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Uncertainty and a Spreadsheet

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Sandia National Laboratories

GUM Admonition

Although this guide provides a framework for assessing uncertainty, it cannot substitute for critical thinking, intellectual honesty, and professional skill. The evaluation of uncertainty is neither a routine task nor a purely mathematical one: it depends on detailed knowledge of the nature of the measurand and of the measurement.

GUM (JGCM 100:2008) section 3.4.8

Measurement Uncertainty Defined

Informal Definition:

The word “uncertainty” means doubt, and thus in its broadest sense “uncertainty of measurement” means doubt about the validity of the result of a measurement.

GUM (JGCM 100:2008) section 2.2.1

Measurement Uncertainty Defined

Formal Definition:

uncertainty (of measurement)

parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

GUM (JGCM 100:2008) section 2.2.3

Demonstration With Excel

Background Slides

The Crash of the B2 Bomber Spirit of Kansas

February 23, 2008
Andersen Air Force Base, Guam

Spirit of Kansas Crash Timeline

2006 – During a deployment to Guam, B2 maintenance technicians notice that the high humidity in Guam is affecting the calibration of the 24 pressure sensors in the skin of the aircraft which are part of the Air Data System (ADS). After conferring with B2 project engineers in Missouri, the maintenance crews find that the moisture can be cleared from the sensors by turning on the pitot heater for a short time before the ADS calibration.

However this work-around was never captured in a formal technical order or lessons learned report. Neither the maintenance crews nor the project engineers fully appreciated how the pressure data was being used by the flight control systems.

9:29AM, February 23, 2008 – During preflight checks, the crew of the Spirit of Kansas receive an "AIRDATA CAL" message from the computer indicating that an ADS re-calibration is required. The ADS is calibrated by a maintenance crew that is unaware of the moisture problem and the pitot heater work-around. Three of the four sensors which make up the upper gust load alleviation (GLA) sub-system within the ADS have been infiltrated by moisture which biases their readings by about -0.9%.

Spirit of Kansas Crash Timeline cont.

10:29AM – As the Spirit of Kansas crew makes final preparations for takeoff, the pitot heater is switched on per the preflight checklist. The wet pressure sensors are dried out. But since they were calibrated in a moist state, the flight computer is now using incorrect calibration coefficients for three of the four GLA sensors.

10:30:12AM – The Spirit of Kansas begins its takeoff roll.

10:30:31AM – The Master Caution Light illuminates and the status display indicates a disagreement between the GLA sensors. However after six seconds, the computer decides that the three bad readings are consistent with each other and discards the one good reading. The caution light clears and the pilots elect to proceed with the takeoff as they are already past to go-no-go point.

Spirit of Kansas Crash Timeline cont.

10:30:49AM – The airspeed indicates about 145 KIAS (based partly on the faulty pressure readings) and the pilots rotate the nose. The actual airspeed is about 133 KIAS. At the instant that the aircraft's weight lifts off its wheels, the Air Data System (ADS) becomes fully operational and data from the air pressure sensors are fed back to the flight control system. Based on the faulty data from the GLA sensors, the computer erroneously calculates that the Spirit of Kansas in in a severe nose down state and automatically commands a full nose up to the flight controls. The bomber abruptly rises into the air and then stalls, and the ADS, faced with this unexpected event, shuts down completely. The pilots, dealing with the malfunctioning computer control system along with a low air speed, high angle of attack condition, never have a chance to regain control.

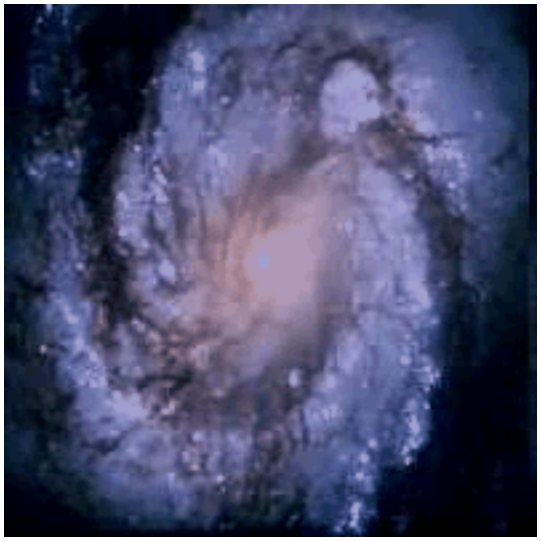
10:31:06AM – The left wing of the Spirit of Kansas hits the ground. Amazingly the pilots are able to eject at this point and survive. The total monetary loss is $1,407,006,920.

Spirit of Kansas Crash Analysis

“Most of the individuals interviewed by the board viewed the air data calibration as a mechanism to correct the aircraft altimeters and nothing more. The board had to consult aircraft design engineers who had not been associated with the B-2 program for over 10 years to find a level of understanding in the system that raised concerns over a need to calibrate PTUs [pressure sensors] on the aircraft.”

