



IMPROVING MARS 2020 ROVER PLANNING

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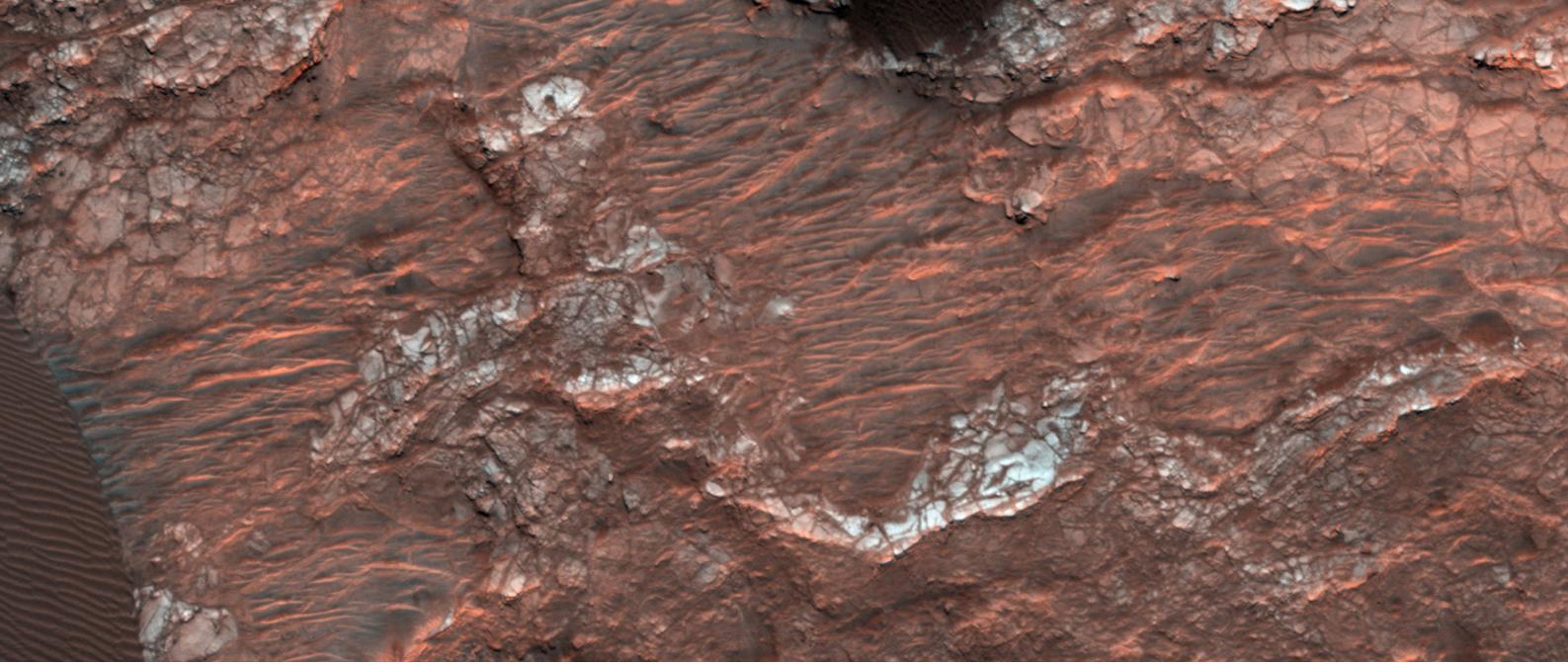
We also want to thank the MHCI+D 2018 team - Daphne, Gabriel, Will, and Victoria for their amazing work which paved the way for our research this year.

Last but not least, we want to embody NASA's culture of Heritage. We have included a detailed research plan, interview guide, and transcripts along with this report so that the team next year can learn and build upon our work.



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EXECUTIVE SUMMARY

In preparation for its upcoming launch, NASA Jet Propulsion Laboratory's Mars 2020 mission is working to reduce the amount of time spent planning rover operations in order to facilitate more time for scientific discovery. Rover planning at JPL is a complex decision-making problem, requiring consensus among various scientific and engineering domains competing for resources when choosing a course of action. This is complicated further by a fragmented tool ecosystem, geographical distribution of teams, and the fact that Mars' distance requires all activities occur asynchronously.

NASA Jet Propulsion Laboratory tasked us with finding some way of reducing deliberation time between these competing stakeholders in order to facilitate greater scientific discovery. We conducted an extensive literature review and 18 specialist interviews in order to gain a holistic understanding of Martian science and rover mission operations. We distilled this research into 8 insights to further our understanding of the problem space, direct us towards appropriate design opportunities, and inform our design requirements. With these insights in mind, we saw an opportunity to help scientists better understand and predict the impact of atmospheric opacity on rover instrumentation and data. We hope to increase data transparency and shift a traditionally tactical planning effort toward the campaign level. This will reduce the time needed for scientists to decide on a course of action and make more efficient use of the rover's limited resources.



INTRODUCTION

NASA Jet Propulsion Lab (JPL) is preparing for its upcoming mission, Mars 2020. This mission is the next stage in NASA's long-term effort of robotic exploration on Mars with multiple scientific goals, including searching for previous signs of life on Mars, characterizing the planet's climate and geology, and preparing for potential human exploration [1].

An accurate understanding of weather on Mars is critical to the success of the mission since there are several cases where conditions on Mars dictate where and how science experiments are conducted. For example, dust levels can dictate camera operability, temperature can affect rover power, the sun's position can affect the timing and feasibility of operations [2].

The Mars 2020 rover will run on nuclear power and as a result, it will have a longer operation time. NASA's internal policy dictates an equal amount of time planning and operating the Mars 2020 rover. This means that planning teams need to meet a daily 5-hour planning window, requiring quickly accessible data and an efficient decision-making process [3]. Seamless collaboration among the science, engineering, and instrument teams is crucial in order to meet this timeline.

Mission planning is dependant on geographically distributed teams comprised of individuals with varying skill sets and knowledge backgrounds. These teams rely on ad-hoc meetings, PowerPoints, and a company-wide wiki for communication. On previous NASA missions, breakdowns in communication have caused costly delays, wasted resources, and even irreparable damage to instrumentation [4]. Due to this lack of tool cohesion and improper documentation, the science intent often gets lost in the process further exacerbating collaboration efforts.



Over 10 weeks, our team conducted extensive secondary and primary research into various topics regarding the Mars 2020 operations. This includes Martian weather, scientific intent, team collaboration, and data visualization. Based on learnings from secondary research, we chose semi-structured interviews, directed storytelling, and iterative diagramming as 3 main methods for our research activity. We selected JPL scientists, engineers, and data visualization experts as the research population. A tailored guide was created for each interview participant based on their background, experience, and involvement with past and current Mars missions. We then used coding as a primary framework to synthesize insights and arrive at design requirements.

From our research, we identified 3 potential directions:

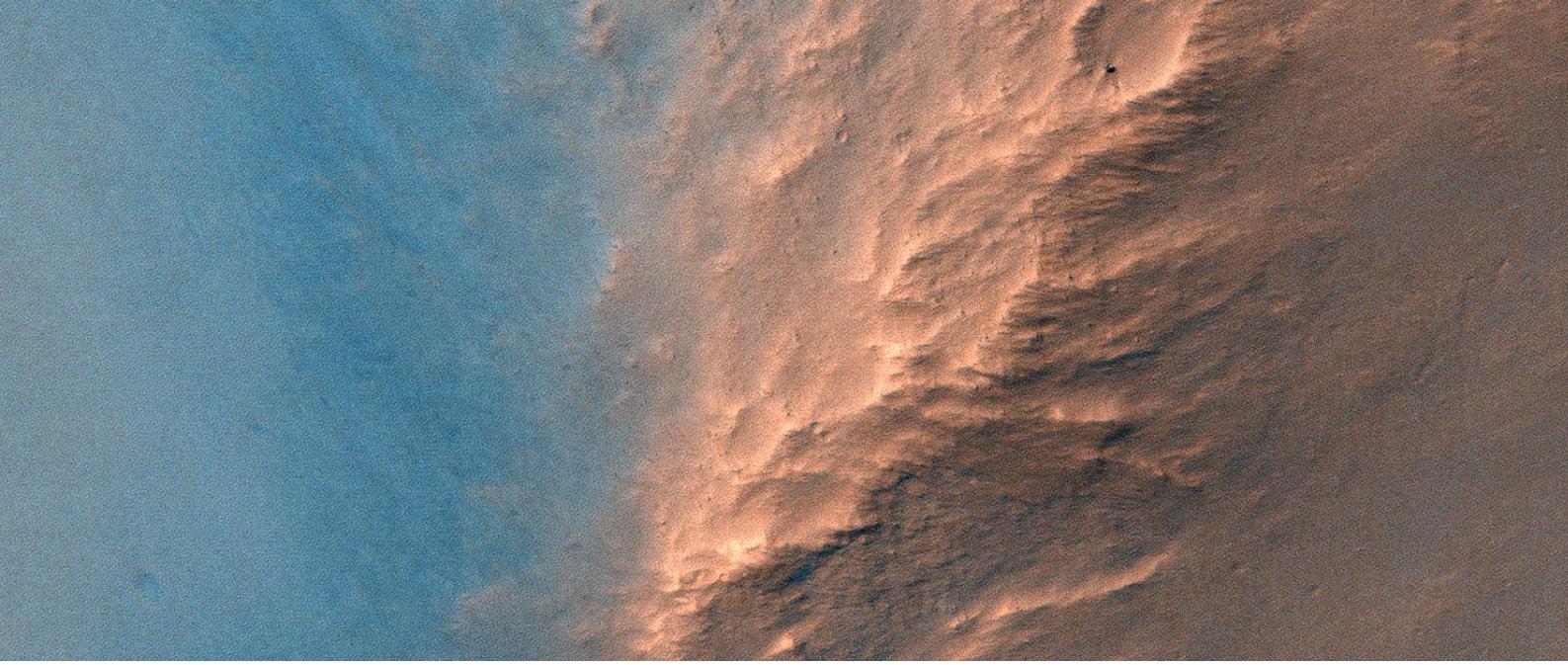
1. Helping scientists understand the effects of tau on instrumentation and data.
2. Preserving science intent to aid collaboration and decision making among operation teams.
3. Visualizing weather on Mars to provide scientists with data context with respect to the terrain.

