Constraint and Flight Rule Management for Space Mission Operations

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Abstract

Thousands of operational constraints govern NASA's human spaceflight missions. NASA's Mission Operations Directorate (MOD) develops, documents, and applies these constraints during mission planning to ensure the safety of the crew, as well as proper operation of the spacecraft systems and payloads. These constraints are currently written as documents intended to be read by MOD staff. Similar operational constraints are developed independently by different organizations, and manually transformed into machine-readable formats needed to drive tools such as automated planners, mission analysis and mission monitoring tools. The resulting process is inefficient and error prone. In response, NASA has developed Constraint and Flight Rule Management (ConFRM) software to centralize the capture of operational constraints and to transform these constraints into different products for different uses. ConFRM will help MOD staff create constraints using disparate information, update operational constraints using new information, and check sets of constraints for errors and omissions.

Human Spaceflight Mission Operations

NASA's Mission Operations Directorate (MOD) develops, documents, and applies operational constraints to ensure the safety of the crew and the proper operation of the spacecraft systems and payloads. During pre-flight planning, NASA and its partners systematically develop, document, and approve these constraints. MOD provides training and operations teams with approved constraint documents in paper form and online searchable databases. During training, flight controllers and related personnel learn all of the constraints relevant to their disciplines, and configure tools to help enforce those constraints. During nominal operations, the Flight Control Team and crew ensure that the constraints are continually satisfied. During off-nominal operations, these constraints indicate corrective actions the Flight Control Team should take in order to return to an acceptable mission state.

Many operational constraints are developed in order to mitigate a hazard documented in a *Hazard Report*. Many more are derived from engineering analysis of spacecraft systems. Yet more operational constraints are derived from the operational experiences of Flight Control Teams and crew. There are several types of operational constraints. The Flight Control Team uses *Flight Rules (FRs)* to avoid hazards or guide reactions to unexpected events. Mission planners, who are part of the Flight Control Team, use *Ground Rules and Constraints (GR&Cs)* and *Crew Scheduling Constraints (CSCs)* to plan the crew's daily activities. The Flight Control Team uses FRs and GR&Cs mitigate hazards that must be avoided, while Crew Scheduling Constraints are 'best practices' developed over years of operational experience. *Generic* constraints apply to all missions. *Flight-specific* constraints are specific to a mission's payload, objective or system configuration. For a typical six month period, the Flight Control Team manages 1000 generic FRs, 100 flight-specific FRs, 300 GR&Cs, and 100 CSCs.

Development of Operational Constraints

The following scenario illustrates a common life-cycle of operational constraints. Suppose a new Hazard Report specifies that hand-held radios onboard ISS interfere with some communications between ISS and Mission Control. The Flight Control Team may write a Flight Rule to ensure that the crew has powered off these radios prior to sending critical commands to ISS, and link this rule to the Hazard Report. In addition, the Mission Planners may document the GR&C to ensure the crew's plan contains these activities explicitly, and link this GR&C to the Flight Rule. Over the course of several missions, the specific details of the constraint may change; the number of radios that must be turned off, the type of radio, and the specific ISS commanding activities that require the radios to be turned off. Also, these mission specific constraints may be changed to generic, i.e. they impact every flight.

ISS crew activity planning happens in stages. The Long-Range Plan (LRP) is generated for roughly six months worth of ISS activities (equal to one ISS Increment and crew rotation). Versions of this plan are initially generated using Excel and Microsoft Word. Once the major mission milestones are decided, the LRP for the Increment is generated using the Consolidated Planning System, a model-based planner. CPS permits the declaration of state and resource requirements, as well as temporal constraints on activities. These constraints are manually translated from GR&C and CSC documents. CPS allows operators to add activities, delete activities, and automatically generate plans according to constraints on activities [1].

Operating constraints may change from mission to mission. A constraint created for a specific flight may be deemed generally applicable, or changes in vehicle configuration may lead to new crew scheduling constraints. Similar operational constraints are developed independently by different organizations. A GR&C may contain identical information to a Flight Rule, but today these documents are created by different parts of the Flight Control Team, and may be mutually inconsistent because of changes to the Flight Rule that are not reflected in the GR&C. Manual input of constraints into machine-readable formats needed to drive tools such as automated planners, mission analysis and mission monitoring tools is performed after documentation of the constraints. The resulting process is inefficient and error prone.

ConFRM

The creation and management of consistent operational constraints to drive automated planning has been addressed previously by the AI planning community. Existing tools can detect ill-formed rules, mutually inconsistent rules and automatically infer rules from plans [2,3]. However, the task of managing these operational constraints for human spaceflight offers some unique challenges. First, the constraints must be documented so that both people and AI planners can use them. Second, the constraints will be created by a large, distributed team of knowledge engineers. Third, these tools will be used by experienced spaceflight operators and engineers who are not AI experts. While rules for automated planners have been extracted from documents e.g. for Orbital Express [7], this is not common practice today. Lastly, the gradual changes of constraints over long periods of time introduces the problem of 'lifetime rule management'.

NASA has designed and prototyped a software solution called Constraint and Flight Rule Management (ConFRM). ConFRM's approach to authoring and managing operational constraints addresses the problems described above. ConFRM's main features are: 1) ConFRM provides direct links to the many spacecraft command and telemetry descriptions, databases of hazards, previously created operational constraints, and analysis products that the constraint references. ConFRM automatically reads XML command and telemetry descriptions [5]. ConFRM can establish links to these products either manually or automatically. ConFRM can also detect changes to product content and location, so the constraints and links are always up-to-date. 2) ConFRM enables export of relevant information from operational constraints to planning and monitoring tools, thereby reducing the effort in mapping the documented constraint to the tools used to ensure the constraints are followed. ConFRM's approach to capturing constraint knowledge in a central database also allows each group to export the content it needs, reducing duplication of effort and operational constraint mismatches between groups. 3) The ConFRM prototype includes basic error and inconsistency detection supported by formal modeling. The NASA team is evaluating a promising enhancement to automatically integrate constraints with monitoring and planning software.

ConFRM's technical architecture has three layers: 1) A Storage Layer uses a relational database for scalability and rich searching and reporting functionality. 2) A Business Layer encapsulates document lifecycle, version control, error checking, authentication, and authorization. A plug-in mechanism allows for modular 2-way integration with external applications. Separating the Storage and Business layers enables flexibility in database technology and design. 3) A Presentation Layer provides a rich authoring UI with wiki formatting. An alternative, lightweight web UI can provide access for casual and external users (such as hardware manufacturers, whose role is limited to providing technical details for some constraints). The UI is built using Eclipse tools, following in the footsteps of other recent developments in mission operations software such as Mars mission operations [4] and human spaceflight procedure development [6].

We will demonstrate the features of ConFRM, particularly those used in configuring a planning system. We will show how Wiki formatting allows non-programmers to add various types of formal structure to text-based documents, and how GR&C's can be exported in order to configure a planner. We will show how ConFRM facilitates tracing back of GR&Cs to parent FRs, searching for products based on keywords, browsing imported command and telemetry, detecting errors in constraints, and automatic creation of both human- and machine-readable content.

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