IAC-10.E1.2.7

HOLDING A TECHNICAL REVIEW IN AN EDUCATIONAL PROJECT: IMPLEMENTATION AND LESSONS LEARNED FOR THE OUFTI-1 CUBESAT

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This paper presents the experience of tailoring an ECSS (European Community for Space Standard) document to an educative project. In this case, the ECSS-M-ST-10-01 document [1], that describes the process to perform a project review, has been adapted to conduct the Interface Technical Review of the OUFTI-1 project.
The OUFTI-1 project aims at designing and building a CubeSat. Its main payload is the use of the D-STAR radiocommunication protocol in space. The entire technical work is done by students, and managed by academics and young engineers from the University of Liège. Experts from the industry support the project. As the work is done by students in the frame of their MS thesis, technical advice and review from experts is essential. Moreover, the need for a project review was not evident at first, but became clear as the technical work went on.
The ECSS document has been adapted according to the needs of an educational project. The roles of the different participants to the review and the review requirements have been adapted to the specificity of the OUFTI-1 project, whereas the fundamentals of a review have been kept the same. Documentation was written, describing these different steps.
The practical implementation of the review, including the review objectives and the review schedule are presented. The principles of the initiation of the review, the preparation of the data-packages, the review of the documentation, the preparation of the review item discrepancies (RIDs), the kick-off meeting, the coordination and collocation meetings, and the close-out meeting are described, as well as the different reports written all along the review process.
The results obtained from this review process are then described and analyzed. It starts with an analysis of the data-packages produced, and a conclusion about the RIDs emitted by the experts. The opinion of all the participants has also been analyzed, and the achievements of the objectives as well as the lessons learned are presented.
Section I briefly presents the OUFTI-1 project. Section II explains the need for a technical review. Section III describes the tailoring of the ECSS standard document. Section IV describes the practical implementation of the review process. Section V explains the results of the review process, and lessons learned from it.

I. THE OUFTI-1 PROJECT

OUFTI-1 will be the first Belgian student nanosatellite. It is currently being developed at the University of Liège, Belgium, in collaboration with two engineering schools (HEPL ISIL and HELMO Gramme) and the Université Catholique de Louvain, Belgium.

OUFTI-1 is a CubeSat: a cube-shaped satellite with a size of 10x10x10 cm and a weight of at most one kilogram. The key, innovative feature of OUFTI-1 is its main payload: the D-STAR digital-communication protocol. The D-STAR is a recently-developed amateur radio protocol which provides a lot of new built-in features including digital communication, simultaneous voice and data transmission (e.g., GPS data and computer files), complete routing over the internet and callsign-based roaming on a worldwide basis. OUFTI-1 will be the first satellite to test the use of the D-STAR communication protocol in space. Another experiment that will fly aboard OUFTI-1 is an innovative electrical power system developed in collaboration with Thales Alenia Space ETCA. OUFTI-1 will also fly new high-efficiency solar cells from AzurSpace.

Beyond these technical objectives, OUFTI-1 is definitely an educational project. It aims at providing hands-on experience to students in the design, construction, and control of a complete satellite system. The various subsystems are thus developed by students during their M.S. thesis. Students come from different engineering fields: aerospace, mechanics, computer science and electrical engineering. They are advised in their choices and tasks by an “advisory board" composed of professors and specialists from the industry. They can also take full advantage of the significant expertise and experience available in Liège in the space arena. Technical choices are supervised and kept coherent by a system engineering team composed of former students currently working at the university. The entire, highly multidisciplinary team is managed by a teaching assistant from the aerospace department. Figure 1 shows this organization.

II. NEED FOR A TECHNICAL REVIEW

The need for a review appeared as the project reached a point at which individual work was not possible anymore. Indeed, at the beginning of the project, students could work on their own to develop the principles of the subsystem they were in charge of. As OUFTI-1 was the first nanosatellite developed at the university, the need for an Interface Control Document or for interface management was not clear in the beginning of the project. Only rough technical directions were given and students developed on their own technical solutions for their subsystem. It became thus of uppermost importance to check and fix the interfaces (i.e. mechanical, electrical, thermal, and operational boundaries between subsystems). Technical solutions had also to be checked by experts and documented. The primary objective of the review is thus technical and focused on interfaces. The review was therefore called Interface Technical Review (ITR).