We decided to move forward with direction #1 as it is well-scoped and aligned the most with our insights and design requirements.

There are 3 limitations to our research process: time, mission confidentiality, and location. Since NASA has a complex organizational structure, it is difficult to get a comprehensive picture of team collaboration and dynamics within 10 weeks. Second, the Mars 2020 mission is still evolving; information regarding operations and planning have not yet been finalized and can only be shared among internal employees. Third, our team conducted research remotely. This set a constraint in the type of method that could be used; ethnographic methods such as contextual inquiry or observational method which would have been a strong learning resource weren't a viable option.

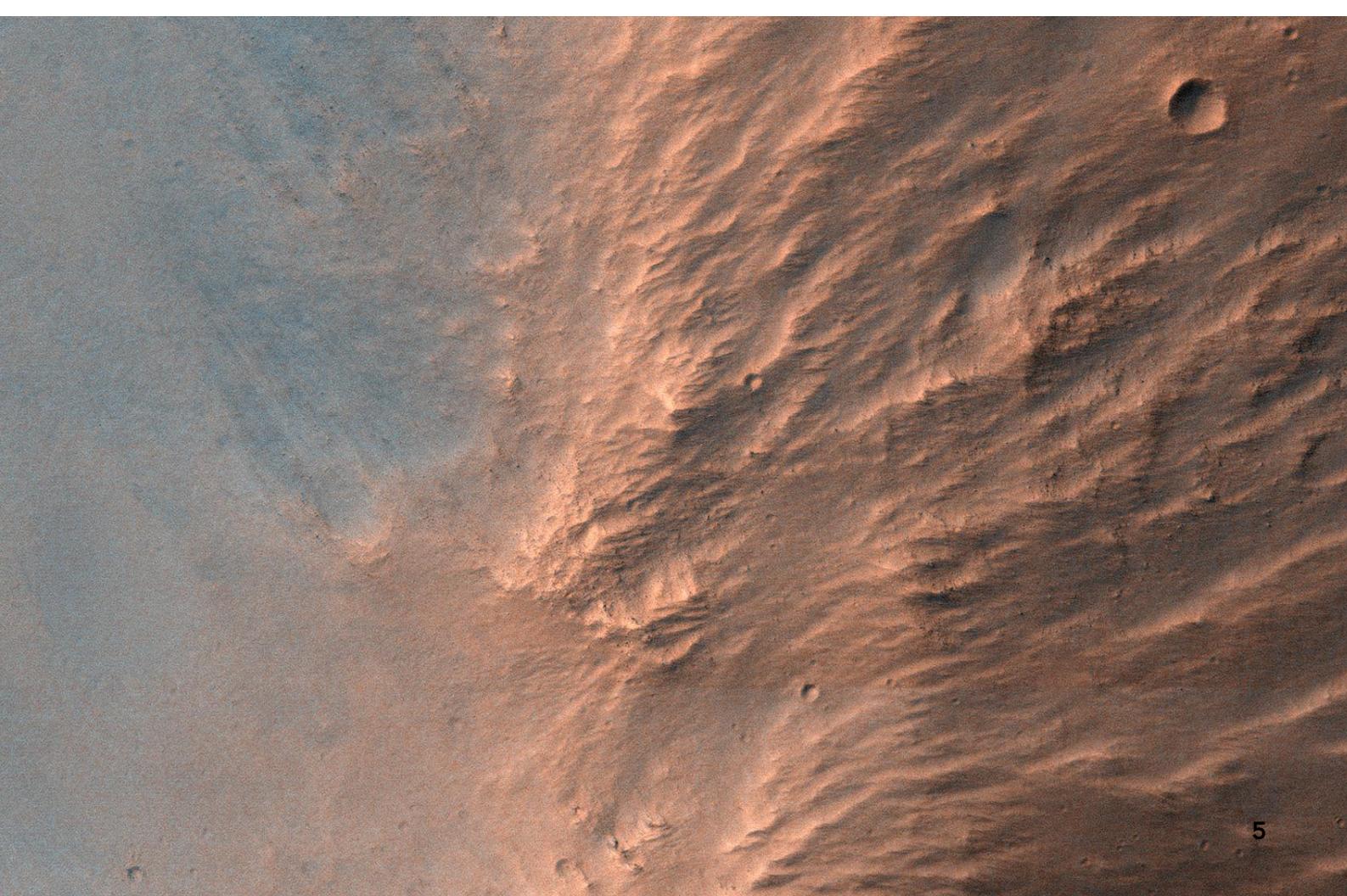
CHALLENGE STATEMENT

How might we help scientists understand and predict the effects of tau on instrumentation and data?



01

B a c k g r o u n d





LITERATURE REVIEW

Past Missions

NASA's Mars Exploration Program (MEP) was designed to study Mars as a planetary system using a variety of landers, rovers, and orbiters. Each mission builds upon previous research and innovations to continue to push to new discoveries. The goal of the program is to understand the geological and atmospheric processes on Mars, to study the planet's potential to sustain life, and to gather information that might help plan possible future human exploration on Mars. The original theme of Mars exploration was to "Follow the Water" as water is an indication of an environment that can support life. When past missions found evidence that water used to exist on the Martian surface, the Mars exploration theme evolved to "Explore Habitability," with the purpose of seeking additional chemical elements that were necessary for life [5]. Finally, with findings from the Curiosity rover, MEP marked a transition to the upcoming Mars 2020 mission, shifting the theme to "Seek Signs of Life".

Mars 2020

With findings from Curiosity rover, MEP marked a transition to the upcoming Mars 2020 mission, shifting the theme to "Seek Signs of Life". The Mars 2020 program has 4 long-term science goals.

- 1** Determine whether life ever existed on Mars
The rover will conduct studies on the Martian surface and seek biosignatures from rock samples.
- 2** Characterize the climate of Mars
The rover will look for evidence of ancient habitable environments where microbial life could have existed in the past.
- 3** Characterize the geology of Mars
Each layer of rock provides information about past Martian environmental conditions, revealing the history of how Mars' crust and surface evolved through time. The study could be further extrapolated to uncover the history of Earth itself. Current and future rovers will cache geological samples to be studied in the future.

4 Prepare for Human Exploration

The rover is demonstrating key technologies for using natural resources in the Martian environment for life support and fuel. It is also monitoring environmental conditions so mission planners get a better understanding of how to protect future human explorers.

Relevant instruments and spacecraft

The Mars Environmental Dynamic Analyzer (MEDA) is the instrument attached to the Mars 2020 rover that will help scientists gather information about weather on Mars. MEDA measures a wide range of variables such as temperature, wind speed and direction, humidity, and the size of dust particles in the Martian atmosphere [6].

Mars Reconnaissance Orbiter (MRO) is a spacecraft orbiting Mars since 2006 [7]. The mission goal is to study the Martian atmosphere and terrain, including the history of water flows on or near the planet's surface. It also serves as a key data relay station for other Mars missions. On May 15, 2019, it completed 60,000 orbits around Mars [7].

Mars Atmosphere and Volatile Evolution (MAVEN) is a satellite developed to study the Martian atmosphere and its composition. It has recently provided significant data around the loss of water and atmosphere on Mars and the role solar storms play [8].

Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight)

is a Mars lander that aims to study the "inner-space" of Mars: its crust, mantle, and core. It seeks to uncover how Mars was formed and evolve over time along with determining the tectonic activity on the red planet [9].

Weather variables and implications

Atmospheric Opacity

Similar to the effect of water on Earth, dust dominates the surface of Mars and dictates most of its atmospheric conditions. Dust storms significantly reduce power on solar-dependent rovers, due to obscurement and settling of dust on the rover's arrays [10]. This obscurement risk has been somewhat mitigated in the Mars 2020 mission through the use of a nuclear power core, but meteorological data still holds significant mission planning repercussions. For example, the amount of dust particles in the atmosphere affects the optical opacity measurement (τ) which dictates camera operability, exposure times, and image quality [11]. Depending on the visibility, rover planners may also delay science activities that depend on external camera data [12]. Similarly, dust storms could damage delicate instruments and rover planners would need to know when to retract them in order to increase their longevity [13].

