Revisiting Training and Verification Process Implementation for Risk Reduction on New Missions at NASA's Jet Propulsion Laboratory

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[Abstract] In 2003 we proposed an effort to develop a core program of standardized training and verification practices and standards against which the implementation of these practices could be measured. The purpose was to provide another means of risk reduction for deep space missions to preclude the likelihood of a repeat of the tragedies of the 1998 Mars missions. We identified six areas where the application of standards and standardization would benefit the overall readiness process for flight projects at JPL. These are Individual Training, Team Training, Interface and Procedure Development, Personnel Certification, Interface and procedure Verification, and Operations Readiness Testing. In this paper we will discuss the progress that has been made in the tasks of developing the proposed infrastructure in each of these areas. Specifically we will address the Position Training and Certification Standards that are now available for each operational position found on our Flight Operations Teams (FOT). We will also discuss the MGSS Baseline Flight Operations Team Training Plan which can be tailored for each new flight project at JPL. As these tasks have been progressing, the climate and emphasis for Training and for V&V at JPL has changed, and we have learned about the expansion, growth, and limitations in the roles of traditional positions at JPL such as the Project's Training Engineer, V&V Engineer, and Operations Engineer. The need to keep a tight rein on budgets has led to a merging and/or reduction in these positions which pose challenges to individual capacities and capabilities. We examine the evolution of these processes and the roles involved while taking a look at the impact or potential impact of our proposed training related infrastructure tasks. As we conclude our examination of the changes taking place for new flight projects, we see that the importance of proceeding with our proposed tasks and adapting them to the changing climate remains an important element in reducing the risk in the challenging business of space exploration.

I. Introduction

For over a decade, flight projects have changed their approaches to conducting missions as a result of cost caps and shortened schedules. Some of these changes are new approaches while many others are just scaling back of traditional approaches. The problem with scaling back an effort is that risk scales in the opposite direction. This is precisely the case with the preparations of individuals, teams, interfaces and procedures. Decreased preparation has increased the risk of error. In light of this situation, we identified the following Statement of Need:

> The Mission Management Office needs to reduce risk factors for project success associated with personnel performance, interfaces, operational processes, and system implementations.[1]

We proposed a new approach for the Mission Management Office (MMO) (now the Multi-mission Ground Systems and Services [MGSS] Office that we felt could be effective in the current climate of small, innovative, low cost space missions. Attempting to stay with JPL's traditional approach to operations training has led to two unacceptable scenarios. The first is to delay funding for project training and then expect to hire a training engineer

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who can miraculously produce a trained team with one or two operations readiness tests. The second scenario attempts to combine dissimilar functions with similar names but quite different experience and performance requirements. We believe a third scenario is available to avoid the problems which have been encountered. This third scenario is to develop a very clear and extensive infrastructure for operational preparations. We proposed to implement this third scenario by developing infrastructure to support Individual (Position) Operations Training, Operations Interface and Procedure Development, Flight Team (System) Operations Training, Personnel Certification, Interface and Procedure Verification, and Operations Readiness Testing. In the following paragraphs, we will examine how the training related segments of this effort faired by looking at the cases for the Mars Reconnaissance Orbiter (MRO) Mission, the Deep Impact Mission, and the Dawn Mission.

II. Mars Reconnaissance Orbiter

As MRO prepared to launch, the Project's training development and implementation was taking place in parallel with the MMO effort to develop standards and an infrastructure for training and verification practices. MRO utilized the initial templates for the development of the Project Training Plan and Operations Training and Certification Standard templates. This parallel effort was complicated by another factor faced by MRO and other missions. This factor is the use of a systems contractor with extensive experience in space operations and thus their own way of preparing for and conducting operations. The natural result is that frequently they work on procedures and preparation tasks independently and then present their work in an advanced state. As we might expect, they are then reluctant to change direction to accommodate standards and templates which JPL is attempting to implement. This situation evolves as a result of the lack of specification in the original proposal (written before the MMO effort was undertaken) to include the standardization effort as part of the system contractor's task description. Consequently, the MMO standardization effort was not strongly emphasized on MRO as long as the desired result was achieved - a team training plan, procedures and a means to track training and certification progress. The MRO team successfully worked through their training, procedure, and operations process development and implementation and is flying a very successful mission.