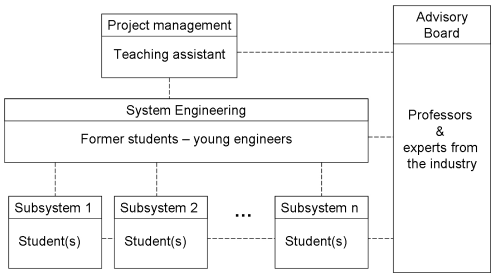

Fig. 1: organization of the OUFTI-1 team.

Beyond this technical objective, the ITR represents an amazing opportunity for education. First, students are given a chance to become familiar with a widespread process in companies and agencies. It is thus desirable that the process implemented sticks to real ones, for example in terms of procedure, players, major steps, and reports. The review also requires students to have both a sharp knowledge of their topics and a global view of the whole project. While being expert of their own subsystems, they also have to be aware of technical specificities of others. Moreover, students will get a chance to discuss their technical solutions and implementations with experts from the industry.

Last, the ITR should gather the entire team in order to strengthen team spirit and to increase communication between people from different fields.

The review has thus technical, educative, and team-oriented objectives.

III. METHOD: TAILORING OF AN ECSS STANDARD

In order to achieve technical objectives of the review while maximizing education, it was decided to consider currents standards, especially ECSS standards. ECSS, standing for European Cooperation for Space Standardization, is “an initiative established to develop a coherent, single set of user-friendly standards for use in all European space activities”. The ECSS publishes standards to be applied together for the management, engineering, and product assurance in space projects and applications. In particular, ECSS-M-ST-10-01 (Space Management – Organization and conduct of reviews [1]) is of interest in the context of the review. This standard (further referred to as: “the ECSS document”) identifies elements (basic principles, entities, and activities) to be implemented during a review process. The ECSS document was tailored to an educative CubeSat project as follows. It should be noted that the text below is structured as the ECSS considered, in order to facilitate a parallel reading.

ECSS	Project
Customer	Project manager
Supplier	Students in charge of subsystems
Consumer	(term not used)
Review authority	Professor in charge of the project
Review team	System engineering team
Review team leader	Member of the system engineering team

Table 1: Correspondence between terms defined in ECSS and roles in the OUFTI-1 project.

Terms

Most of the terms used in the ECSS are kept or slightly adapted, in particular regarding reviews entities. Table 1 shows the correspondence between terms defined in ECSS and roles in the OUFTI-1 project. Terms "Review Item Discrepancy (RID)" and "review prerequisite" are not modified.

Fundamentals of reviews

Basic principles are kept and exposed to students: technical status of the project will be examined by exterior experts (panels) on the basis of data-packages prepared by suppliers. RIDs will be emitted, discussed, and answered. The process will be implemented following well-defined steps and concluded by reports including major findings.

The main review tasks are kept and adapted as follows:

- **Initiation of the review:** The preparation phase is performed by the review team and the customer. This includes assignment of review members to the review bodies and preparation of the review procedure. An "initiation of the review" meeting is held with the entire student team ("suppliers"). The review procedure is released and explained by the customer and the review team during this meeting.
- **Preparation and distribution of the review data-package:** Each supplier has to prepare a data-package relative to the subsystem he is in charge of. Each supplier is assigned a coach from the review team in order to ensure the quality of the data-package. Distribution to the panels is operated jointly by the review team leader and the customer.
- **Review of the documentation:** Major guidelines from the ECSS are kept. Data-package is examined by the review team and by panels. Identified problems, questions and solutions arising from the examination of the documentation are recorded on review item discrepancy (RID) forms. Unlike ECSS process, the RIDs are released and answers are prepared by the suppliers before a kick-off meeting. This kick-off meeting is followed by thematic collocation meeting where RIDs and answers are discussed by the panels, suppliers, and review team. Reports are issued as suggested in the ECSS document.
- **Review findings and conclusions:** this step is implemented as suggested in the ECSS document.

Requirements

The **"Requirements"** section of the ECSS document formalizes the different elements to be implemented and the roles and objectives they must fulfil. Most of the original requirements are respected, in order to be as close as possible of the process implemented for companies' or agencies' projects.

