed and agreed upon by the customer, if necessary, before a final Test Plan is published.

Once the test plan is finalized, the next stage is to perform a preliminary test and to review the results obtained. The quality of the data can be checked against the expectations from the DMP, and the discrepancies can be investigated. Comparisons are made between the current test results and expected results obtained from similar tests or model simulations. These comparisons provide checks of the uncertainty estimates and help to identify problems with the test program. The report emphasizes the importance of planning this preliminary test into the program since it offers the last, but most effective opportunity for revisions to the test plan before formal testing commences.

Following the execution of the tests, the actual results must be analyzed and their uncertainties estimated. Since much of the groundwork for this exercise will have been carried out already in an earlier stage, the effort required here is reduced.

Finally, a post-test review is recommended, where the results obtained and the uncertainties associated with them are compared with predictions and discrepancies are investigated. Such investigations should be reported openly and may be used to assist in planning the next similar testing program.

1.2 Concluding Remarks

Measurement uncertainty is a tool that can be applied to test programs in order to optimize resources and save money. Sections 3 through 8 of this document describe how this tool is used, with an example. Figure 1 gives a roadmap of the report.

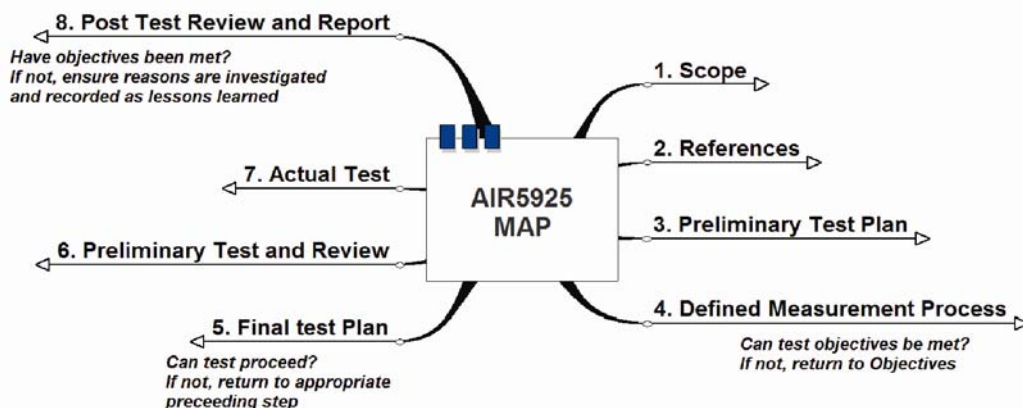


FIGURE 1 - AIR5925 MAP

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

2.1.1.1 AIR1678B, Uncertainty of In-Flight Thrust Determination

2.1.1.2 AIR1703A, In-Flight Thrust Determination

2.1.2 ANSI Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

2.1.2.1 PTC 19.1-2005 American National Standards Institute/American Society of Mechanical Engineers, Test Uncertainty, ASME, New York, 2005.

2.2 Applicable References

2.2.1 International Organization for Standardization, Guide to the Expression of Uncertainty in Measurement, ISO, Geneva, 1995.

2.2.2 Coleman, H. W. and Steele, W. G., Experimentation and Uncertainty Analysis for Engineers, 3rd Edition., John Wiley and Sons, Inc., New York, 2009.

2.2.3 Robert V. Hogg and Elliot A. Tanis, "Probability and Statistical Inference", Macmillan.

2.2.4 "Experimental Determination of Time Constants and Nusselt Numbers for Bare-Wire Thermocouples in High-Velocity Air Streams and Analytical Approximations of Conduction and Radiation Errors," Marvin D. Scadron and Isidore Warshawsky, NACA TN 2599, January 1952.

2.2.5 Boris Iglewicz & David C. Hoaglin "How to Detect and Handle Outliers" Volume 16, The ASQC Basic References in Quality Control: Statistical Techniques Series. 1993.

3. THE PRELIMINARY TEST PLAN



FIGURE 2 - PRELIMINARY TEST PLAN

3.1 Introduction

Uncertainty analysis applied in the earliest stages of a test program can help in the decision making process and can lead to an economical use of resources. The Preliminary Test Plan defines the test objectives from customer requirements and then defines the test process. An initial uncertainty analysis at this stage, based on historical information, lessons learned and best estimates provides guidance for the defined measurement process and test plan development which will follow.

