MISALIGNMENT ESTIMATION SOFTWARE SYSTEM

Richard L. desJardins

I want to describe a system of computer software and spacecraft and ground system activity called the Misalignment Estimation Software System (MESS). This enables spacecraft precision attitude sensors such as startrackers and inertial reference assemblies to be aligned and calibrated from the ground after the spacecraft has achieved orbit.

Advantages of this approach will be pointed out and actual results of application of MESS to OAO-C will be given.

Spacecraft with very high precision three-axis attitude slewing and maintenance requirements typically combine a number of external reference sensors, such as startrackers and sun sensors, with one or more internal reference sensors or inertial reference assemblies. These units are bolted to the spacecraft structure and carefully aligned to the coordinate axes. But the sensors have such high precision that even residual misalignments are detectable. Therefore these residual misalignments are measured during test and integration and modeled in the computer so that account may be taken of them when the spacecraft is being controlled.

When the spacecraft is launched, however, extreme mechanical vibration causes changes to these misalignments, and once in orbit, the solar duty cycle and resulting variations in thermal load on the structure again cause changes to the misalignments. Finally, the slew angle scale factors of the gyros must be calibrated against the weightless conditions in orbit. Therefore, to achieve the high precision of which these units are capable, it is necessary to redetermine the misalignments after the spacecraft has achieved orbit and again from time to time throughout the mission.

Before describing the technique used in MESS, let it be clear that this is mathematically a nontrivial problem. The difficulty is that parameters are not directly observable in general, but only the attitude sensor errors resulting from them. Any particular observed error—for instance, if it is observed that the spacecraft is pitch-slewing off to one side—is attributable in general to a combination of several misalignment parameters.

Therefore, the analyst must first of all define the type and number of exercises which will render specific misalignment parameters visible, and secondly, he must process the observed errors to determine statistically the best estimate of misalignments which caused those errors.

From an information flow point of view, all MESS exercises are conceptually identical. In the uplink flow, given a nominal spacecraft model, MESS generates an exercise designed to render visible a particular set of misalignments (Figure 1). The exercise is sent to the spacecraft, and in performing it, the spacecraft inserts the misalignments of interest into the information in the form of attitude sensor errors. The information is downlinked to MESS, which processes it to arrive at estimates of the misalignments. These estimates are then used to correct the spacecraft model in the data base.

As MESS was developed, its architecture and analysis were kept general where possible, so that a version could be implemented to support other spacecraft and attitude sensors aboard those spacecraft. In this connection, we are currently investigating the application of MESS to ATS-F and G.

However, the version currently implemented is for OAO (Figure 2). Included in this implementation are five gimballed startrackers, for each of which both an arbitrary rotational misalignment as well as a shift in the inner gimbal null position are modeled; a boresighted