Figure 1 Celebrating a Successful Launch: Training (and V&V) Engineer, Ruth Fragoso, and Mission Operations System Engineer (MOSE) Glenn Havens give a big thumbs up as MRO climbs off the pad

Another challenge for MRO was that two functions (verification and validation (V&V) and training) were assigned to a single individual. Even with some standardized infrastructure available, the size and technical challenges of the MRO project and its associated support elements meant an overload on the one individual to successfully implement either effort. This led to an increased sharing of tasks with other FOT members to a greater level than seen in the past. As a result, "future focused" individuals were predicting that the Training Engineer would become extinct. Efforts to reduce project costs clearly influenced this thinking. In some cases, portions of traditional tasks of the Training Engineer, especially in the responsibility for planning, implementing and conducting rehearsals were being assumed by a Systems Engineer or Phase or Flight Activity Lead. Even though System Engineers and Activity Leads traditionally participated in rehearsal planning efforts they have not been responsible for the detailed execution of the rehearsals and were not truly aware of what this entailed. Further, trying this shift in responsibilities added more tasks to the full plate of the System Engineers and Activity Leads who generally lacked the training focus and experience in conducting training activities that a training engineer brings to the table.

Since the catastrophes of Mars Polar Lander and Mars Climate Orbiter, reviews at JPL have increased significantly. During many reviews the voices of the laboratory's respected senior engineering leadership ask the following questions. "Who is your training engineer? What is your training program and approach?" This persistently repeated inquiry gave rise to many Requests For Action (RFA) for Projects to ensure they have dedicated training efforts and fly in the face of those advocating the demise of the Training Engineer. These RFAs emphasize the importance that the senior engineering leadership at JPL places on the training program. The "future focused" colleagues have come to the realization that their efforts to streamline and reduce costs through the elimination of the training engineer is "not the option". The role of the training engineer is to mitigate risk by preparing a well-skilled and fully trained flight team, and the focus for cost reduction should be placed on improving the preparation and delivery of a training program through the standardization of plans and processes leading to the certification of flight team personnel. As we look at a different class of mission, we see increased progress in developing and standardizing the training infrastructure.

III. Deep Impact Mission

Deep Impact was the initial opportunity to apply the limited training infrastructure developed under the MMO to a Discovery class mission. Deep Impact launched in January 2005 on a mission to hit the comet Tempel 1 with its impactor spacecraft while taking photographs with the fly-by spacecraft. As we see in this image (Fig 2), the mission was a success.

As a Discovery Class mission, Deep Impact was a cost capped mission and resources were scarce throughout development. One of the impacts (no pun intended) was the staffing of the Training Engineer position, which began at one-quarter time in early April of 2004 in preparation for a launch in January 2005. This staffing level increased to half time in July of 2004, just six months before launch. Several factors made this staffing level a particular challenge which would not have worked without the use of training related infrastructure which, while immature,