3.1.1 General

The first stage in any test program is to prepare a Preliminary Test Plan. This plan will be used to develop a detailed Defined Measurement Process. Since this plan is intended to be preliminary, it must be prepared with scope for review and revision at a number of stages during the program.

Due to time constraints, some preparatory work may need to be initiated before publication of the Final Test Plan. When this is the case, priority must be given to understanding the consequences of any revisions to the time, cost and technical estimations during the development of the Preliminary Test Plan. Furthermore, it is essential that customers and external contractors, if employed, are included in the appropriate areas of the document control process.

The inclusion of measurement uncertainty principles into the planning process does not demand a large increase in the complexity of the task. The work associated with uncertainty will result in a plan that is significantly more reliable and cost-effective.

To illustrate this, an example of a typical in-flight thrust determination will be worked throughout this report. The full in-flight thrust determination process is complex but is based upon straightforward measurements which must be optimized if the result is to be sufficiently accurate. The sections that follow will describe the preliminary test planning process in general terms and then address the example in the same terms. In this way, it will be seen that the relatively complex measurement process can be planned methodically.

3.1.2 The Worked Example

The worked example is a case of in-flight thrust determination of an aircraft engine, using information taken from flight tests, ground level tests and other component rig measurements to derive a value of net thrust at two defined flight conditions. This example applies a Gas-Path/Nozzle Analysis method (based on the ideal thrust group of thrust divided by jet area and ambient pressure F/AP) utilizing a residual error procedure. This concept and other methods for determining in-flight thrust are summarized in Reference 2.1.1.2. Good test practice dictates more than one method should be used to provide greater test confidence; however, additional methods can impact the test program.

The example in this document will concentrate on the flight test part only; the other parts are assumed to have been completed, with all the results of those tests available for use in the derivation of the flight test results. Figure 3 shows the flowchart for the entire process with the flight test part to be worked in this document located at the right of the diagram enclosed by the dashed line.