Statement of Opinion, B-2A, T/N 89-0127 Accident, 23 February 2008
Major General Floyd L. Carpenter, USAF
President, Accident Investigation Board

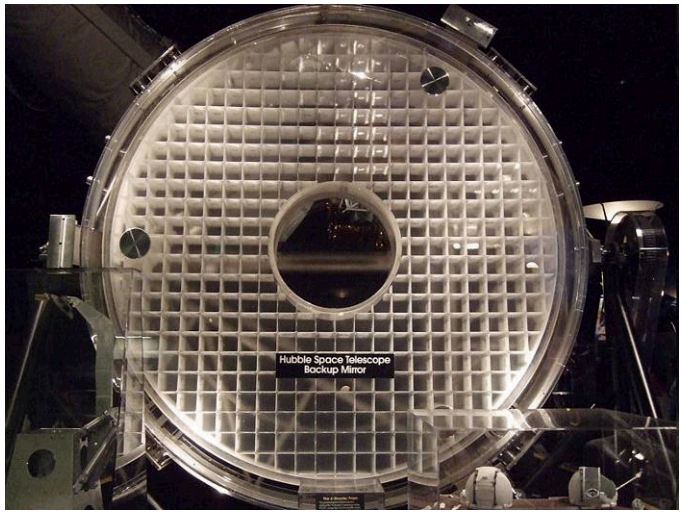
A Measurement Uncertainty Parable: The Hubble Space Telescope Optical Systems Failure



An error during manufacturing resulted in a several micron deviation in the primary mirror profile causing images to be improperly focused.

The Hubble Space Telescope Optical Systems Failure Report, NASA report #TM-103443, November 1990.

The Hubble Space Telescope Optical Systems Failure

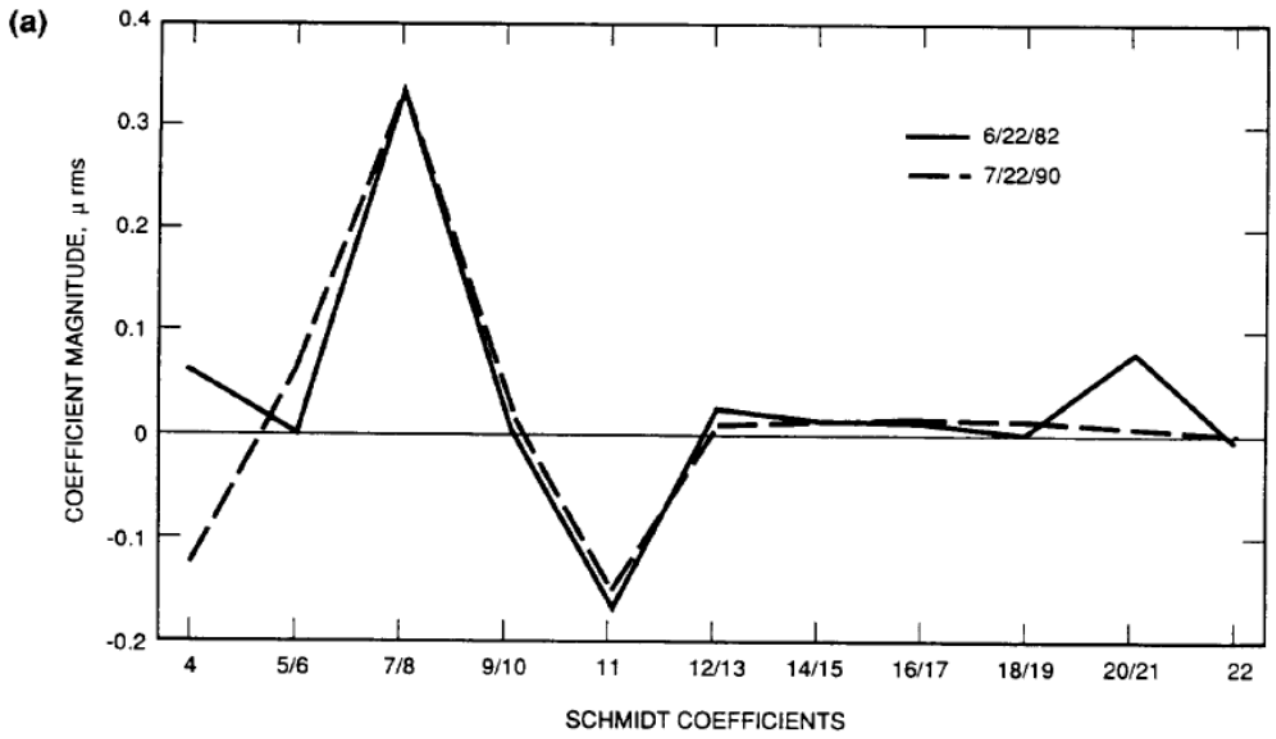


The “reflective null corrector” (RNC) was used to guide the polishing of the Hubble primary mirror with a supposed accuracy of 10 nm.

As part of the alignment procedure a less precise instrument called an “inverse null corrector” (INC) was used with the RNC.