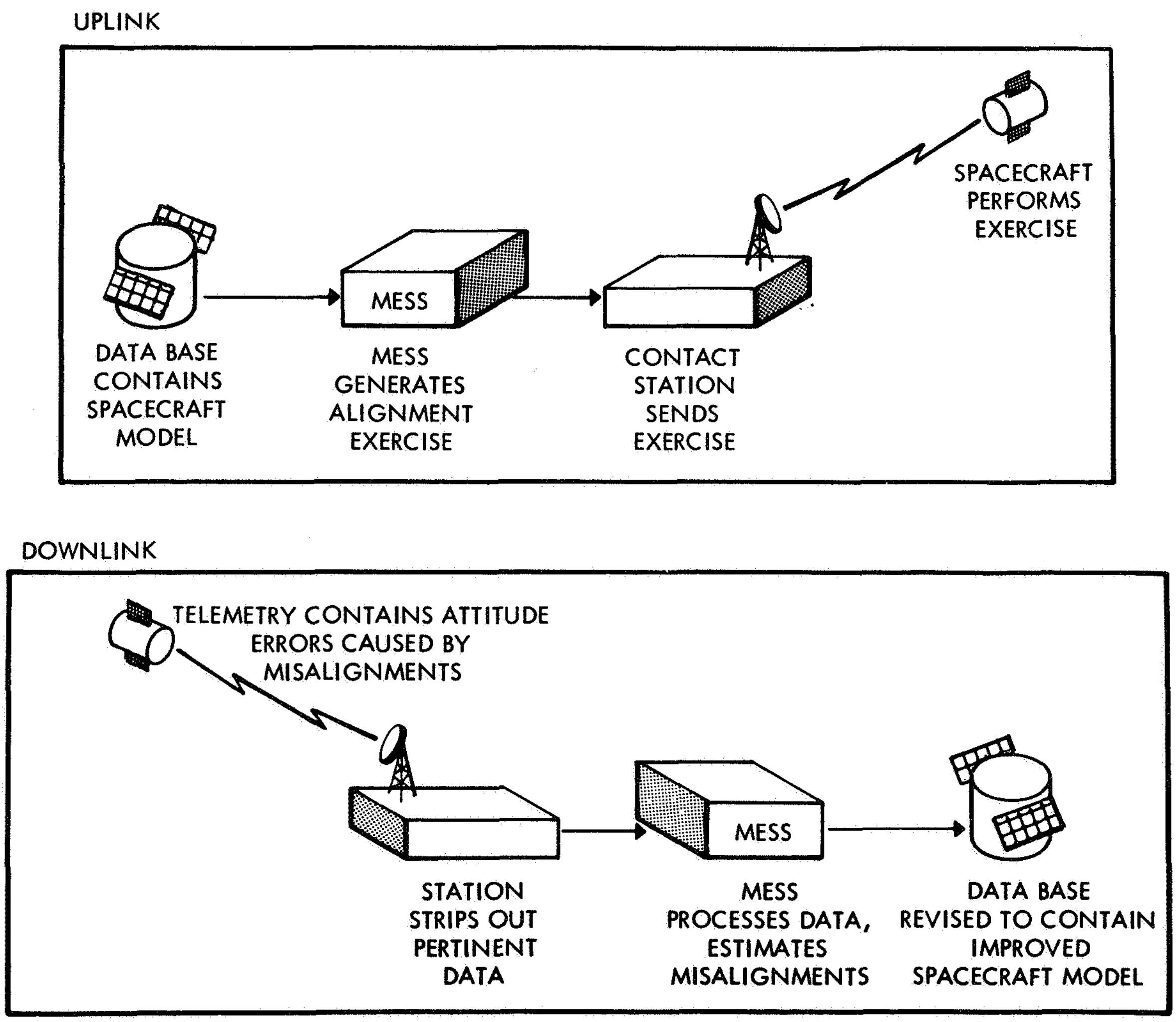

Figure 1. MESS information flow.

		TOTAL
EACH GST:	THREE ROTATIONS OF GIMBAL PLATFORM	15
	INNER GIMBAL NULL SHIFT	5
BST:	PITCH AND YAW OFFSET FROM FES	2
IRU:	FOR EACH AXIS, TWO OFFSET MISALIGNMENTS	6
	FOR EACH AXIS, TWO SLEW ANGLE SCALE FACTORS	6
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Figure 2. Misalignments modeled in MESS/OAO.

startracker, for which an arbitrary offset from the experimenter's fine error sensor is modeled; and three independent inertial reference assembly slew axes, for each of which an offset misalignment and separate positive and negative slew angle scale factors are modeled.

Figure 3 is a summary of the results of the initial in-orbit alignment of OAO-C. "Before" means after launch but prior to in-orbit alignment. You can see that the maximum sensor errors have been reduced fivefold on the gimballed startrackers. After aligning the gimballed startrackers, we were then able to align the experimenter's fine error sensors to the same reference, which resulted in a threefold improvement in overall open loop pointing. We were able to improve slew accuracy by a factor of better than two, and we helped determine compensation terms to dramatically decrease the drift rates of the gyros as shown.

It is important to note here that careful analysis and design of necessary exercises and development of supporting software can minimize interference of in-orbit alignment operations with productive spacecraft operations. For example, the initial in-orbit alignment and calibration of all the sensors shown here consumed only about 10 percent of the first eight days in orbit. (The other 90 percent of course was occupied with initial stabilization and spacecraft and experiment checkout.) As another example, all of the startrackers on OAO-C can be realigned at any time desired in about one hour of orbital operations.

In summary, the MESS system and underlying concepts

- have been developed
- have been used successfully on OAO-C to improve precision by better than twofold
- and are available for use on other spacecraft which have precision attitude-sensing requirements

.SENSOR	MAXIMUM ERROR	
	BEFORE	AFTER
GIMBALLED STAR TRACKERS	2.5 ARCMIN	0.5 ARCMIN
FINE ERROR SENSOR (RELATIVE)	1.5 ARCMIN	0.5 ARCMIN
INERTIAL REFERENCE UNIT (20° SLEW)	1.4 ARCMIN	0.6 ARCMIN
IRU DRIFT RATES	50 ARCSEC/HR	3 ARCSEC/HR

Figure 3. Misalignments modeled in MESS/OAO.