- **"General"** and **"review bodies"** requirements are not implemented, due to the particular educative context of the project. In particular, it would be difficult to deeply involve independent entities. Exterior experts are however involved, but an entity called "panel" is created in order to lighten their task.
- **"Roles and tasks"** are kept as defined by the ECSS document. An additional entity is introduced: panels. The four panels are composed of experts (from academy or industry), divided according to the type of interface the panel will examine: electrical, mechanical, data, or thermal. Panels review the documentation (data-packages) and elaborate RIDs in collaboration with the review team. Panels also take parts in collocation meetings.
- **"Prerequisite conditions for holding a review"** are implemented as defined in the ECSS document. Prerequisite conditions are stated in the review procedure. They mainly aim at giving a sense of responsibility to students.
- The names, attendees, and objectives of the **"review meetings"** are kept as defined in the ECSS document. Their practical implementation is detailed in section IV.
- The mechanism of **"RID processing and action item follow-up"** is implemented according to the ECSS document, even if the proposed RID form is slightly customized.

Document Requirement Description

The Document Requirement Descriptions (DRD) suggested in appendices A to D of the ECSS document are implemented accordingly.

IV. PRACTICAL IMPLEMENTATION

The Interface Technical Review is implemented as follows, conforming to the tailored ECSS document. Table 2 summarizes the different steps.

The review procedure

A review procedure document [2], whose content is defined by a DRD of the ECSS document, is prepared by the review team and the customer. This procedure really constitutes a reference guide to be followed all along the review process. It defines the objectives of the review and the associated success criteria, the prerequisite conditions to hold the review, the different entities and their roles, the different steps and their schedule, and the documents to be issued.

Objectives of the review

Two main objectives are defined in accordance with the needs of the project and detailed in the review procedure:

1. To define interfaces between subsystems and functional blocks; this involves to:
   - (a) Check already defined interfaces;
   - (b) Define interfaces not yet fixed;
   - (c) Elaborate an ICD (including block-diagrams).
2. To facilitate further work and discussions by giving a technical overview of the different subsystems.

In order to assess their accomplishment at the end of the process, associated success criteria are stated:

1. For the first objective:
   - (a) Every identified interface was considered;
   - (b) A technical value was assigned to each interface

   OR a technical solution is foreseen within a fixed time limit.
2. For the second objective:
   - (a) Each participant has attended succinct presentations about every subsystem;
   - (b) Each participant is able to actively take part in technical discussions involving different subsystems.

Schedule of the review process

- Initiation of the review: The ITR was initiated during a team meeting scheduled at T=0. Customer, suppliers, and review team were present. The review procedure were released and explained.

- Preparation and distribution of the review data-packages: The different data-packages were prepared by the suppliers and released for day T+31. Each supplier was assigned a coach from the review team in order to ensure the quality of the data-package.

- Review of the documentation: Data-packages were examined by the review team and panels. Identified problems, questions and solutions arising from the examination of the documentation were recorded on review item discrepancy (RID) forms. RIDs were released for day T+43. One week was then allocated to the suppliers to read and understand the RIDs, and to prepare answers. RIDs are classified and prioritized by the review team in order to prepare the collocation meetings.

It should be pointed out that the following activities, from prerequisite key point to close-out meeting, were held during the same week-end at EuroSpace Center of Redu. This Belgian space education center hosted the entire team for three days. That permitted an intensive schedule of meetings and parallel technical discussions. Moreover, the infrastructure was well adapted for space team-building activities. This relaxing break was important between intensive meetings, and strengthens team spirit.

- Prerequisite key point and kick-off meeting: The prerequisite key point confirms that all conditions necessary to start the review are fulfilled. These conditions are defined in the review procedure and are considered as prerequisites for the go-ahead of the review as planned:

1. The review data-packages are complete;
2. The different documents of the review data-package were delivered on-time;
3. RIDs were delivered 7 days before the kick-off meeting;
4. RIDs are read and understood by the suppliers.

If the prerequisite conditions are not fulfilled, the review team leader proposes one of the following to the review authority for final decision:

1. Redefinition of the review with revised objectives;
2. Corrective actions necessary for the review to proceed;
3. Postponement of the review.

The kick-off meeting provides a presentation of the documentation submitted for review and formally authorizes the start of the review. Prerequisite key point and kick-off meeting gather the review authority, the review team, the customer, and the suppliers. They took place at EuroSpace Center of Redu, on day T+50.