* (τ) - Tau, a measure of optical depth, or how much sunlight cannot penetrate the atmosphere. In the Martian context, it directly relates to how much dust present in the atmosphere

Temperature

Temperature is critical to rover operations, especially for Mars 2020 since the rover is running on nuclear power. Temperature profile includes near-surface air temperature and ground temperature. Near-surface air temperature affects rover powers as it influences how much heat is needed to warm up rover instruments. The rover also radiates heat which affects the surrounding soil temperature [14]. Understanding ground temperature, in this case, helps the operation team separate natural temperature effects from artificial ones to account for data error and uncertainty.

Wind

Wind can raise dust from the surface into the atmosphere, absorbing solar radiation and acting as an internal heat source. Near-surface wind speed and wind direction can have a direct influence on dust behavior and the formation of dust devils [15].

Atmospheric pressure

Atmospheric pressure and thermally driven tides are factors contributing to dust storm creation [16]. Understanding the effects of pressure and thermal tides can help scientists study and predict dust storm formation and behavior.

Relative humidity

Understanding water is critical for future human missions since it is a prerequisite for Earth-type life. Hence the study of relative humidity and its water vapor content is a paramount of scientific interests as it helps scientists identify the presence and behavior of water on Mars [17].

Radiation

Radiation from space and the sun can alter traces on Martian rocks which inhibits scientists from learning about the history of Mars. Measuring radiation will also help scientists measure habitable conditions and prepare for future human missions [18].

Seasonal and Interannual variability

All weather variable characteristics and patterns vary significantly depending on the time of the year. Studying how each variable behaves differently allows the operation teams to plan rover operations and scientific experiments at both short-term and long-term planning. For example, regional dust devils happen more frequently during the summer months [19]. Understanding this cycle helps the engineering team identify good windows for the rover's dust-cleaning schedule [20].

Remote Collaboration

Approximately 3 months from the date of the mission's launch, the team begins transitioning to operate via a distributed operations network, centralized at JPL. This enables the remote science teams to work remotely for the duration of the mission. The teams communicate with one another through telecommunication and video-conferencing software. This method of communication and collaborative work presents a set of complications may impact productivity. Research has found that videoconferenced discussions tend to be less social and more task-oriented than face-to-face discussions [21]. As a result, these meetings tend to be less efficient than face-to-face ones [22].

Remote collaboration is made more challenging when the collaboration occurs asynchronously. Research in the area of asynchronous collaboration has reported the success of view sharing, discussion, graphical annotation, and social navigation in addressing the challenges of asynchronous collaboration [23].

Decision-making process at high stake environment

In high-stakes domains, different roles and responsibilities must often work together to make decisions while geographically dispersed. While shared mental and situation awareness models are likely to be largely similar across an organization, some differences will persist as a result of distance, misaligned goals, and analytical methods. When these sense-making frameworks break, they present a risk to team cohesion and, ultimately, the project itself [4].



A mental model is defined as an internal representation of objects, actions, situations, or people [24]. They include knowledge of a system and of the relationships contained within them, supplying a "mechanism whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states" [25]. Many studies have found that the greater the degree of overlap between the team members' mental models, the better that team performs [26], particularly if those shared mental models are accurate [27]. As such, an up-to-date and accurate mental model is imperative to effective decision-making processes in a high-stakes environment.

Team situation awareness is a shared understanding across the team of what is happening and what is going to happen due to well-defined campaign level goals. This allows a predictable process to occur in both nominal and abnormal events. When team situation awareness breaks down, predictability suffers, and communication becomes more difficult, if not impossible [4].

Closed-Loop communication is employed to prevent these breakdowns through stating the current action to reinforce trust between team members and providing a check on assumptions. This involves three steps: (1) A sender transmits, (2) A receiver accepts and acknowledges receipt, and (3) The original sender acknowledges the receipt message. This simple method is extremely effective by making what is usually implied overt - leaving no room for assumption [28].

When breakdowns do occur, decision-makers employ recovery functions. These are ways of repairing a broken line of communication in the decision-making process [29]. One such method is the incident report which is used to assess breakdowns through open lines of communications and classification so that an organization may learn from and prevent future errors [30].

Despite safeguards and constructs meant to prevent breakdowns of decision-making capabilities, breakdowns will inevitably still occur in high-stakes distributed systems. Research suggests that informational (lack of information) and evaluative (a misunderstanding of information) disconnects lead to mental model and team situation awareness degradation, which in turn causes operational (difference in expected and actual actions) disconnects. Utilizing this model, they suggest that by focusing on the former, you can prevent the latter from occurring [4]. These studies highlight the importance of ensuring all information is uniformly shared and understood in a decision-making process.

Visualizing Scientific Data

Web-based data visualization tools have become more accessible, sophisticated, and interactive due to the profusion of open source software and tool kits. While the commercial industry has adopted multiple applications of data visualization, the scientific domain still faces a wide range of challenges due to the inability to accommodate the specific nature of scientists' needs. There are many factors that contribute to this problem but two critical ones of note are: the method of data collection and the scale of scientific data [31].

Collecting scientific data is difficult and instrument-specific. Depending on the source, each data variable comes in with a specific measurement, accuracy, or resolution [32]. Even though scientists have a good understanding of their own data and have means to make sense of raw data, getting the same intuitions from data across multiple instruments or from an unfamiliar research



area is difficult [31]. The second challenge is data scalability; scientific research requires a continuous influx of better data at a growing scale. Without live linking and quick data integration within internal tools, data visualization becomes its separate entity. As new data accumulates, the visualization quickly becomes outdated; it no longer reflects new findings and patterns [31].

Additionally, major scientific problems nowadays rely on the interdependence and integration of data from multiple sources and instruments. The role of visualization for complex data needs to evolve beyond aesthetic representation. It has to support scientists in forming hypothesis and exploring alternatives throughout the research life cycle [31].

Jim Gray described his vision of data-intensive science and called for a generic set of tools that could accommodate scientists through 3 main activities: data capture, curation, and analysis [33]. First, data needs to be holistically captured both at the mega-scale and a milli-scale [32]. Curation starts with identifying the right data structures to map into various stores. It must include the schema and the necessary metadata in order to integrate across instruments and make data interpretation become explicit [32]. Data analysis includes a set of activities such as workflow pipeline, the use of databases, analysis and modeling, and then visualization.



JPL STRUCTURE

Science Team Roles [34]

SOWG Chair: Leads the science team in tactical meetings and helps them reach a consensus for daily planning.

Science Uplink Representative (SUR): Represents science during the uplink process and documents any changes to the science plan.

SOWG Documentarian: Documents the science intent behind activities and any scientific breakthroughs.

Long Term Planner (LTP): Presents material that summarizes current rover activities and ensures the tactical plan is in line with the campaign goals.

Science Theme Lead (STL): Represents a specific science theme group (STG) during meetings and advocates for their desired observations.

Science Theme Group (STG) Member: Analyzes instrument data, develops and tests hypotheses.

Payload Downlink Lead (PDL) - Instrument Specific: Verifies and monitors the health and status of the received instrument data.

Payload Uplink Lead (PUL) - Instrument Specific: Creates instrument sequences and assess the compatibility of uplink commands with operational constraints.

Science Team Meetings (Tactical)

Science Kickoff Meeting: Scientists come together to review the data from the previous day and determine their highest priority science observations for the day.

Science & Engineering Tag-Up: Engineers and scientists meet so that engineers can inform scientists of any restrictions that they need to be aware of for that particular day.

Science Operations Working Group (SOWG) Meeting: This is the main tactical meeting where scientists and engineers have their discussions about the next day's targets.

Science Team Meetings (Campaign)

Principal Investigator (PI) Team Meeting:
Instrument team meeting to discuss
strategies for operations, scientific
hypotheses, and findings.

Science Discussion Meeting: Science team
members present science results, discuss
working hypotheses, and campaign plans.

Project Science Group Meeting: Scientists
discuss campaign issues, staffing and
scheduling of roles.

MSL Science Team Meeting: Happens
approximately once every 6 months to
discuss status, results, and strategies of the
mission.

for the following day. Campaign planning
refers to activities that focus on developing
long-term plans spanning weeks or months to
achieve the mission's high-level objectives.
The supratactactical stage provides a bridge
between the long-term plan and the day-to-
day processes [34].

A typical day's tactical meeting is 8 hours
long and begins with a limited "uplink"
window in which the team sends new
commands to the rover. Throughout the day,
there are periods of "downlink" where the
teams receive data back from the rover; for
example, this can include measurements from
instruments or pictures that the rover has
captured. Teams of scientists, rover planners,
and engineers work together to make sense
of this data and decide on the next course of
action which will achieve scientific goals
while still maintaining the rover's safety.
Coming to a consensus about the next day's
activities is a difficult process because
various science teams must advocate for
their plans. Additionally, scientists sometimes
need to convince the engineering teams to
implement specific plans that could put the
rover at risk of lower power or instrument
damage.

Workflow/Meeting Challenges

One of the challenges of the Mars
Exploration Laboratory missions compared to
other NASA missions, is the degree to which
operations are impacted by the ever
changing environmental variables. The
operations teams can use previously
captured orbital images to guide future
activities, but these images don't capture all
the information needed to decide what the
rover's next target will be. As a result,
planning happens daily based on the
comprehensive data which is only available
after the rover sends back the prior day's
activities. Teams need to be reactive and
responsive to this data in order to quickly
develop the next day's plan which also aligns
to the mission's long-term science goals [34].