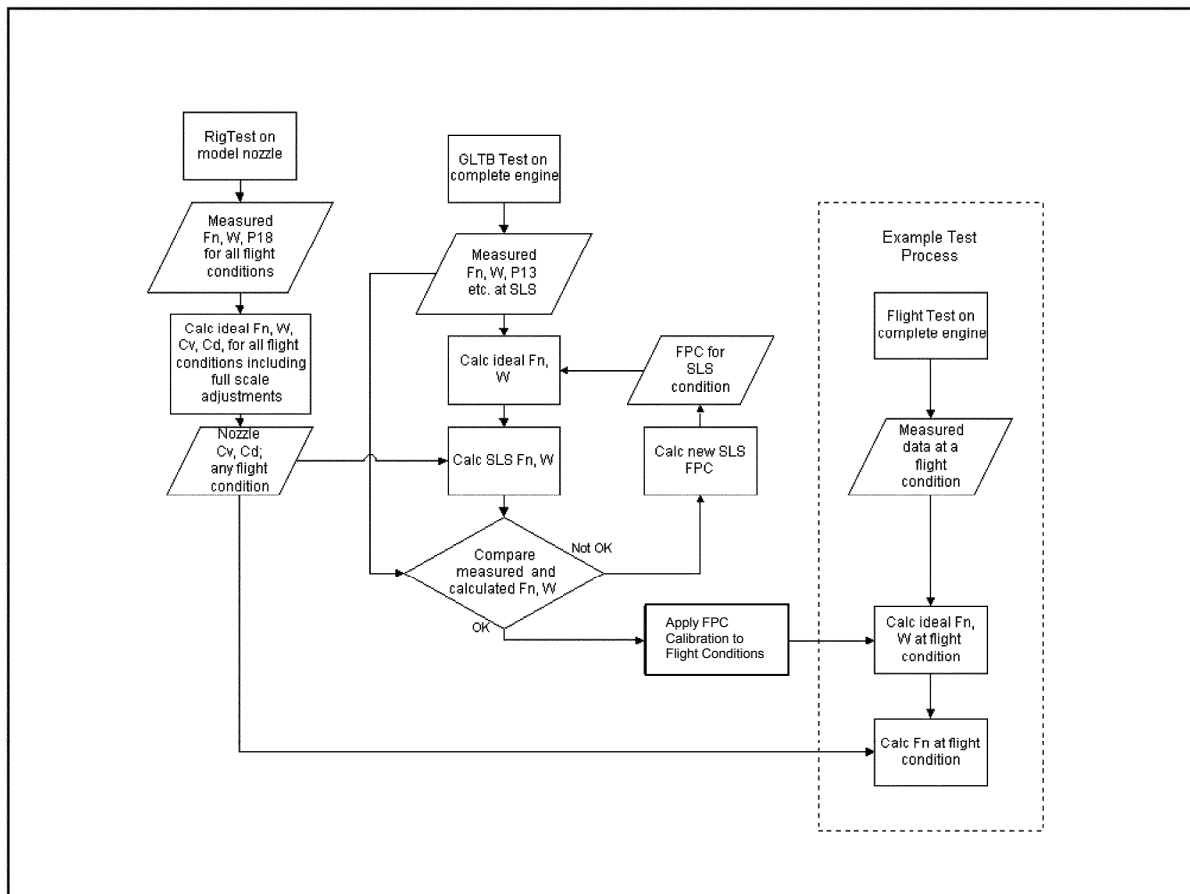


FIGURE 3 - TYPICAL IN-FLIGHT THRUST DETERMINATION PROCESS

Since the thrust of an aircraft engine in-flight is difficult to measure directly through force instrumentation, other measurements are used to derive the thrust indirectly. In this example, fan delivery total pressures are measured in the bypass duct of a turbofan engine using “radial” rakes to provide a defining relation for thrust as a function of fan pressure. Adequate sampling to determine the representative gas path average pressure from such measurements is not always possible. This is especially true in the fan (by-pass) duct where large radial and circumferential variations often exist. One sea level test stand method assumes this known inability to measure the fan duct gas path average pressure to be the primary cause for any disagreements between the calculated versus measured air flow and thrust. The method recognizes that other unknown measurement/modeling errors (Reference 2.1.1.2) could also contribute to the lack of closure.

A ground level test stand calibration is used to define the fan pressure-thrust relation by means of a fan pressure correlation (FPC). Fan pressure correlation is a scalar applied to the average measured fan duct pressure for use in calculating both nozzle thrust and air flow. The calculated values of thrust and air flow are then compared to the equivalent test stand measurements. Typically, errors other than those in fan duct pressure measurement prevent derivation of a unique pressure correlation that simultaneously equates calculated and measured values for both thrust and flow. Instead, the procedure establishes a fan pressure correlation that minimizes the calculated to measured inconsistencies leaving residual errors on both air flow and thrust.

Fan pressure correlation is derived on the ground level test bed using the following procedure. Core nozzle flow is determined from the high-pressure turbine nozzle flow function (HPTFF). This flow along with measured P5 (LPT discharge pressure), calculated T8 (LPT discharge temperature), and core nozzle velocity coefficient are used to determine core nozzle thrust. The difference between the core flow and thrust and the total inlet bellmouth flow and measured thrust is attributable to the bypass exhaust after proper accounting for parasitic flows, fuel flow additions, internal recoups, leakages, scrubbing drags, etc. This provides equivalent measured test stand values for the bypass duct flow and thrust. An iterative solution for the fan duct total pressure that minimizes the root sum squared differences in bypass duct measured and nozzle calculated flow and thrust values (residual error) is then evaluated. The resulting "calibrated" fan duct gas path average pressure is compared to the rake measurement (P13) to establish the pressure correlation at a given test condition. Alternatively, the residual error terms can be defined using overall flow and thrust instead of the bypass values, providing better alignment with the test stand measurements.

A unique pressure correlation characteristic is derived as a function of power for each podded engine. On-wing the individual pressure correlation of each calibrated engine is applied to the fan duct radial rake measured pressure. The resulting fan duct "gas path average pressure" is then used in the determination of nozzle calculated in-flight thrust and air flow.

