XVIII IMEKO WORLD CONGRESS
Metrology for a Sustainable Development
September, 17 – 22, 2006, Rio de Janeiro, Brazil

MENIR – A CONTRIBUTION FOR FINAL UNCERTANTY EVALUATION OF ROCKETS MASS MEASUREMENTS

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Abstract: The weight is a very significant property for several rocket projects' calculations. The cost of satellite mass is very high and a reduction of 1% can save thousands of dollars. Then it's necessary to know the most important uncertainty sources to obtain a reliable result. In this paper, a developed method is shown to find the smaller uncertainty of a rocket's weight among several available weighing instrument parks.

Keywords: Mass measurement, Uncertainty analysis

1. INTRODUCTION

The rockets mass measurements at IAE (Aeronautics and Space Institute) follows the basic principles described at each equipment manual, from weighing instruments to air bearing mass properties measurement devices [1].

Nowadays mass measurements are based only in the equipments calibration charts uncertainties or the scale division values assumed as uncertainty, which are incorrect assumption about the weighing instruments uncertainties values. Moreover, it's not rare that calibration charts are outdated, which can induce unknown errors.

The internal standards for rockets pieces measurement indicates two measurements for each piece [1], but there are no requirements for keeping the same parts configuration for each weighing procedure in different rockets, even that from the same family. This means that there is no reliable information about past measurements to conduct statistical data evaluation. In the final assembly stages, most of the weighing measurements are done in the nearest measurement system, which sometimes are not the best available equipment.

Taking all above in consideration, it's necessary to make a deep evaluation about uncertainties sources that affect weighing measurements from the rockets parts and the available weighing instruments at each location, to minimize the final uncertainty of the rocket mass determination.

2. OBJECTIVE

The correct mass determination of a rocket, for satellite launching for example, has a significant importance to several calculations during the design phases to obtain trajectories, aerodynamic behavior, launch controlling, among others. In fact, Sutton [2] assures that the rate between the propeller mass and the rocket initial mass indicates the design quality of a rocket propulsion system. The same author relates 37 key equations for an ideal rocket, from which 10 equations consider some rocket mass value in its formulation.

Another important aspect to be evaluated is the cost of the mass transported by the rocket. Global launch costs are in the order of US$ 122,000.00/kg of payload [1], which justifies any gain in the determination of rocket mass and utile load.

This paper describes studies conducted to obtain an adequate combination of available weighing instruments to optimize the final uncertainty value of the rocket mass measurement. The paper also concerns the ideal number of rocket subdivisions needed to make the measurements with multiple weighing instruments, each one with their own individual uncertainties.

3. METHODOLOGY

A theoretical analysis leads to more than 30 uncertainties sources influencing weighing measurements, as shown at figure 1. Each one affects the results with more or less impact. Most of them have insignificant effect on day by day measurements results. In some cases the sources can be evaluated like they were only one. In other cases the influences from each sources must be evaluate separately and the relative significance will show which from those must be considered.

A criterion suggested for Miller [3] is that an uncertainty source is considered significant if affects at least as the last significant number of the combined uncertainty.

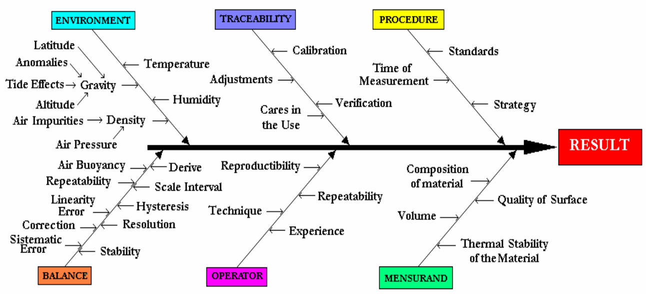

Figure 1 – Sources of Uncertainty

One must also be aware about systematic errors introduction from any uncertainty source. To avoid this, calibration procedures must be done at the right times in all equipments, resulting in pure random errors expected in each one. These calibrations will also evaluate each uncertainty source, which results in the expanded uncertainty to each weighing measurement process.

As the final rocket mass will be given from the sum of parts measurements, all the weighing instruments must be considered to compose the combined uncertainty.