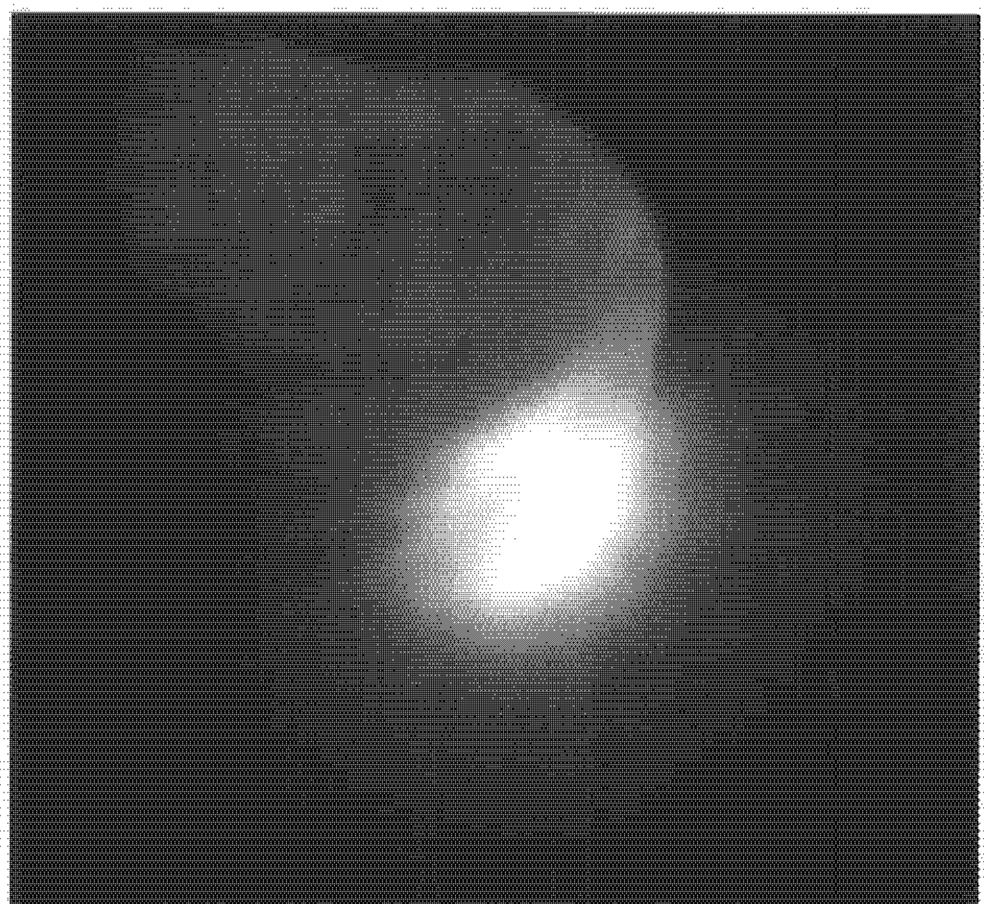

Figure 2 Deep Impact Scores a Bull's-eye: The impactor's impact with comet Tempel 1 formed a crater, with ice and dust debris ejecting from the crater. Sunlight reflecting off the ejected material provided a dramatic brightening. This brightening slowly faded as the debris dissipated into space and fell back onto the comet

had been developed. These factors included, in addition to the very short schedule, a spacecraft contractor which was new to deep space mission operations, a complicated, two part spacecraft, and a difficult mission profile which involved optical and autonomous navigation as required capabilities to ensure a successful impact.

Since development of the training plan did not have to start from scratch, it was possible to deliver a draft in less than a month and a final just three months later. This compares to the traditional timeline of a year or more between deliveries of Training Plan versions when starting from ground zero. Not only was the schedule reduced, but also the staffing was lower by 75% initially and by 50% during the final six months prior to launch. So how were these reductions absorbed without dooming the mission?

First, a systems engineering approach to training development and implementation was in place. This approach provides a structured approach to developing and implementing a training program for a flight project. We begin by identifying the requirements for training through a process that is traditionally known as a needs analysis. We examine the jobs at the individual and system level which must be performed to successfully conduct systems operations. Then we determine what training is required to ensure that individuals and teams are prepared to perform these jobs. Where necessary, we then develop training curriculum and materials to provide the necessary training. Finally, we implement the training program to prepare individuals to perform their roles in specific positions and to prepare them to perform in concert with the other members of the Flight Operations Team (FOT) as a cohesive team in accomplishing mission operations. When starting without any existing training infrastructure, this process is long and arduous and would have clearly been untenable on Deep Impact. Thus we come to our second element, which helps us shorten the process.

The instantiation of the process in institutional documentation to provide the infrastructure needed by the Training Engineer to implement the process more quickly with reduced staffing constitutes the second element. Initially, for Deep Impact, this took the form of a Training Plan template with appendices to support various aspects of the systems engineering approach to training. Development of this infrastructure is possible because many of the functions associated with deep space mission operations are the same or very similar regardless of the mission. Clearly there are differences in instruments and specific subsystems, but in general, there is significant commonality between missions in the areas of telemetry acquisition and monitoring, tracking and trajectory determination, and commanding and controlling the spacecraft and its subsystems. These three functions, telemetry, tracking, and commanding are common to every deep space mission and employ similar processes regardless of the specific mission being flown.