- Coordination and collocation meetings
Coordination and collocation meetings were held at EuroSpace Center of Redu, at days T+51 and T+52. Four collocation meetings were held according to four types of interface: electrical, mechanical, data, and thermal. Each collocation meeting was attended by the concerned suppliers and panels and by the review team. RIDs were successively examined according to their priority. The meeting was led by a member of the review team and moderated by another. A secretary was also chosen amongst the review team. Coordination meetings were held between the customer and the review authority or review team in order to supervise the progress through the week-end.

- Review team close-out meeting
A close-out meeting was attended by all the review entities at the end of the week-end (day T+52). The review team close-out meeting synthesizes the results of the collocation meeting, provides inputs for the review team report, and agrees on major issues requiring the attention of the review authority. Each participant had the opportunity to express his feelings after the review. Participants (panels, suppliers, and review team members) were asked to fill in an opinion form.

- Issue of panels and review team reports
The panels and the review team issued a report [3] at the latest 10 weeks after the start of the review process. This report was mainly prepared by the review team leader. Its content is defined by a DRD of the ECSS document. It states RID statistics, assessment of the review, and lessons learned.

- Review authority meeting
The review authority meeting was held at the latest 11 weeks after the start of the review process. This meeting was attended by the review authority and the review team.
The review authority meeting:
(a) confirms that the review has been performed according to the approved procedure;
(b) examines the findings of the review team;
(c) endorses or amends the recommendations;
(d) makes decisions if mandated by the consumer;
(e) confirms the achievement of the review objectives;
(f) issues a review authority report [4], conforming to the DRD of ECSS document, summarizing the recommendations and decisions to the customer.

- Elaboration of an ICD
An ICD is still being elaborated on the basis of the discussions held and information gathered during the review.

Meeting or activity	Initiation of the review	Preparation of the data-package	Review of the documentation	Prerequisite key point and kick-off meeting	Coordination meetings	Collocation meetings	Review team close-out meeting	Issue of panels and review team reports	Review authority meeting
Date	T = 0	From T=0 until T+31 days	From T+31 until T+43 days	T+50 days	T+51 and T+52 days	T+51 and T+52 days	T+52 days	T+10 weeks	T+11 weeks
Entities involved	Customer, suppliers, review team	Suppliers (+ coaches)	Review team, panels	Review authority, customer, review team, suppliers	Review authority, customer, review team	Review team, panels, suppliers	Review authority, customer, review team, suppliers	Review team, panels	Review authority, customer, review team
Document released	Review procedure, by review team and customer	Review data-package, by suppliers	RIDs					Panels and review team report	Review authority report
Remark		Are relayed to panels and review team by the customer		Held at EuroSpace Center, Redu					

Table 2: Review schedule.

V. RESULTS AND ASSESSMENT

The assessment of the review is recorded in the Review Team Report [3] and the Review Authority Report [4] in accordance with the Review Procedure [2] explained in section III. These documents aim to summarize the review progress, list the issues and the major findings as well as record the recommendations and decisions. An evaluation questionnaire was also carried out for the participants. This section presents an assessment and the results of the review. First the documentation is assessed; second the results of the RIDs and the collocation meetings are presented. Third the conclusions of the questionnaires submitted to the various participants are presented. Finally the achievement of the review objectives is assessed.

Assessment of the documentation

The data-packages provided by the suppliers were the bases of the review. The data-packages were oriented towards interfaces. This documentation covered the whole OUFTI-1 system and thus provided an overview of all the interfaces between subsystems. However there were some gaps in data-packages. Indeed, technical overviews of subsystems and product trees were sometimes incomplete or not enough detailed and schematics were sometimes missing. These technical overviews were important to help the experts understand easily the OUFTI-1 system and the interfaces between subsystems. Concerning the description of the interfaces there were inconsistencies between the different data-packages regarding the type of interface (e.g. an interface listed as electrical interface in a document was listed as a data interface in another) and the nomenclature. Moreover, there were technical mistakes in the documentation.

The review team considered that the documentation was well adapted to the needs of the review. The main suggestion is to take care of the data-package by implementing a better individual coaching for the students.