A set of weighing instruments used to determine one rocket final mass can be called measurement park, which can be defined at MENIR on the spread sheet named **Choice of Weighing Instruments**.

To characterize the measurement park, it's possible to group weighing instruments from a particular location or mix them choosing the best available weighing instruments. It's also possible to characterize a measurement parks from external companies instruments, or from the best available instruments from commercial catalogues, which composes a virtual park. The comparison between the results from each measurement park can indicate where to measure and what can be done to improve the IAE weighing Instruments Park, from the market results.

The quality of the result gotten for the MENIR method is directly related with the quality of the procedures of calibration of each weighing instrument registered in the spread sheet.

As the weighing instruments are suppose to be correctly calibrated and at the validation time, the instruments errors portion are purely random, leading to a situation where the uncertainties sources are statistically independent or with no correlation.

With this assumption, the combined uncertainty from the sum of two or more random variables can be obtained by the equation [1]:

$$u^2(X_1 \pm X_2 \pm ... \pm X_n) = u^2(X_1) + u^2(X_2) + ... + u^2(X_n) \qquad (1)$$

This equation can be described as:
"The square of the standard uncertainty from the sum and/or subtraction of measurements with no correlation are obtained from the sum of the standard uncertainties squares related to each entering quantity".

From this basic rule it's possible to compose a calculation spread sheet that uses different weighing instruments sets and different rocket mass distribution and configuration to optimize the final uncertainty value obtained. The spread sheet is called MENIR and is based on the Microsoft Excel® program.

The bigger Brazilian rocket has more than 15,000 parts [1]. The mass measurements can be performed with the entire assembled rocket or with subsystems combinations. Depending on the weighing instruments quality at each measuring range for the subsystems, the final uncertainties results can demand big variations. Concerned about this, the MENIR method has the option of entering several rockets subsystems configuration to evaluate the final result uncertainty behavior for each case. The MENIR method also indicates the best weighing instrument for measuring each subsystem.

The total mass of the rocket can be gotten from several different situations, for example:
a) At once;
b) Divided in little number of modules or
c) Divided in big number of modules.

Measuring the mass of a rocket at once, would be necessary to consider only the expanded uncertainty of that used measurement instrument. The mass of rocket M_F could be described as:

$$M_F = N \pm A \qquad (2)$$

N is the value measured for the measurement instrument and A, the associated uncertainty.

If, however, the same rocket will be measured in more number of modules, in the same measurement instrument, considering a maximum error for all its range of measurement, the mass of rocket MF could be described as [1]:

$$M_F = \sum_{j=1}^{nc} N_j \pm \sqrt{\sum_{j=1}^{nc} (A_j)^2} \qquad (3)$$

nc, is the number of components of the rocket.

In this case, it is clear that the most favorable situation is that where the lesser number of modules from the rocket is used, but only for the case where the same weighing instrument are used and with the same uncertainty. When weighing measurements with lesser capacities and minor uncertainties are considered, nothing can be affirmed previously about the final combined result.

However a combination of weighing instruments and respective uncertainties, and an ideal number of total mass subdivisions exists that leads to a total expanded combined uncertainty that is the smallest possible. This is the MENIR main objective, to indicate the best measuring park and rocket subdivision.

Moreover, it is necessary to consider aspects related to availability and opportunity to use a weighing instrument or park. Availability means that the instrument has to be accessible, and opportunity means that it's necessary to follow any change of the actual mass with reference to the calculated mass of the rocket. The data is routinely passed to the sector of analysis of trajectory for verification and refinement of the calculations.

Through MENIR method, it's necessary to predict the final mass measurement uncertainty before execute the measurements, which can be useful in some design calculations.

TABLE 1 – Weighing Configurations

CONFIGURATION	DESCRIPTION
1	Entire rocket
2	Rocket divided in 3 modules
3	Rocket divided in 10 modules

Considering all these parameters, an optimized circuit can be programmed that, using the best weighing instruments of several available parks in the region, supplies the lesser total uncertainty a rocket. The Choice of the Weighing Instruments spread sheet was elaborated only to demonstrate the concept and give no real weighing instruments values. This example, conceived with four configurations of measurement to a rocket and four available measurement parks, it can be expanded for more configurations and more parks. The adopted configurations of measurement are shown at table 1.