To address training for these three areas, the template used by Deep Impact contains several key items which were tailored by the Training Engineer to apply directly to the project. One of these is a description of the approach to operations training at both the individual level and at the system level. The focus of tailoring here was fitting the approach to the fact that the primary composition of the FOT was a systems contractor which was new to operating deep space missions. This resulted in greater emphasis on the operations processes used at JPL for conducting deep space missions than on technical training for the subsystem experts. Specifically the learning objectives for training sessions and the scenarios for rehearsals were adapted to the unique FOT makeup and the differences in processes necessitated by the unique elements of the mission such as having a two part spacecraft with each part having its own mission. These learning objectives are another key item provided in the template (as an appendix) to shorten aspects of the process relating to determining the training requirements and developing the training to be implemented. Perhaps the most important key item in streamlining the process is the Operations Position Training and Certification Standard template which is tailored for each operational position. This tailoring is a shared responsibility of the Training Engineer and each Team Lead on the project. The standard contains a comprehensive list of operational tasks associated with a specific position, the training required to enable an individual to perform those tasks, and criteria which an individual must meet to demonstrate that they are qualified to perform in the position. These are easily and quickly tailored to contain information specific to each operational position on the FOT and to the particular spacecraft and mission for which the training is being implemented. Also in the appendices is a risk matrix which is tailored for the specific mission/spacecraft and which aids in quickly determining system level training requirements. The purpose of training is to reduce the risk of personnel errors, consequently this key item is crucial to identifying the real needs for training that will contribute to achieving its purpose. A final key element available in the Deep Impact template is an outline of the steps to follow in developing and implementing rehearsals which can ensure that the rehearsal provides valuable training in a realistic operational environment. The benefit of using the outline is that all the preparatory activities can be identified for implementation in a timely manner to ensure the rehearsals are conducted without negatively impacting the project schedule.

The experience on Deep Impact demonstrated the value, in terms of saving resources, of being able to tailor the Project's Training Plan instead of trying to develop it from scratch. With the essence of an effective training program encapsulated in the Training Plan template, a starting point is provided that literally saves multiple work years of effort which were necessary for successful training programs on earlier missions (the lack of which impacted mission success as seen in the Mars missions of the 1998 era). On Deep Impact, we found that the implementation of a standard infrastructure benefited the implementation of a Discovery class project. Are there other approaches which can be taken to reduce costs and schedule? Let's look at the approach used on Dawn and how well it has worked.

IV. Dawn

The Dawn mission was started, stopped, and restarted with the result of a shortened schedule and initially reduced staffing. The increase of funding for the Training Engineer to full time approximately a year before the scheduled launch in June 2007 combined with the MGSS (formerly MMO) supplied infrastructure permitted the training program to be finalized correctly and for the Training Engineer to provide additional support to Activity Leads in developing operational products for use both in training and for flight operations.

Dawn's goal is to characterize the conditions and processes of the solar system's earliest epoch by investigating in detail two of the largest protoplanets remaining intact since their formations. Ceres and Vesta reside in the extensive zone between Mars and Jupiter together with many other smaller bodies, called the asteroid belt. Each has followed a very different evolutionary path constrained by the diversity of processes that operated during the first few million years of solar system evolution. The spacecraft uses three ion propulsion engines to thrust to its first target, Vesta, where it will enter a near polar orbit to perform a planned period of scientific observations. Orbits will be varied in order to provide optimal vantage points for a range of observation campaigns. Once objectives are complete at Vesta, the Dawn spacecraft will use its ion propulsion system to depart and travel to Ceres. Once there, Dawn will complete a similar science campaign to that completed at Vesta.

The use of ion propulsion requires that JPL's standard processes for maintaining the correct trajectory and performing maneuvers must be modified which means the development of new training material and activities for the FOT when compared to previous JPL missions. International science partners and a systems contractor with earth orbiting but not deep space mission operations experience also introduced unique challenges in developing an effective training program for Dawn. Fortunately the use of multi-mission capabilities was mandated early on by the Project, thus paving the way for the use of the MGSS Flight Team Training Plan template by the Training Engineer. As on Deep Impact, the development of the Dawn Training plan was accelerated over previous projects with a preliminary following the draft within two months and the final being delivered, reviewed, and signed less than three months after that.