Analysis of the results of the RIDs and collocation meetings

RIDs were carried out on the basis of the data-packages documentation. They permitted to list and highlight the technical issues. A RID template based on the ECSS document was suggested to panels. After the first uses a simpler and useful document in the form of an Excel file was favoured. This file used the elements from the ECSS document but was more convenient to classify and process the RIDs than the ECSS-based system.

Table 3 presents the RIDs figures after the collocation meetings. There were 145 RIDs divided into four categories by type of interface: electrical, mechanical, data and thermal interfaces. The RIDs were also classified as major, minor and cosmetic regarding their degree of criticality. A collocation meeting was held for each category of interfaces.

It can be stated from Table 3 that the time allocated for the meeting about electrical interfaces was insufficient as only 60% of the RIDs were considered, but was well estimated for the other meetings as between 79% and 100% of the RIDs were considered. However, 6 mechanical and 5 thermal RIDs were not considered because of the absence of the supplier.

For each meeting several minor and cosmetic RIDs were considered whereas some of the major RIDs issued were not. Indeed, the RIDs were processed not only regarding their degree of criticality but also by issue in order to consider all the RIDs concerning a subject at the same time and therefore to facilitate the debates (e.g. all the electrical RIDs concerning a same microprocessor were processed together).

Difficulties were met in collocation meetings because the suppliers had not enough time to process the RIDs in depth and to bring answers before these meetings. One week was allocated for this step. A longer period between RIDs issue and the collocation meetings should have been allowed.

Collocation meeting (time used - allocated)	Number of RIDs		Major RIDs		Minor RIDs		Cosmetic RIDs	
	Issued	Considered	Iss.	Cons.	Iss.	Cons.	Iss.	Cons.
Electrical (3h – 3h)	48	29 (60%)	23	15	21	13	3	1
Mechanical (1h30 – 2h)	30	24 (80%)*	15	13*	15	11*	-	-
Data (2h30 – 2h30)	43	43 (100%)	23	23	8	8	12	12
Thermal (1h30 – 1h30)	24	19 (79%)*	6	6	18	13*	-	-
Total (9h – 9h)	**145**	**115 (79%)**	**67**	**57**	**62**	**45**	**15**	**13**
** The review of RIDs not considered during collocation meeting were postponed because of a supplier absence.*								

Tab. 3 – RIDs figures

Opinion of the review participants

After the collocation meetings, questionnaires were submitted to all the participants. The topics of the questions were different for the suppliers (students), the panels and the review team, according to their role. The questionnaires consisted in rating the different review elements on a scale from 1 to 4, 1 meaning very bad and 4 meaning very good, with comments opportunity as well as to give opinions about the strengths and weaknesses of the process. This section presents the results (Table 4) and the major findings of the questionnaires.

From the students' viewpoint it was an enriching experience concerning the process and the human aspect of the review. Moreover, the review is believed to be an essential step in the project. The workload was well balanced for students but difficulties appeared in the elaboration of the data-packages because the template was not well defined. The data-package template was indeed rated 3,2/4. Regarding its contribution for the thesis, the review process would have been more beneficial if it had been sooner in the academic year. The moment was thus rated 3,1/4. The contribution of experts from the industry was appreciated as well as the team building activities that improved team spirit. The panels and the team building activities were rated 3,5/4 and 3,9/4, respectively.

	Suppliers (14)	Panels (6)	Review Team (5)	Average *
Review approach	3,9	3,9	4	3,9
Procedure	3,6	3	3,3	3,3
Workload	3,2	3,3	2,8	3,1
Data-packages template	3,2	2,7	2,7	2,9
Data-packages quality	-	3	2 ,4	2,7
RIDs	3,4	3,3	3	3,2
Panels	3,5	3,4	3,4	3,4
Week-end progress	3,7	3,6	3,7	3,7
Collocation meetings	3,4	3,8	3,2	3,5
Organisation – logistic	3,9	3,8	4	3,9
Adequacy of facilities	3,7	3,7	4	3,8
Communication	-	3,7	3,2	3,4
The moment	3,1	-	-	3,1
Team building activities	3,9	-	-	3,9
Supervision of students	3,4	-	-	3,4
Contribution for the thesis	2,9	-	-	2,9
Contribution for the project	3,9	-	-	3,9
**Based on the groups average , no coefficient concerning the number of participants is used*				

Tab. 4 – Results of the questionnaires

The panels were composed of academics and industrial specialists. According to the panels the review is an inescapable approach to achieve the project. The review approach was rated 3,9/4. The quality of the data-packages was found unequal between the different subsystems and sometimes not enough clear or complete. The template of the data-packages and their quality were rated 2,7/4 and 3/4, respectively. The collocation meetings were found well managed by the panels but there was a lack of time to prepare RIDs and discuss issues. The collocation meetings were rated 3,8/4. It could be noted that after this first review, panel members were all enthusiastic and ready to do it again. The professionalism of the process and its management was also emphasized.