A spreadsheet can be used to determine the in-flight net thrust measurement uncertainty due to the errors in the process-measured inputs (see 4.3.5). The spreadsheet also calculates the required process sensitivity coefficients. Standard methods, i.e., AIR1678B (Reference 2.1.1.1) or PTC 19.1-2005, Urss 95% coverage (Reference 2.1.2.1), are used to propagate the measurement uncertainties for the flight test ("on-wing") phase to in-flight net thrust uncertainty. This uncertainty would be combined with the calibration and ground test uncertainty to get the total uncertainty of the thrust. For this report, these additional uncertainty components have not been included. Key assumptions in the uncertainty calculations are outlined below:

- a. Separate flow and complete expansion of the (non-mixed) hot and cold jets.
- b. Thermodynamic parameters (C_p , specific heat ratio, etc.) remain constant for the small perturbations under consideration.
- c. Core nozzle temperature, T8, found from energy balance.
- d. Core flow from High Pressure Turbine Flow Function (HPTFF).
- e. Fan exit temperature measured as TT13.
- f. Nozzle characteristics assumed constant for small error perturbations.

3.2 Defining the Test Objectives and Customer Requirements

3.2.1 Test Article

The first step is to identify the test article (subject of the test.) In the context of this document it is likely that this will be either a complete aircraft engine or an engine component, but the principles described below are applicable to many other testing activities and technical disciplines.

3.2.1.1 Example Test Article

The example test article will be a full-scale turbofan aircraft engine, complete with podded installation nacelle and flight-worthy instrumentation systems. In practice, it is likely that there would be more than one engine to be tested, but for the purposes of this document, only one will be considered.

3.2.2 Test Objectives

It is important to identify and define the principal aim (primary objective) of the test at an early stage. Supplementary (secondary) test objectives should also be identified. It is necessary to justify the test, both technically and commercially in terms of the principal and supplementary objectives. The justification is often supported by a hypothesis statement such as the new engine part will improve specific fuel consumption by 1%. The justification may be addressed in terms of the benefits of the test, or alternatively, the risks of not doing the test if the status quo is unacceptable. The technical and commercial benefits and risks are better understood by discussing the actual, sometimes underlying, needs of the customer.

3.2.2.1 Example Test Objectives

The primary objective of the example test is to determine the in-flight net thrust of the engine at discrete, nominal flight conditions, expressed as altitude, aircraft Mach number and inlet temperature. A flight test is an expensive exercise and so many other tests will be performed in parallel with the thrust measurement to maximize the investment. Such ride-along tests typically include:

- a. assessment of thermal transient characteristics;
- b. definition of power management control schedules;
- c. validation of production operating limits.

Such tests are beyond the scope of this document, but are mentioned here to illustrate the need for clarity in the setting of objectives since the inclusion of secondary objectives must not impede or displace the primary objective.

3.2.3 Test Requirements and Uncertainty Levels

The critical output parameters or Defined Test Results (DTR) required to meet the stated objectives must be established. These may be either direct physical measurements or derived (calculated) performance parameters.

The required uncertainty and statistical confidence levels of the defined test results must be established through expert dialogue between the supplier/measurement engineer and the customer/user. The stipulation, "as good as possible" is unacceptable. Current achievable levels of uncertainty of in-flight thrust determination are given in AIR1703A (Reference 2.1.1.2). To stipulate requirements that are unachievable or inappropriate can lead to a test that is not cost-effective.

The application of uncertainty analysis may vary for different types of tests, from demanding some absolute level of accuracy for an engine performance parameter (e.g., thrust) to specifying some level of significance in a comparative (back-to-back) test. Back-to-back tests can benefit from improved uncertainty in their results since, if properly planned, it is likely that many sources of systematic uncertainty are common to both tests and may be reduced.

The uncertainty analysis needs to be developed in such a way that the results are easily understandable and usable. All parties of the test team must coordinate in the definition of key engine and flight conditions for the analysis. Not all test conditions need to be analyzed in the pre-test uncertainty analysis, just those that are critical for the defined measurement process that follows.

3.2.3.1 Example Test Requirements

The primary defined test result is net thrust of the engine at both take off and cruise flight conditions. The total uncertainty of the result is to be no greater than $\pm 1\%$, with 95% confidence.

3.2.4 Limitations

There will be limits on the scope and accuracy of a test. Again, these must be established early in the preparations if unpleasant surprises are to be avoided. Areas that may impose limitations include:

- a. safety and regulatory issues;
- b. financial constraints;
- c. time constraints;
- d. availability of test article, test facilities, and other resources;
- e. technical shortcomings;
- f. commercial and contractual issues;
- g. political constraints.

3.2.4.1 Example Test Limitations

The example test is a flight test; this demands certain minimum safety standards to be met regarding the design, construction, and installation of instrumentation and these standards must be addressed in the test plan.