NASA has introduced three categories of
mission planning: tactical, supratactical and
campaign. Tactical refers to the short-term,
daily planning activities which include
analyzing the most recent data, coming to a
consensus about the next desired science
observations, and generating new commands

Science Intent

Science intent is the context around how a
given activity fits into the larger picture of
the mission. This context is used to
determine a tactical list of goals, as well as
prioritization of the overall task, given its
relative importance [35]. Clear
communication of scientific intent is a critical
step in planning both scientific and
engineering activities during planning
meetings. Engineering needs this information
in order to plan activities on a cadence so as
not to inadvertently interfere with the
scientific activities by calibrating instruments
during a longitudinal study [36]. Historical
knowledge of intent can be a useful tool in
streamlining goal generation and
prioritization. It prevents duplicative work



over time as previous discussions may be applicable to past debates [35].

Proper communication of scientific intent during rover operations is a subject of hot debate, but some common practices have emerged throughout the years. Generalists aggregate information and distill it to be understandable across the organization. This communication is largely done via annotated PowerPoint decks, which act as one of the few widely used tools across the organization [37].

This method works well in terms of communicating current intent, but breaks down when there is a need to access historical intent. The information is not easily searchable or accessible after its initial dissemination, so if a scientist needed to reference previous discussions around the scientific intent of an activity, she would have to sift through hundreds of PowerPoint decks [36].

necessary capabilities to ensure effective communication. PowerPoint doesn't help preserve the context of the conversation. Science intent, critical discussions, detailed clarifications, and situational nuances tend to get lost in the process.

MSLICE

The Mars Science Laboratory InterfaCE (MSLICE) is a planning tool that helps scientists and engineers prepare for rover activities on a daily basis. It models the energy and time of all the instruments and intended activities on the rover's traverse in order to optimize scientific data and ensure rover safety.

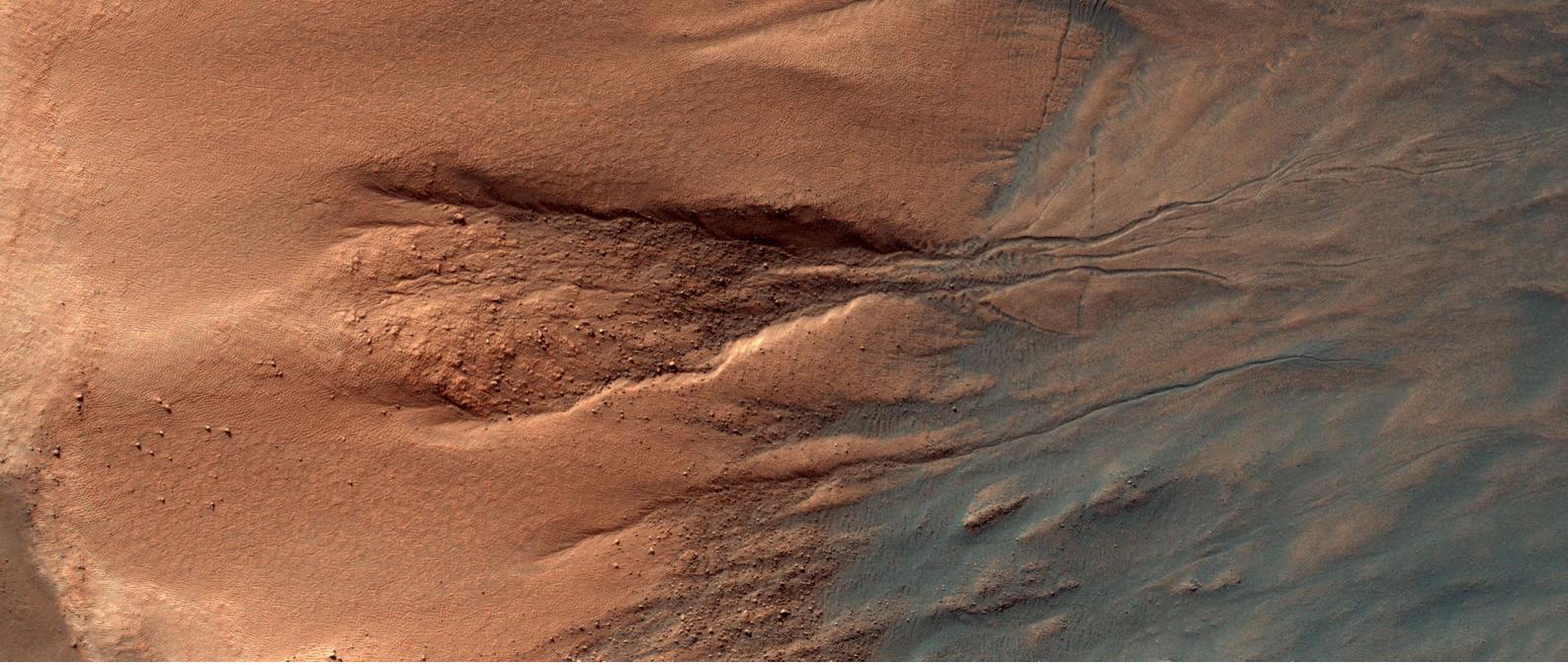
Internal Tools

ASTTRO

The Advanced Science Targeting Tool for Robotic Operations (ASTTRO) is used by rover planners and scientists for selecting rover targets. The tool reconstructs the Martian terrain from images taken by the rover as scene visualization for situational awareness. The operation teams can tag target coordinates, scientist, and specific instrument, etc. as metadata. However, the tool currently only has limited information regarding the sun and doesn't include weather information.

PowerPoint

The science team uses Microsoft PowerPoint as the main tool to communicate scientific findings and proposals during meetings and planning discussions. While PowerPoint is a commonly acceptable tool with an easy learning curve, it doesn't provide all



COMPETITIVE ANALYSIS

The competitive analysis helped our team explore existing tools in various domains, assess their pros and cons, and draw insights on how we might utilize existing features for our own design. We approached the competitive analysis with the intention to assess a variety of tools related to collaboration, communication, mapping, and data visualization. The analysis included translational products to better understand how other fields approach solving issues related to collaboration in time-pressing situations.

Based on our research, we identified five important criteria to measure the tools against: transparency, customization, shareability, comparability, and annotation. For each criteria, there was at least one tool that did a great job at mastering the interaction design. This could potentially serve as reference point for our team when we move into the ideation process.

A more detailed version of our competitive analysis can be found in the Appendices.



Mapping Tools



JMARS



Access Mars

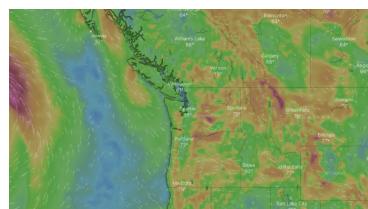


Google Earth Pro

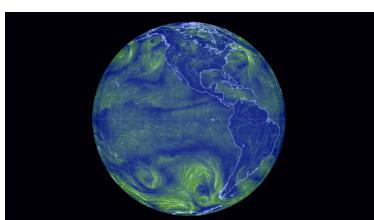
Weather Tools



NOAA Weather and Climate Toolkit
(WCT)