The Hubble Space Telescope Optical Systems Failure

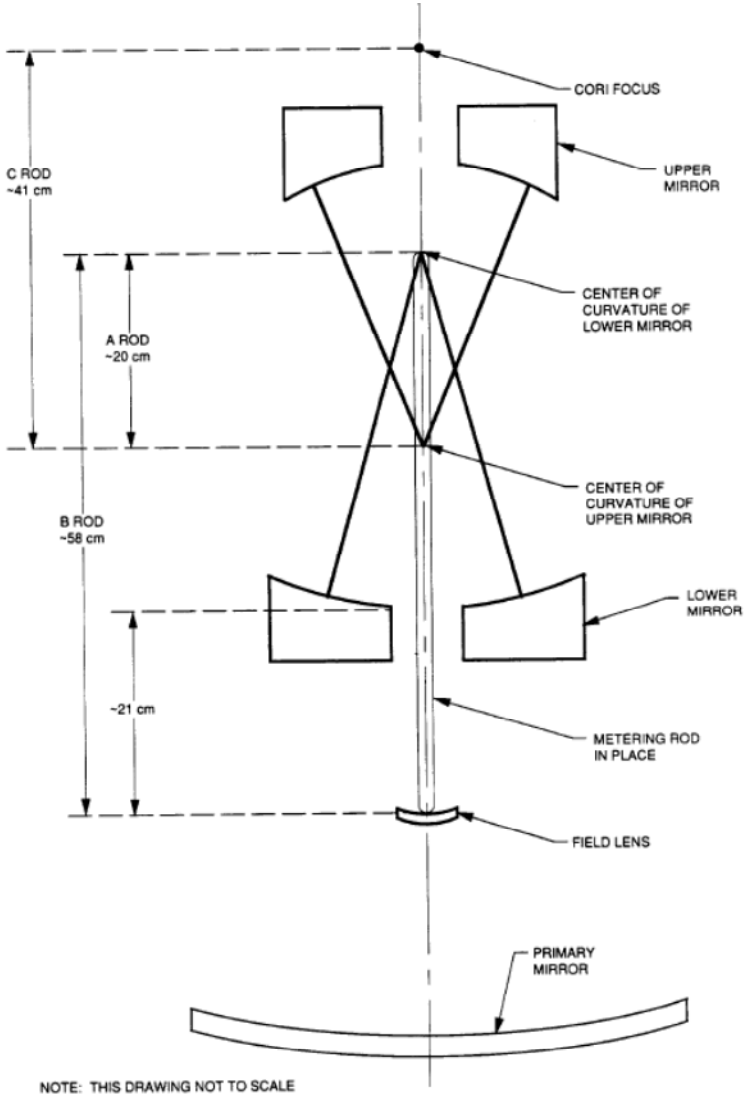
The wave front distortions from the (critically important) RNC as measured by the (less precise) INC:



Do the deviations from zero represent “noise” from the INC or do they indicate a problem with the RNC?

The Hubble Space Telescope Optical Systems Failure

RNC Setup using metering rods:



The Hubble Space Telescope Optical Systems Failure

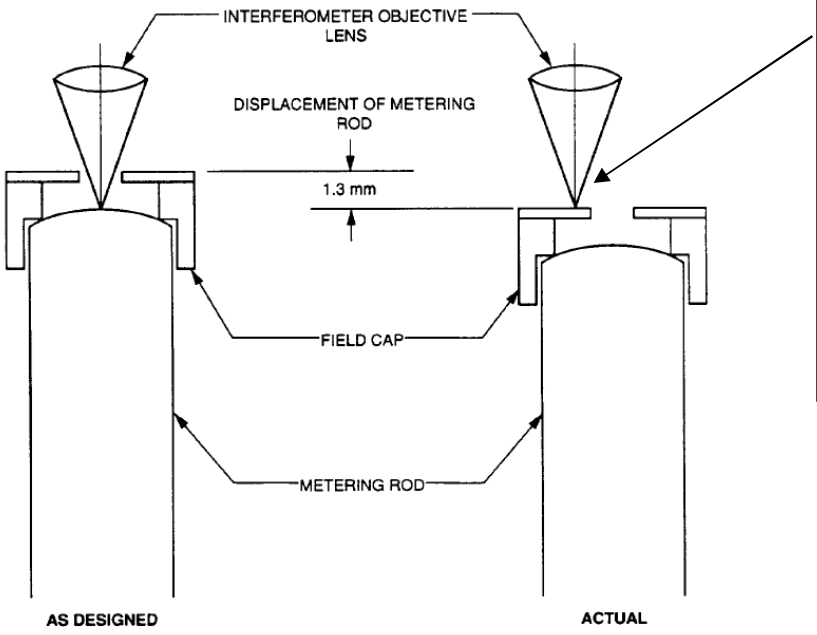


Figure 7-4. Displacement due to the interferometer focusing on the field cap instead of the metering rod.

An adjustment to a metering rod used to set up the RNC was incorrectly made. This happened when an interferometer measurement was made on the shiny surface where a chip of paint was missing on a field cap rather than off of the end of the metering rod.

The Hubble Space Telescope Optical Systems Failure

Would you have included the possibility of a paint chip on a field cap in the RNC uncertainty budget? If not, what is the point of doing uncertainty analysis at all?