The test article (engine to be used in the flight test) will need to be run in a ground level test stand as part of the overall thrust measurement process. If systematic measurement uncertainty is to be minimized, the ground level tests and the flight tests must utilize the same instrumentation systems. Consequently, the flight-worthy instrumentation systems must be utilized for both tests, even though they are not otherwise necessary for ground level testing.

The test must be performed to meet requirements within cost constraints. Timescales are dictated by business requirements; therefore, deadlines for completion of the tests and for the production of milestone results, must be agreed between the supplier and the customer.

The test will require ground level tests on both the full engine and also rig tests on the engine nozzle assemblies prior to flight testing. The availability of facilities for all these tests must be established and included in the test plan.

There may be technical shortcomings in the method used to derive net thrust from the measurements. The existence and impact of these shortcomings must be agreed between the customer and the supplier.

3.2.5 Risk Assessment

There are likely to be many factors that could prevent meeting the test objectives. The most significant factors must be identified in a risk assessment. The risk assessment evaluates the likelihood (probability) of occurrence, and impact (severity) on the outcome of the test. Any of the areas listed as possible limitations above may constitute a risk, since an excursion outside such limits naturally compromises the success of the test. The risk assessment should include plans to mitigate risks that are deemed unacceptable. The risk assessment process is conducted separately from the uncertainty analysis and is not covered in this report. The basic concepts of risk assessment are covered in Reference 2.2.3.

3.3 Defining the Test Process

3.3.1 Outline Test Procedure

The basic steps of the procedure to be adopted for the test need to be established. This preliminary procedure needs to be of sufficient detail to allow conventional project planning techniques to be used to estimate the work involved and resources required. Flexibility will be necessary, since the procedure is likely to be modified once later planning stages have been addressed.

Experience and “lessons learned” from previous similar testing programs should be applied here to optimize the outline test procedure and to highlight vulnerable areas.

3.3.1.1 Example Outline Test Procedure

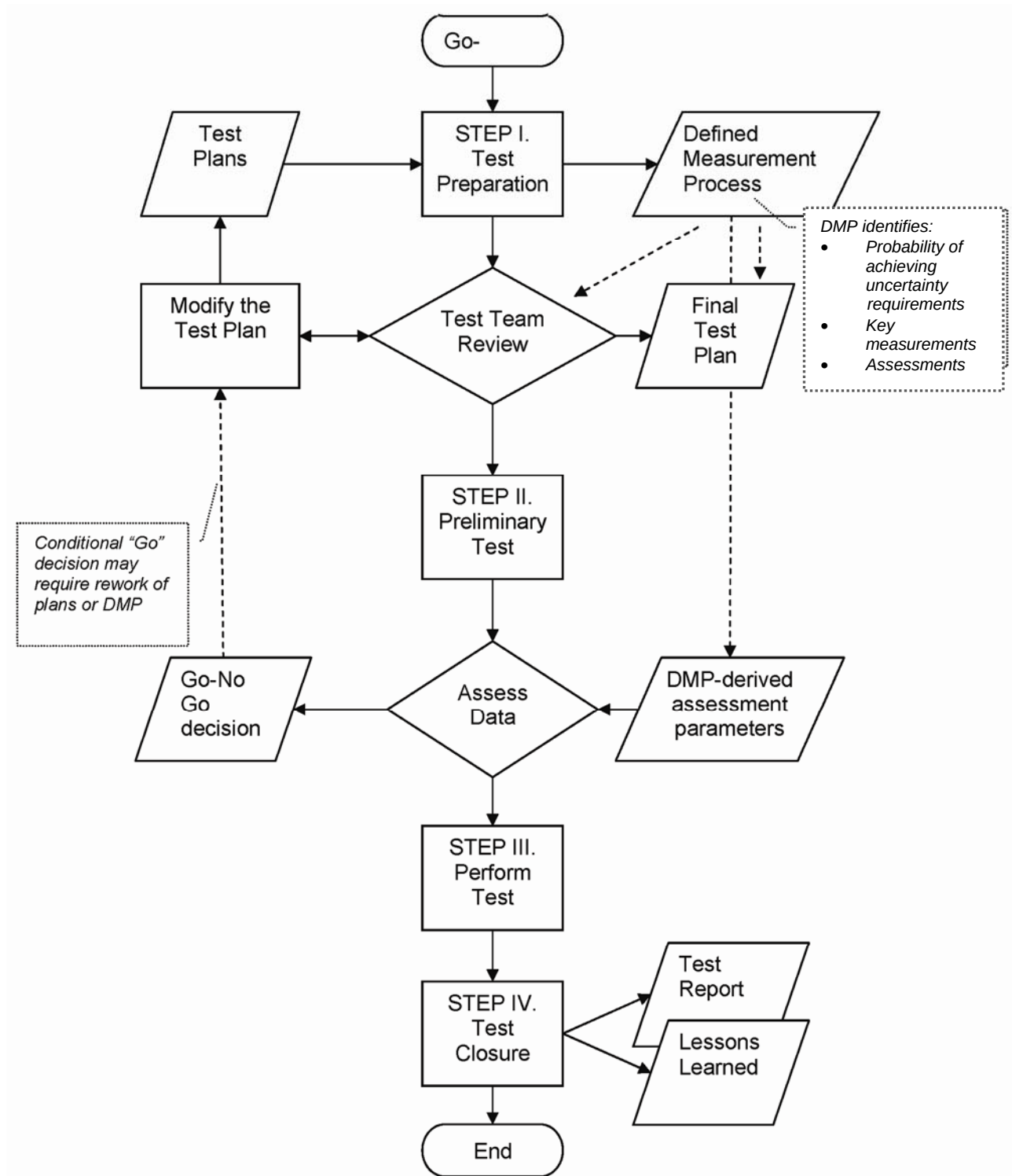
The outline procedure for the flight test is as shown in Figure 4.