Several key elements of the Training Plan were particularly useful to the Dawn FOT as they prepared for their mission to the asteroids. With an initial set of learning objectives for standard Flight Schools, it was a straight forward and quick task to develop a good set of learning objectives for the new Ion Propulsion System Flight School session. The Operations Readiness Test (ORT) Development Process template enabled the increased involvement of Activity Leads and the V&V Engineers in planning and conducting ORTs without the drawbacks experienced on MRO. Finally, the templates for Operations Training and Certification Standards expedited the development of Team Training and Certification Plans for the operations teams constituting the FOT as well as the training and certification of individual team members. As seen from the excerpts (Figs. 3,4,5) from an Operations Training and Certification Standard, the job description, training for the specific job, and the certification criteria are spelled out for a specific operations position. When tailored by the Team Lead, the Standard spells out the team's plan for training each individual and provides each individual with a record of their training progress.

By utilizing the available training infrastructure, it was possible to expedite the training development and implementation for international science team, contractor team, and JPL team members of the FOT that was consistently effective and useful across the breadth of the Dawn Project.

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Operations Training and Certification Standard for Mission Control Engineer

NAME: Larry Bryant	**PROJECT:** DAWN
TEAM: Mission Control	**TEAM CHIEF:** Ben Toyoshima
PREVIOUS PROJECT(S): DI, MGN, ODY, SDU, MO, MER	**TRAINER: Ben Toyoshima**

POSITION DESCRIPTION	
Operational Tasks	✓ **Each That Applies**
1. Communicate with other DAWN team members during operations (mission, rehearsal or test) using the VOCA and following proper voice protocol	✓
2. Provide updates for DMD window/configuration maintenance as needed for specific mission phases	✓
3. Report unexpected performance, problems, etc. using the institutional Problem Reporting System	✓
4. Initiate Red Alarm notification and/or response per Dawn operations procedure	✓
5. Record shift activities, problems, etc. in ACE operations log	✓
6. Report issues, problems, and successes during shift debriefings conducted by the Flight Director/Mission Manager	✓
7. Brief incoming ACE on current DAWN status, significant events during your shift, problems or anomalies, status of ongoing anomaly resolution, significant events scheduled in future, planned commanding, planned activities, DSN and GDS status and any issues expected to arise.	✓
8. Implement ACE actions per applicable DAWN anomaly response procedures(s) or as directed by Flight Director/Mission Manager	✓
9. Direct DSOT to establish/update data routing and broadcast channels per DAWN operations procedure to ensure best data available on primary broadcast channel	✓
10. Inform Flight Director/Mission Manager of status/progress of downlink acquisition by DSN station(s)	✓
11. Troubleshoot delays in acquisition of DAWN downlink or telemetry lock in accordance with DAWN operations procedures	✓
12. Troubleshoot loss of DAWN telemetry to the Mission Support Area in accordance with DAWN operations procedure	✓
13. Report DSN and GDS status to Flight Director/Mission Manager during polls	✓
14. Conduct pre-pass briefings for DSN Stations and DSOT in accordance with DAWN operations procedures	✓
15. Verify proper DSN Station(s) configuration for support based on voice reports and Monitor 0158 data displayed using an instance of DMD running on an AMMOS workstation	✓
16. Verify proper GDS configuration for support based on DSOT voice reports and monitoring of TDS and broadcast status.	✓
17. Serve as voice communications interface between DAWN flight team and DSMS during operations and test activities	✓
18. Transfer files from DAWN DOM to command system as directed/approved by Flight Director/Mission Manager	✓

Figure 3 Position Description

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Operations Training and Certification Standard for Mission Control Engineer

REQUIRED INITIAL TRAINING: tools, procedures, processes, ground system, flight system

General Operations (APPLICABLE EXPERIENCE MAY BE SUBSTITUTED)	✓ APPLICABLE	EXPERIENCE OR COMPLETION DATE	TRAINER INITIALS
Voice Operational Communication Assembly (VOCA)	✓	ODY, MGN	LWB
Workstation Basics	✓		
Basics of Space Flight (http://www2.jpl.nasa.gov/basics/)	✓	1994	LWB
Command Workstation (ACE) / ~~Command Vue~~	✓	04/23/07	LWB
Operations Process Flight School – Uplink Process	✓		
Reporting Problems	✓	02/07/2007	LWB
PEF Review		04/09/2007	LWB