Figure 2 shows a simulated park number 4. In this park exists 6 weighing instruments, labeled as B1 to B6. To each weighing instrument, measurement ranges can be defined with their own related uncertainties. The uncertainties values must be introduced by the system operator. MENIR selects which are the lesser uncertainties available to each measurement range from this measurement park.

Figure 2 also shows the final uncertainty result to each selected configuration using this measurement park, indicating the lesser value and weighing instruments to use.

In this article, the choice about the number of modules to be measured was basically didactic, searching to simulate the model effectiveness in the forecast of uncertainties for each configuration. In fact, the number and the size of modules that compose the rocket must be tailored concerning the practical situation.

Figure 3 shows the MENIR results panel, with the calculated final uncertainties to each evaluated configuration and each weighing instruments' park.

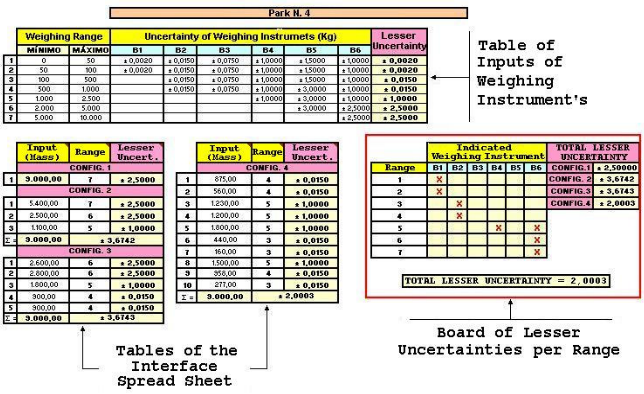

Figure 2 – Example of a park panel.

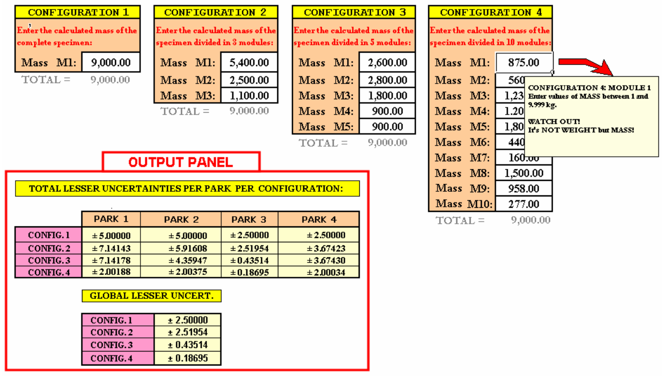

Figure 3 – Simulated Results panel.

In this sheet the operator can define and input the configurations to be evaluated. Naturally, the final sum from the parts that compose the configurations must be the same, which indicated the total rocket mass. In a prior moment, ordinary measurements are done to find out a reference mass value to each module only to locate the module in the available measurement ranges.

Figure 3 also shows an output panel where all the parks and configurations uncertainties values are shown in a crossed table, indicating the global lesser uncertainty to each configuration and parks. From this information it's possible to take decisions about the best measurement configurations to use and about the weighing instruments sets behavior. Logistics decisions must be also evaluated. Weighing instruments sets far from the actual location can be avoided if their results don't have great compensations. New weighing instruments are also evaluated to cover specific inefficient measurement ranges.

All the information also can be used during the rocket design optimization, allowing important decisions to be made in the earlier design phases.

4. CONCLUSION

The method organizes the mass measurements information, making all the procedure more controlled and reliable.

The MENIR method showed to be very utile for the evaluation of final uncertainties expected in rockets mass measurements. It also gives information about the needed measurement volume and the weighing instruments to be used. It also compares catalog weighing instruments to rule new acquisitions.

ACKNOWLEDGMENTS

The authors would like to thank FAPESP - *Fundacão de Amparo à Pesquisa do Estado de São Paulo* (process 05/00136-3), the Brazilian Space Agency, the General Airspace Technology Command (CTA), the Aeronautics Technological Institute (ITA) and especially the Aeronautics and Space Institute (IAE) for all support received.

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