Windy



NullSchool

Data Visualization Tools



Tableau

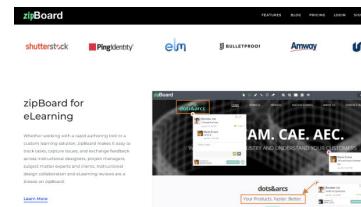


The Pudding

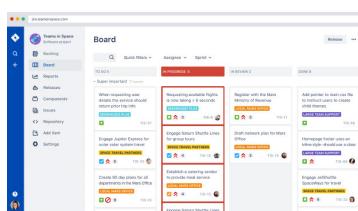
Collaboration Tools



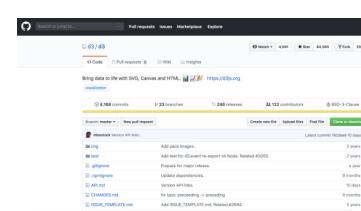
Slack



zipBoard



Jira



GitHub



Translational Tools



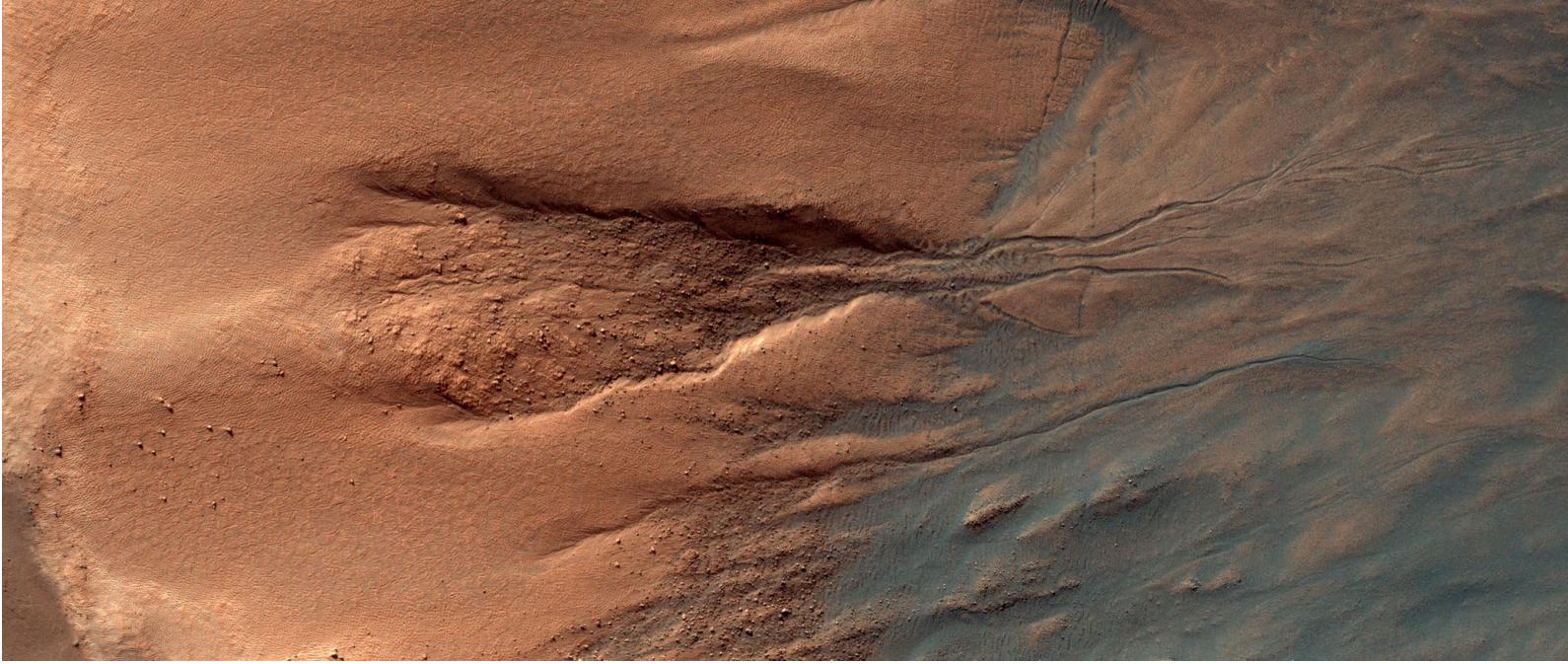
War Room



No Man's Sky



Bartending



Key Findings

01 **Provide Collaborative Experiences:** Users should be able to have shared experiences when collaborating. A way to enhance collaboration is allowing users the ability to share their work with each other. Most JPL scientists use web-based tools when processing and analyzing weather data.

02 **Add context to data when possible:** Metadata plays an important role in providing additional contexts to data. A data point should have relevant metadata, tags, comments, and annotations so that users can interpret the dataset with a common ground. It could be enhanced if users can interact with the visualization, hovering over a data point to view more information.

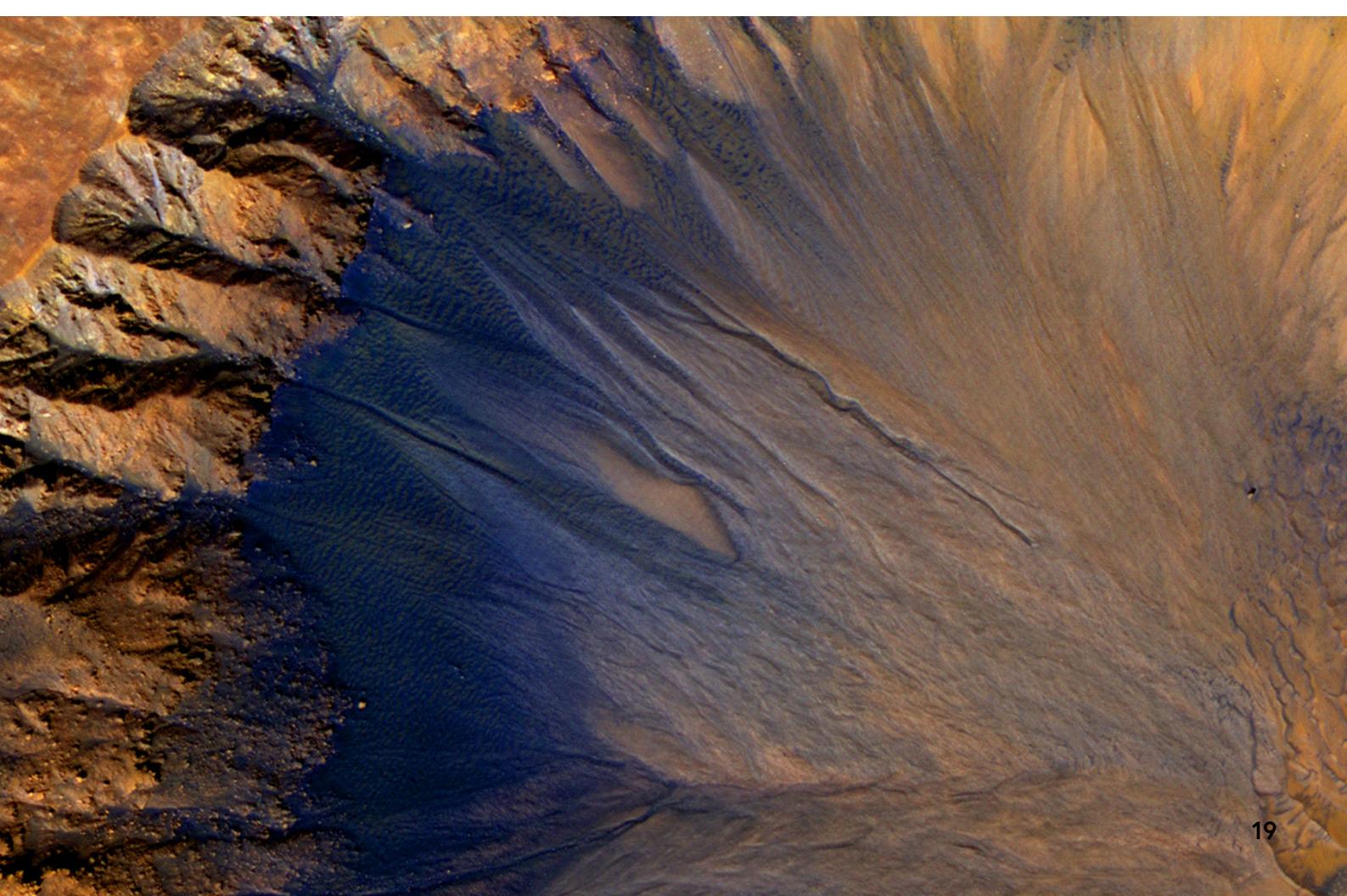
03 **Trace back to raw data:** When conducting data analysis or exploring a dataset, scientists prefer to have access to the raw data so that they can conduct a variety of analysis and manipulate different visual presentations.

04 **Enhance customization:** Customization can add significant values when analyzing data. Each user has a different need and a preferred method for exploring and manipulating dataset. This also extends to having the capability to adjust the tool bars, layout, customize the codes to accommodate personal needs.



02

R e s e a r c h





GUIDING QUESTIONS

What is the typical workflow for rover mission planning and what collaborative and operational challenges do they face?

Rover operations require collaboration between rover planners, scientists, engineers and other stakeholders. Understanding their typical workflow will help us uncover any flaws which could lead to a disconnect in their mental models regarding weather.

What tools and technology does the mission operation team currently use, or plan to use, to collaborate and assess weather information for mission planning?

Decomposing the tools that are currently being used for mission planning, with a focus on the ones that involve weather analysis, will help us uncover any limitations with the current technology which could act as opportunities during our design process.

What weather information does the mission operation team need to know and how do they use this information in making time-sensitive decisions?

There are a number of different weather variables that have varying levels of impact on short-term and long-term mission planning operations. We hope to understand what weather variables the mission operations team prioritizes, how often they examine them and how they interpret them to make decisions.



PARTICIPANTS

01 Weather Experts

We needed to interview Martian weather experts in order to better understand the domain and the needs of the field. We also were interested in the types of weather events they were interested in, and the tools they use to analyze and share data.

02 Rover Mission Personnel

We were interested in speaking to rover mission personnel such as engineers, drivers or planners to gain a full picture of the collaboration and workflow involved in a high stakes environment.

03 Data Visualization Experts

Data visualization experts provided us with information on best practices for communicating data to others.