3.3.2 Outline Measurements

A list of the measurements needed to achieve results of the required uncertainty must be drawn up. This should only be in sufficient detail to allow visibility of the general level of instrumentation and calibration standards necessary. In doing this, it must be acknowledged that there will be a minimum number of instruments, of some known standard of calibration and level of redundancy, to achieve the uncertainties and confidence level demanded by the Test Objectives. This minimum instrumentation set will be estimated through the Defined Measurement Process (DMP), so this aspect will be subject to modification before the test plan can be finalized.

Again, experience of previous testing is valuable in identifying the most important measurements. For example, it has been established (Reference 2.1.1.2) that for in-flight thrust measurements, pressure measurement errors are dominant in determining the accuracy of the results. With this knowledge, the DMP may be designed to ensure that the pressure measurements are particularly well engineered. Furthermore, the DMP may be used to confirm that such examples of previous experience are indeed applicable.

While the precise algorithms for derived output parameters may not be required at this stage, they must be specified before the final DMP can be completed. Assumptions need to be explicitly defined.



3.3.2.1 Example Outline Measurements

The in-flight thrust is derived from the following measurements and inputs:

- a. Ambient pressure, P_0
- b. Free stream total pressure, PT_2
- c. Free stream total temperature, TT_2
- d. Fan discharge pressure, PT_{13}
- e. Low pressure turbine discharge pressure, PT_5
- f. Compressor discharge pressure, PT_3
- g. Compressor discharge temperature, TT_3
- h. Fan nozzle area, A_{18}
- i. Velocity coefficient on fan nozzle stream, CV_{18}
- j. Flow coefficient on fan nozzle stream, CD_{18}
- k. Velocity coefficient on core nozzle stream, CV_9
- l. Fan discharge temperature, TT_{13}
- m. High Pressure Turbine Flow Function, $HPTFF$
- n. Fuel flow, WF
- o. Nozzle discharge suppression factor, CD_{18SUP}
- p. Fan Pressure Correlation Extrapolation Factor, $FPCEX$

Required measurement ranges and expected measurement uncertainties may be defined using knowledge of the flight conditions to be tested, the design of the engine (and hence pressure, temperature ratios, fuel flows, turbine capacity, etc.) and previous experience. For example, reference to standard atmospheric tables will show the range of P_0 to be expected at the maximum and minimum altitudes specified and the instrumentation must be selected to cover this range. Likewise, knowledge of the flight Mach numbers to be flown will allow the range of PT_2 to be easily found. The engine performance model is used to determine internal engine conditions.

The specification of accuracy requirements requires a detailed understanding of test objectives, success criteria, and the required level of confidence that will be associated with the final result. In this example, it has been assumed that such information has been made available.