Project Specific Courses, Lectures and Workshops	✓ APPLICABLE	COMPLETION DATE	TRAINER INITIALS
Read DAWN Mission Plan	✓		
Read (or develop) Team Procedures {Team Chief insert procedure list here} MCT command Operations, MCT Log Keeping, MCT DSN Prepass Briefing, MCT Anomaly Detection and Response, MCT Real-Time Monitoring, MCT Auto Alarm Notification (AAN) Operations, MCT Red Alarm Updates	✓	04/18/07	LWB
Profiling the Mission	✓	02/07/2007	LWB
Accumulating Science	✓	02/07/2007	LWB
Operating the Flight System	✓	02/07/2007	LWB
Launch Operations Workshop	✓	01/05/2007	LWB
Maneuver / Orbit Transfer Workshop	✓		
Cruise Check-out/Calibration Workshop	✓		
Contingency Response Workshop	✓		
Flight System & Subsystems	✓	12/12/2006	LWB
Fault Protection	✓	12/14/2006	LWB
Flight System Test Bed	✓	12/11/2006	LWB
Flight Software	✓		

Hands On: ATLO; Thread, Scenario, & EEIS Tests; and Simulations	✓ APPLICABLE	PARTICIPATION DATE	TRAINER INITIALS
E01 – Flight/Ground Compatibility			
E02 – Command and Telemetry Flow			
E03 – Science Data Flow			
E04 – Data Accountability			
E05 – Opnav and Pointing			
E06 – Time Correlation			
E07 – Table Dump and Load			
T01 – Instrument Sequence			
T02 – Alarm Limits			
T03 – Cruise Background Sequence			
T04 – Asteroid Background Sequence			
T05 – Ephemeris Table			
T06 – Ion Propulsion System Orbit Maintenance			

Figure 4 Required Initial Training

Operations Training and Certification Standard for Mission Control Engineer

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CERTIFICATION CRITERIA		
Requirements		**Verification**
Training Completed Satisfactorily or Equivalent Experience	[illegible]	
Participate in ORTs (Performance observed by Team Chief/Designee)	✓ REQUIRED	[illegible]
O01 – Launch		
O02 – Launch		
O03 – Launch		
O04 – Spacecraft Checkout		
O05 – Payload Checkout		
O06 – Ion Propulsion System Thrusting Cruise		
O07 – Ion Propulsion System Orbit Maintenance		
Correctly Demonstrate Specific Tasks (Performance observed by Team Chief/Designee):	[illegible]	[illegible]
Proper VOCA use and Voice Protocol		
Run an instance of DMD with proper windows and data source selected		
Transmit commands with command workstation		
Perform data query		
Provide sequence inputs		
Review sequence products		
Identify / characterize anomalous system performance		
Record Review by (MONTHS):	**Recommendation** Reviewer's Initials:	Approve ______ Disapprove ______
Approval		
The above named individual is certified to support **DAWN** operations. (Current Project)		
Team Chief Signature: ______________________		
Project Element Manager Concurrence: ______________________ (Signature) (if required)		

Figure 5 Certification Criteria

V. Conclusion

While progress has been made in developing a standardized infrastructure for Flight Team Training at JPL, it is clear that significant work remains to fully implement the recommendations of our initial paper. Operational Interface Agreements and Operations Procedures are being "re-used" but a structured repository of standardized templates in this area is presently being developed. Codification of the Verification and Validation process at JPL is also in work as procedures and templates are being instantiated in JPL Rules, the laboratory's repository for policies, guidelines, practices, and procedures used by the laboratory to perform its mission. Similarly, documentation to provide the training infrastructure has just been officially released in JPL Rules in the form of a procedure: Train Flight Operations Teams, Rev. 0, a guideline: Flight Team Training Development Guide, Rev. 0, and a training plan template: Flight Team Training Plan Template, Rev. 0. The fact that the reduced schedule and budget for the Dawn Mission has still resulted in an effective training program speaks to the value of this infrastructure and leads us to conclude that we are on the right path to push forward with the implementation of standards and standardization in the six areas we initially identified, but with an eye to the changing nature of Flight Projects in an increasingly fiscally restrained environment.

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