METHODS

01 Semi-Structured Interviews

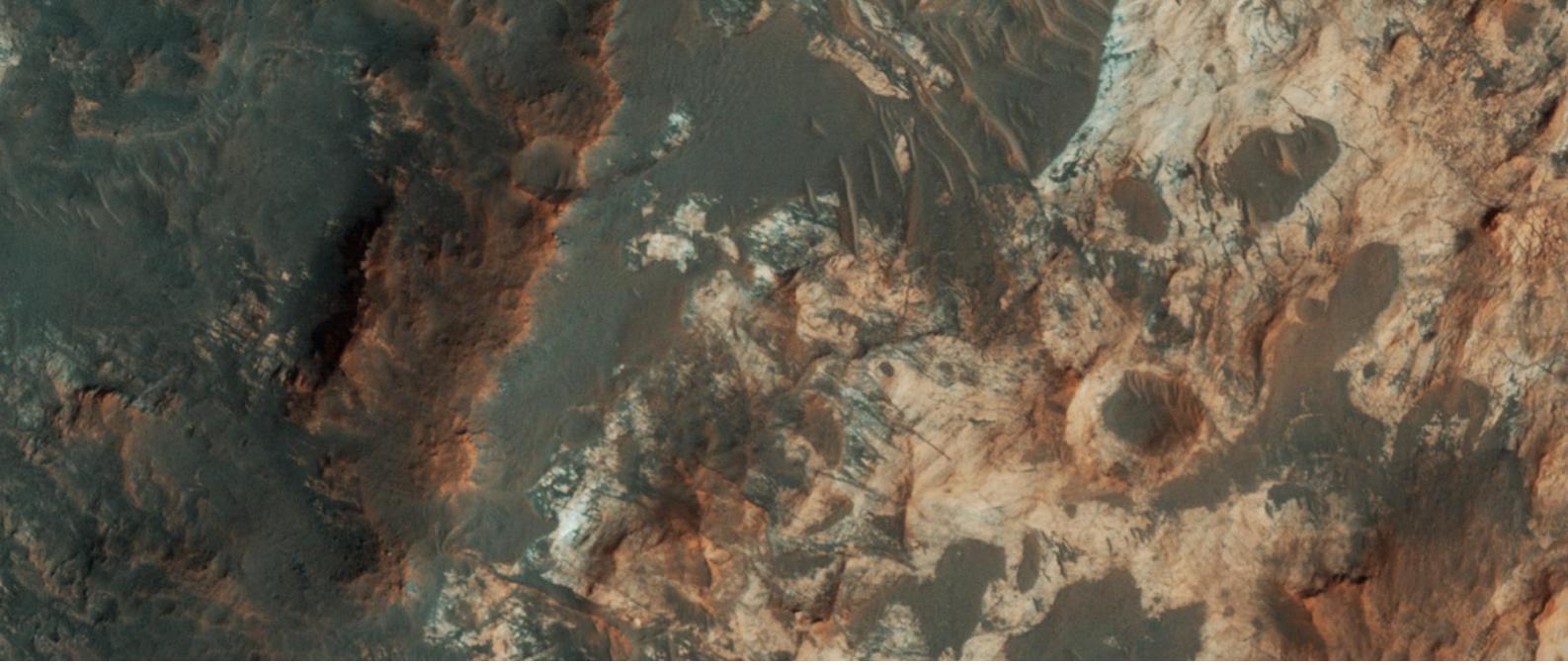
For each of our participants and experts, we created a list of questions that were tailored to each individual to guide our interviews. Their responses to the prepared questions led to new questions and dictated the direction of the conversation. This method opened up a window into our participants' mental models and decision making processes.

02 Directed Storytelling

Participants were asked to talk about a past experience in detail. The questions were centered around events that sparked fear and/or required highly collaborative work. We aimed to understand our participant's perspectives during these experiences and better understand communication breakdowns, motivations, and actions taken.

03 Iterative Diagramming

In order to better understand the needs of scientists and engineers during the rover planning process, we needed to be able to conceptualize the structure of these planning meetings. We constructed a diagram based on information we gather from the literature. Participants were shown our sample diagram and were given time to offer changes or corrections.



03

R e s u l t s





INSIGHTS

01

Meeting the proposed 5-hour operational timeline is unattainable unless rover teams shift focus to long-term goals.

02

Weather no longer poses a critical risk to rover safety, but still must be considered due to its impact on instruments and power constraints.

03

Weather on Mars is relatively predictable, however, there is no weather forecasting despite its potential applications to long-term planning purposes.

04

Unavailable atmospheric opacity (τ) measurements in internal tools negatively impacts operational efficiency.

05

Despite tactical disagreements and the varying cultures, rover safety takes precedence because without a rover, there is no scientific discovery.

06

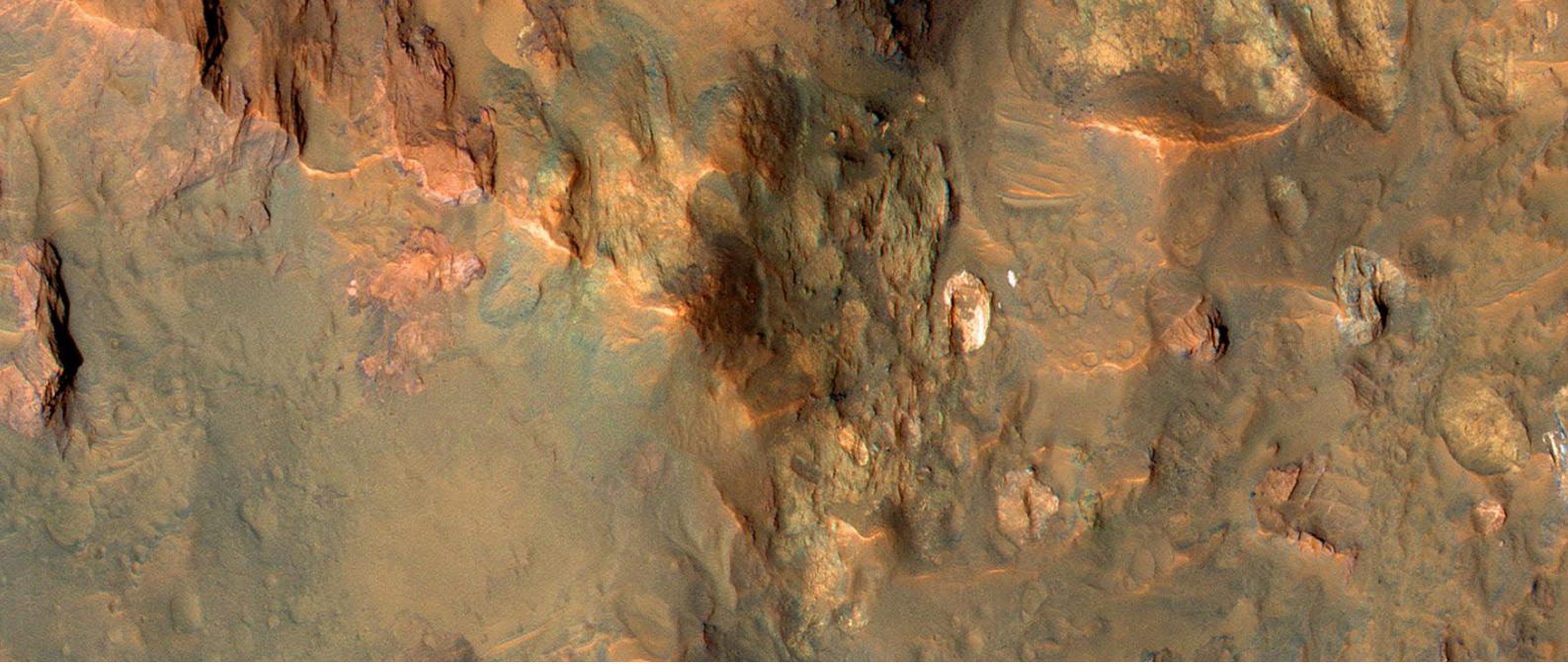
In the conflict between mission groups, the only shared language is data. Even then, every specialty has its own dialect, leading to misunderstandings.

07

Data is more revealing when contextualized with other observations. Existing tools do not have this capability, hindering scientific discovery.

08

The use of numerous custom-built tools is "both a feature and a bug"; it makes output inconsistent, but leads to advancement through productive scientific discussions.



01

Meeting the proposed 5-hour operational timeline is unattainable unless rover teams shift focus to long-term goals.