3.3.3 Initial Uncertainty Analysis

Known or estimated values for instrumentation uncertainty should be combined with the known or estimated influence coefficients to produce an initial estimation of uncertainty for the results. Clearly, if this preliminary estimate of uncertainty is greater than the required level, then the plans must be immediately reviewed. If it is acceptable then the plan may proceed.

3.3.3.1 Example Initial Uncertainty Analysis

In this example, the test methodology is well established and previous analyses have determined the typical levels of systematic and random uncertainties and also the non-dimensional influence coefficients. These are summarized in Table 1 for the take-off condition and Table 2 for the cruise. The methodology used for the combination of these uncertainty estimates is presented in Section 4 of this document. Also shown are Pareto charts for the two conditions, indicating the relative contributions of errors in the parameters to the overall uncertainty of the result.

The Pareto chart analysis presented in Figures 5 and 6, reveals that some parameters have a high contribution to errors in thrust measurement at both flight conditions (e.g., CV18, CD18 and FPCEX), while others do not (P0). Knowledge of these characteristics allows optimal expenditure on instrumentation (e.g., numbers and types of sensors and calibration requirements.)

TABLE 1 - UNCERTAINTY ANALYSIS FOR IN-FLIGHT THRUST DETERMINATION
(ON-WING PHASE - TAKEOFF CONDITION)

	Parameter Description	Parameter	Influence Coefficient	Systematic Standard Uncertainty % RDG	Random Standard Uncertainty %RDG
1	Ambient Pressure	P0	2.905	0.034	0.029
2	Fan Inlet Total Pressure	PT2	-3.971	0.023	0.008
3	Fan Inlet Total Temperature	TT2	0.157	0.077	0.038
4	Fan Discharge Pressure	PT13	1.974	0.026	0.017
5	Turbine Discharge Pressure	PT5	0.276	0.078	0.058
6	Compressor Discharge Pressure	PT3	0.181	0.080	0.124
7	Compressor Discharge Temp.	TT3	-0.038	0.082	0.160
8	Fan Nozzle Area	A18	0.731	0.13	0.000
9	Velocity Coefficient (Fan Nozzle)	CV18	1.094	0.112	0.000
10	Flow Coefficient (Fan Nozzle)	CD18	0.731	0.158	0.000
11	Velocity Coefficient (Core Nozzle)	CV9	0.275	0.112	0.000
12	Fan Discharge Temperature	TT13	-0.161	0.143	0.149
13	HPT Flow Function	HPTFF	0.181	0.5	0.000
14	Fuel Flow	WF	0.090	0.15	0.220
15	Flow Coefficient (Suppression)	CD18SUP	0.731	0.075	0.000
16	FPC Extrapolation	FPCEX	1.974	0.05	0.000

Name	Code	Propagated Uncertainties		
		Systematic Standard Uncertainty	Random Standard Uncertainty	Expanded Combined Uncertainty
Net Thrust	FN	0.28%	0.10%	0.61%