The review team was composed of young engineers of the OUFTI-1 system engineering team. According to this entity, the utility of the review approach is believed to be a powerful tool for technical management. The review approach was rated 4/4. However this process requires hard work and a lot of time for preparation. The workload was rated 2,8/4. One major issue concerns the quality of the data-packages. Their template was not well-defined and the technical writing not rigorous enough. The template of the data-packages and their quality were rated 2,7/4 and 2,4/4, respectively.

The review progress and the results of the review satisfied all the participants as well as the team building activities and the appropriateness of the place for the collocation meetings.

Achievement of the review objectives

The achievement of the review objectives is assessed in accordance with procedure. The objectives were:

1. To define interfaces between subsystems and functional blocks which involves to:
    a. Check already defined interfaces;
    b. Define interfaces not yet fixed;
    c. Elaborate an Interface Control Document (including block-diagrams).
2. To facilitate further work and discussions by giving a technical overview of the different subsystems.

Concerning the first objective each subsystem issued a data-package listing all its interfaces. By the review of this documentation, the RIDs process, and the collocation meetings, already defined interfaces were checked. For the other interfaces, actions were defined and planned during the collocation meetings. Following the review process, an ICD is still being implemented. Concerning the second objective, each data-package provided a technical overview of a subsystem. Moreover, all the students performed a short presentation about their work to the entire team. Therefore, the objectives of the review were met.

Lessons learned

It was the first technical review for most participants. Thus, a lot of lessons have been learned and shall be considered for the next reviews:

- The data-packages are the basis for the success of the review. They must not be neglected and should be well prepared. In order to achieve useful documentation, its template and content must be well defined in accordance to review objectives.
- A document with a high level technical overview of the system, including functional block-diagrams, is essential to provide the panels a good overall view before the data-packages review.
- The use of an Excel file to issue and manage RIDs is lighter and more efficient than the template suggested in the ECSS document.
- A moderator is necessary during all collocation meetings as the number of participants is high. Indeed, it permits to keep discussions focused on RIDs and to avoid discussions to depart from them.
- Allowing a duration to the different collocation meetings is not easy. In our case they were well adapted excepted for the collocation meeting about electrical interfaces.
- Team spirit is essential to achieve a CubeSat project. Taking advantage of the presence of all the actors of the project to make team building activities was highly beneficial. Moreover, it is important to balance work sessions and relaxing activities.

VI. CONCLUSIONS

This paper outlined the strategy adopted to organize and conduct a technical review in the framework of an educative space project. Reviewing is a necessary process in a space project that permits to detect issues, update the technical status, and highlight the key stages to achieve the project. It can also meet educative objectives, by offering students a chance to get familiar with a process widespread in agencies and companies. In order to achieve technical objectives of the review while maximizing education, current standards were considered, especially ECSS-M-ST-10-01 (Space Management – Organization and conduct of reviews). This ECSS document was adapted to the specificities of an educative project, mainly in terms of actors involved and schedule. However, basic principles and major requirements of the ECSS document are kept; and students are considered as professionals. The tailored standard, described in section III, was implemented for the OUFTI-1 project. It led to a 2.5 months-long review process described in section IV. After a preparation phase (initiation of the review, preparation, distribution, and review of the documentation), a week-end gathered the entire team in order to discuss the RIDs emitted. This was also an occasion for team-building activities. During a last phase, review team and review authority released final reports. Major conclusions of these latter are outlined in section V, as well as an assessment of the whole process, based on RIDs statistics and an opinion poll. According to the predefined success criteria, the objectives of the review are met. The review process is considered as a success for the project. Reviewing is thus of primary importance, even in case of students' projects, and ECSS standards constitute a powerful tool to lead the review process and maximize education.

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