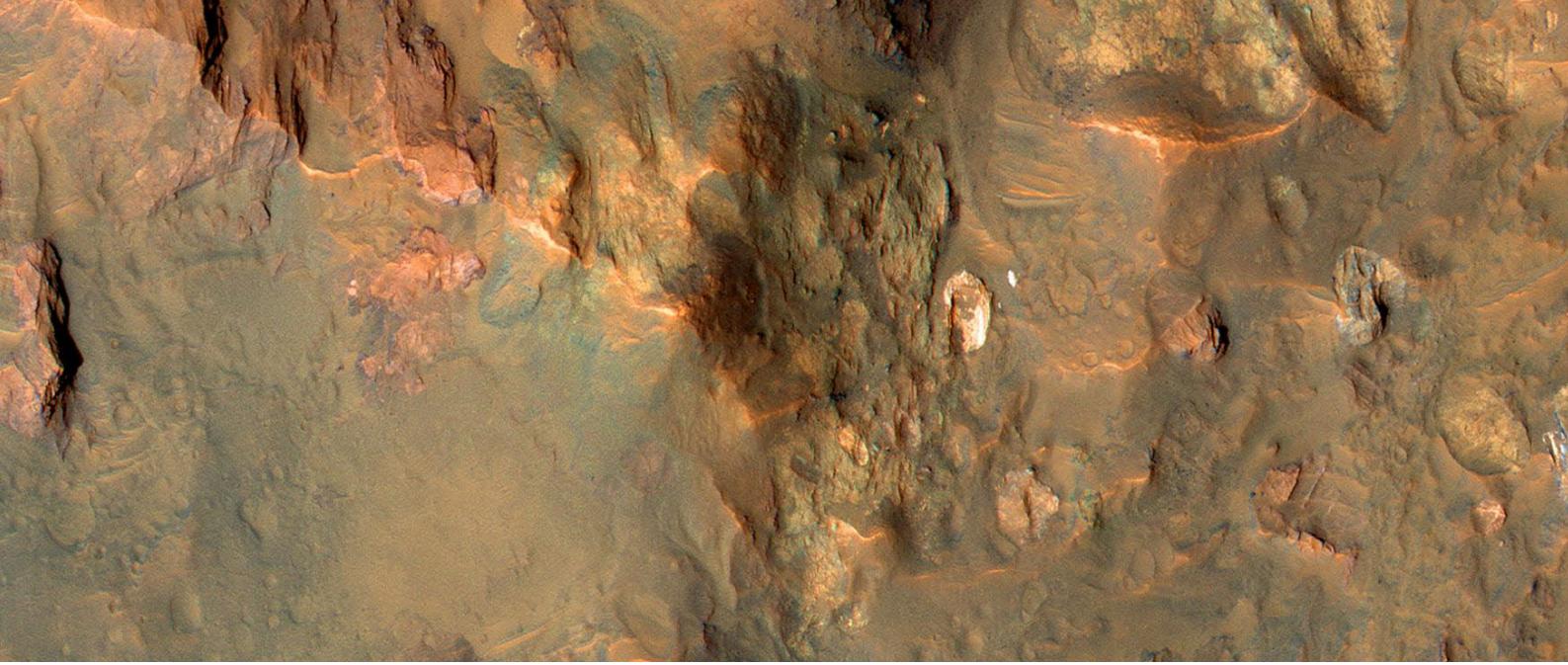
The Mars 2020 mission duration is set to last 90 sols and during that time the rover planning structure will need to be at a campaign (long-term) level. After the initial 90 sols, the nominal mission comes to an end and for the remainder of the rover lifetime, planning meetings can continue at a tactical (short-term) level with mission planning process becoming more reactive. For the first 90 sols, JPL has suggested a 5-hour planning meeting limit. In past rover missions, early planning process often required 12-hour meetings to reach consensus. For this reason, many of the JPL personnel that we spoke to expressed concerns that the 5-hour timeline could result in sacrifices to tactical planning and opportunistic scientific exploration. The timeline leaves little room for discussions and proposals outside of the campaign level.

“

"In the very beginning, it took about 12 hours to just send one day's worth of uplink to Curiosity. I think it reduced down to an average of like seven to eight. On really great days, [...], they got really close to five. " - P8

"A lot of what we do is discovery-driven science. You drive to a new place, and you had a plan, and all of a sudden, someone says, wow, that's so cool. Let's go check that out. And, and that's a trade to be made. " P11

"My understanding is that the way they're kind of doing it is basically removing all decision making from the tactical process, it will all be planned in that strategic time window, which is going to take forever, because you're going to have the same kind of debates going on. " P3



02

Weather no longer poses a critical risk to rover safety, but still must be considered due to its impact on instruments and power constraints.

Unlike past missions, the Mars 2020 rover is nuclear-powered, which means that the weather won't pose that same critical risk. Weather still needs to be considered because of its impact on the rover's instruments. For example, dust storms still need to be closely monitored because the rover's cameras need to avoid dust on the lenses which would hinder the team's ability to take necessary images. Additionally, temperature affects the accuracy of certain instruments on the rover, so unless it was closely monitored data could be misconstrued.

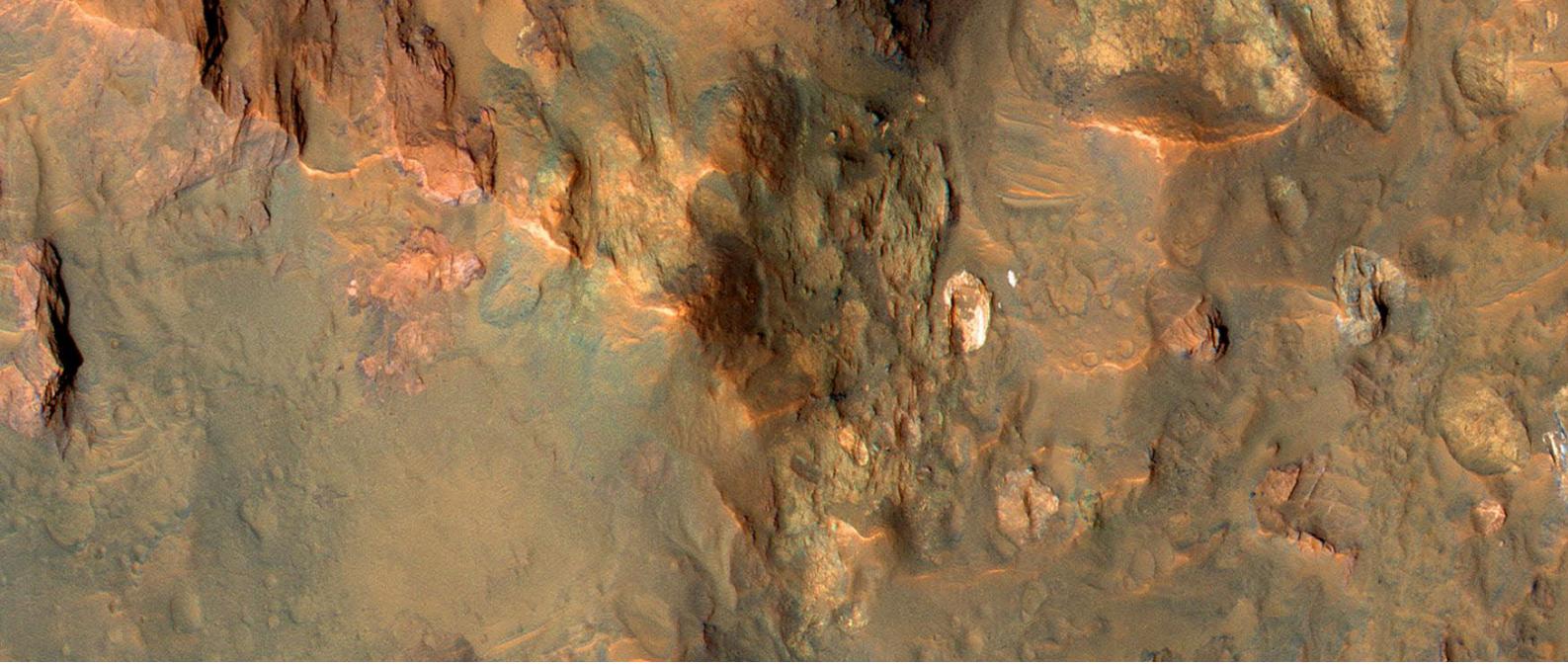
On a tactical level, there's only a certain amount of power available for exploring and collecting scientific data. To optimize data collection, science teams need to be dynamic, flexible, and willing to shift priorities in response to weather events or new findings. This also means seizing the opportunity to collect as much data during unexpected situations.

“

"The Mars 2020 rover isn't going to be as critically in danger when it comes to storms because it's now nuclear powered [...] But dust storms [prevent us from taking] proper pictures." - P2

[Engineering] is going to get touchy about pointing the cameras very high up elevation wise when there is a lot of dust in the atmosphere. Atmospheric observations may be curtailed because you don't want to get your camera stuck pointing at the sky with a bunch of dust falling out of it. - P15

"It can get very very cold on Mars, that cold can be really bad for electronics. And so that means that when it gets too cold, you have to run heaters to do things to make sure there's no damage to electronics." - P13



03

Weather on Mars is relatively predictable, however, there is no weather forecasting despite its potential applications to long-term planning purposes.