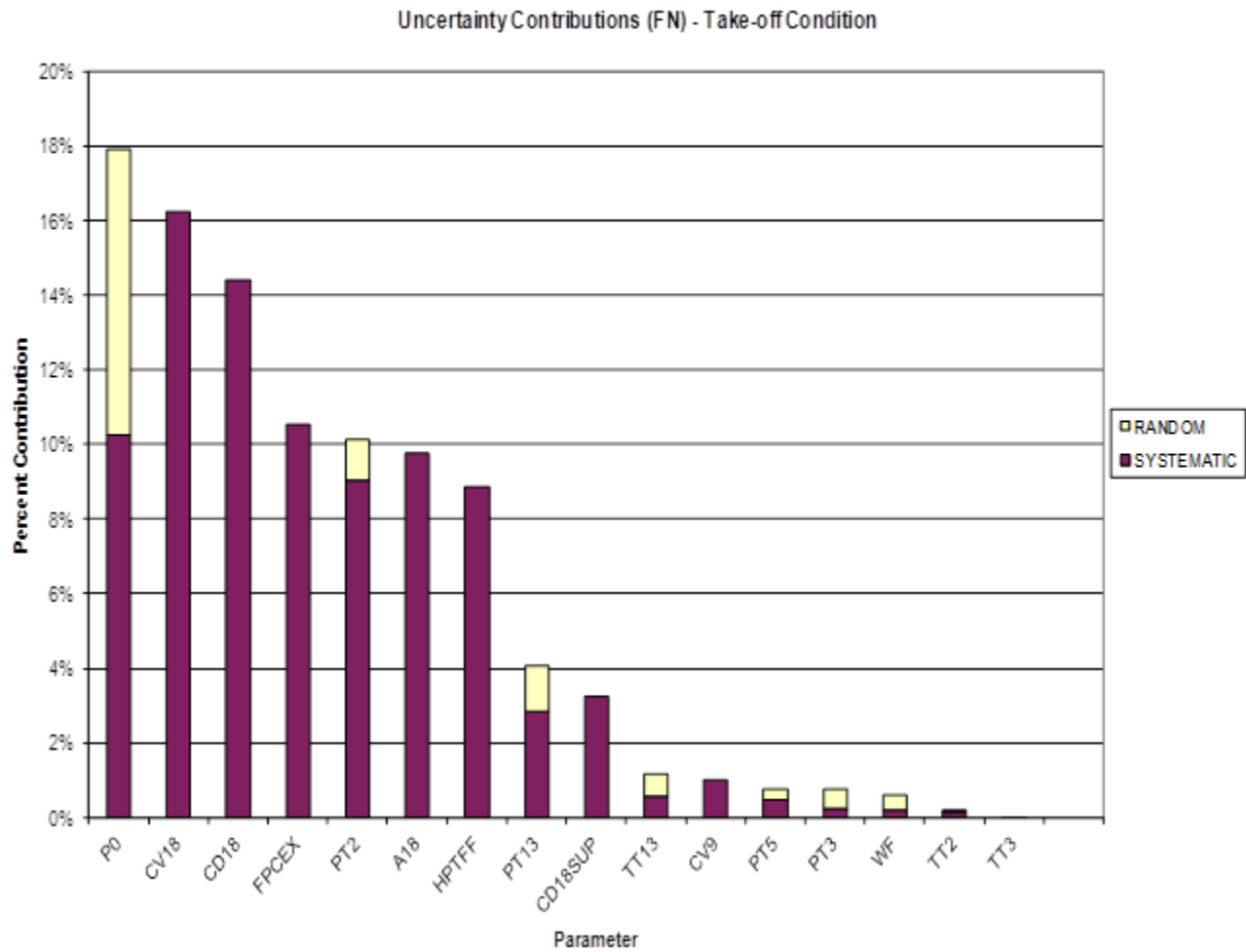


FIGURE 5 - PARETO ANALYSIS OF IN-FLIGHT THRUST PARAMETER UNCERTAINTIES (TAKE-OFF)

TABLE 2 - UNCERTAINTY ANALYSIS FOR IN-FLIGHT THRUST DETERMINATION
(ON-WING PHASE - CRUISE CONDITION)

	Parameter Description	Parameter	Influence Coefficient	Systematic Standard Uncertainty	Random Standard Uncertainty
				% RDG	%RDG
1	Ambient Pressure	P0	0.425	0.034	0.029
2	Fan Inlet Total Pressure	PT2	-2.024	0.023	0.008
3	Fan Inlet Total Temperature	TT2	-0.248	0.077	0.038
4	Fan Discharge Pressure	PT13	1.901	0.026	0.017
5	Turbine Discharge Pressure	PT5	0.325	0.078	0.058
6	Compressor Discharge Pressure	PT3	0.142	0.080	0.124
7	Compressor Discharge Temp.	TT3	-0.031	0.082	0.160
8	Fan Nozzle Area	A18	0.630	0.13	0.000
9	Velocity Coefficient (Fan Nozzle)	CV18	2.521	0.112	0.000
10	Flow Coefficient (Fan Nozzle)	CD18	0.630	0.158	0.000
11	Velocity Coefficient (Core Nozzle)	CV9	0.550	0.112	0.000
12	Fan Discharge Temperature	TT13	0.156	0.143	0.149
13	HPT Flow Function	HPTFF	0.142	0.5	0.000
14	Fuel Flow	WF	0.231	0.15	0.220
15	Flow Coefficient (Suppression)	CD18SUP	0.630	0.075	0.000
16	FPC Extrapolation	FPCEX	1.901	0.125	0.000

Name	Code	Propagated Uncertainties		
		Systematic Standard Uncertainty	Random Standard Uncertainty	Combined Expanded Uncertainty
Net Thrust	FN	0.41%	0.07%	0.84%