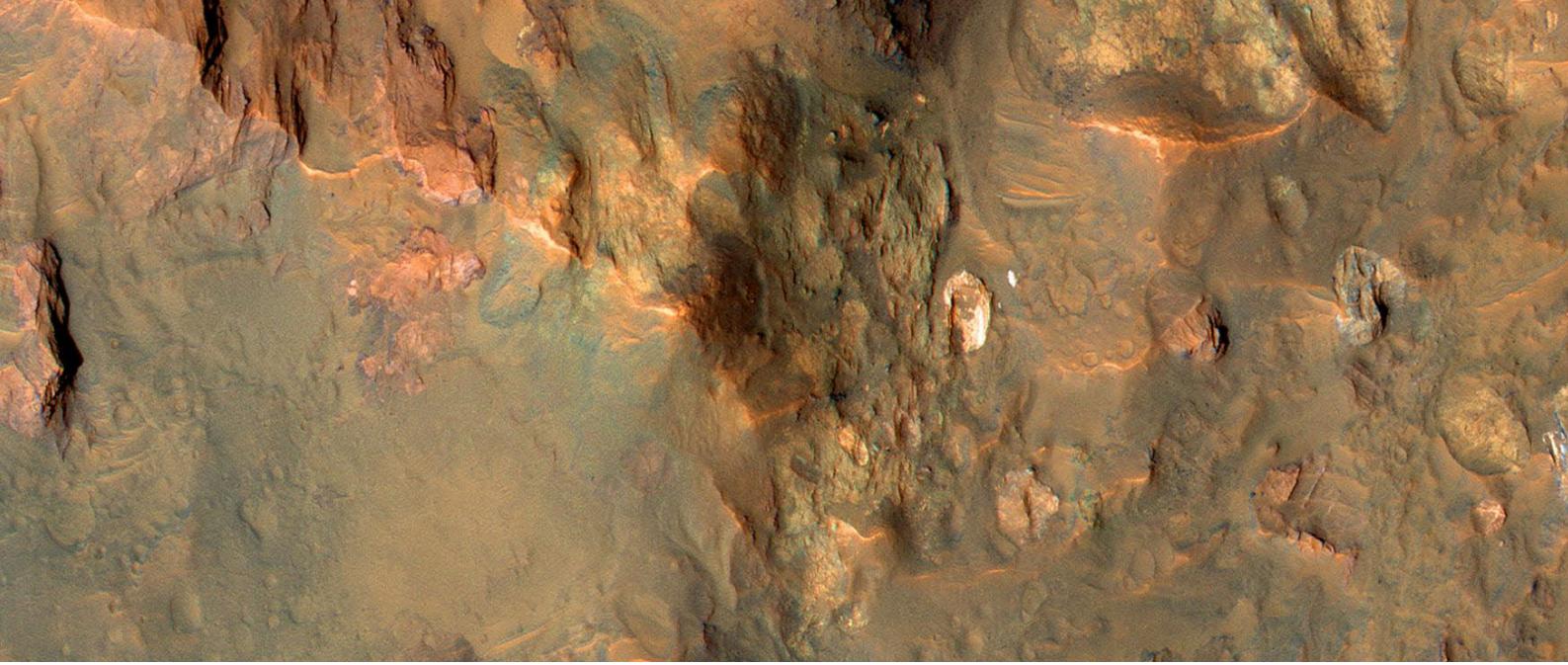
Due to the lack of oceans, weather events on Mars can be predicted up to one Martian year (687 Earth days) in advance with variance of only a few weeks. This predictability is not surprising as Martian weather conditions are controlled by several factors that do not change much from year to year: seasonal heating from the sun, polar melting, and topographical features such as mountains. Despite this cadence, there is no tool to let mission teams know the weather forecast along the planned rover path. This presents an opportunity to aid the mission teams by surfacing expected weather conditions to facilitate proactive instrument and science activity planning, moving planning away from day-of tactical planning as is required by the Mars 2020 5-hour uplink goal.

“

"Scientists [predicted]...that Mars was going to get a really big dust storm and it did. That's why Opportunity no longer works, but they were able to predict it fairly well and that's because there's this pattern pretty frequently that occurs on Mars." - P2

We always know there's a dust season on Mars which is typically associated with the summer. There's typically a more cloudy season as the seasons change. [...] So at least on a seasonal cycle, things are fairly predictable. - P3

You actually plot the predictive temperature [...], it changes your access scale up to that much lower. I don't know what the temperature will be precisely, but here's the predicted range, add that to the chart, because that's the context in for the decision you're making. - P10



04

Unavailable atmospheric opacity (τ) measurements in internal tools negatively impacts operational efficiency.

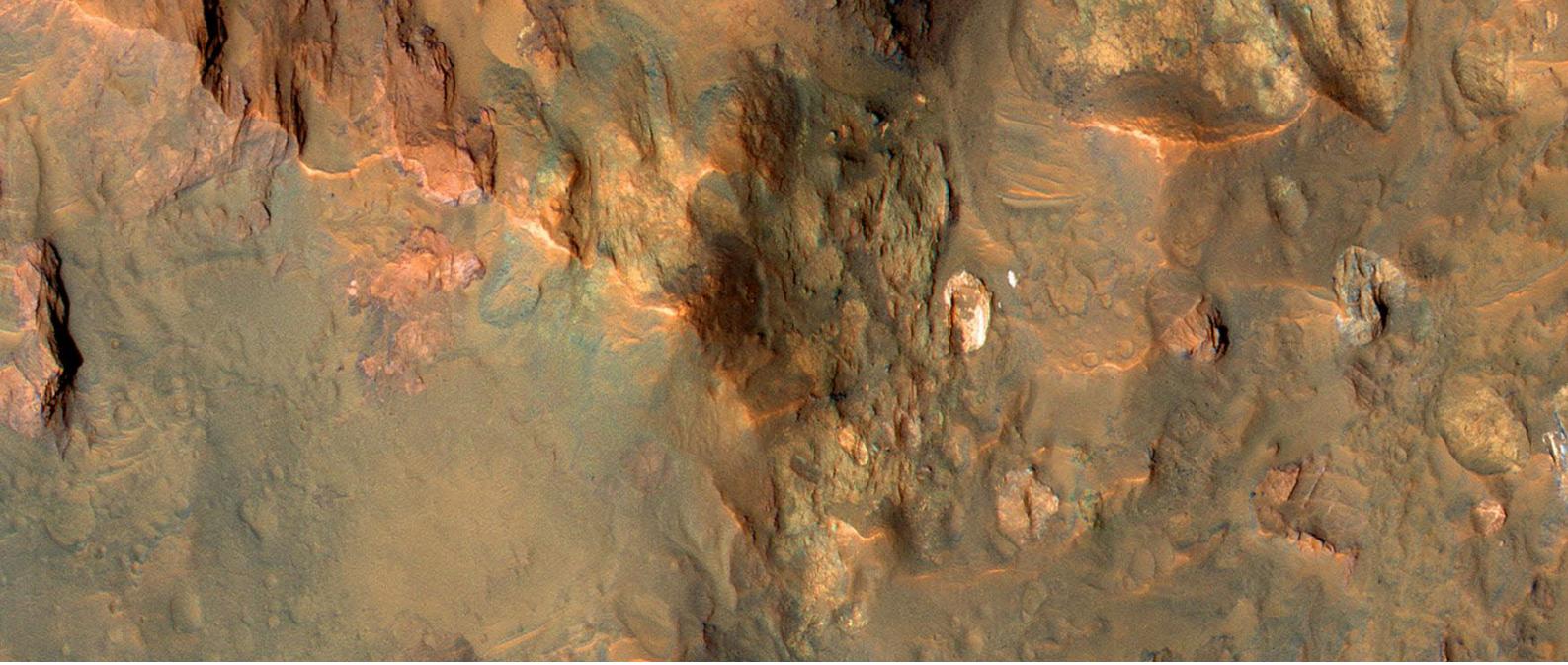
The visibility measurement (tau) indicates how much dust is present in the atmosphere. This information affects 3 main stakeholders: science, engineering, and image processing teams. The engineering team ensures the safety of the rover and its instruments by taking into consideration how the rover's arm should move, the angle of the movement, and the topography of the terrain. However, current rover targeting tools (i.e., ASTTRO), without tau information, do not inform scientists of the engineering feasibility of their target requests. The lack of tau information also creates a communication setback between scientists and the image processing personnel. Both parties need to understand the amount of dust in the atmosphere to estimate image exposure and processing time in order to produce the highest image quality.



Before [scientist] go off and start harassing the folks that do the image processing to get it into the pipeline of what's wrong and why is this broken? It's a lot nicer to go, 'oh, okay, I'm dealing with the local dust storm, kick the tau up for a day or two.' - P15

I could see how [tau] might impact the way people think about things. And people generally keep it in mind, but I've never seen it in the planning tool. -P16

You're trying to take photos that have the same sort of lighting across a long traverse because you're comparing [rocks color and sizes]. If the lighting [of the image] changes halfway through your traverse, then it's a problem. - P7



05

Despite tactical disagreements and the varying cultures, rover safety takes precedence because without a rover, there is no scientific discovery.

During daily tactical meetings, engineers and scientists work together to decide on the next day's targets. This can sometimes lead to disagreements due to differing priorities and cultures. Scientists want to explore as much as possible to meet the mission's scientific goals, while engineers are concerned about the rover's safety and functionality. This leads to situations where scientists are more risk tolerant than engineers. These discussions tend to be difficult for both sides because engineers are trained to be quantitative and binary, while scientists are less apt to quantify the trade-off of risk and reward due to the uncertain and imperfect nature of science. At the end of the day, they will negotiate and find an acceptable level of risk to ensure rover safety is not compromised while still advancing science.



"It's very difficult for the science teams when you're doing [planning] trades, to be as quantitative and sure of ourselves as the engineering team [...] I wouldn't call it a conflict, but you know, just different culture expresses itself." - P14

"Engineers, of course, are extremely cautious [...] we don't want to stand on the science, because, of course, that's how we get our next round of funding. [...] it's a balance, [...] in order to make sure that we're doing the best we can with the science collection, while also keeping the rover safe." - P11

"You kind of have to argue with them... 'Well, I'm the engineer, and I'm not going to do what you want, because I don't believe it will be safe for the rover.' And that typically is when they'll actually back off" - P3



06

In the conflict between mission groups, the only shared language is data. Even then, every specialty has its own dialect, leading to misunderstandings.

During daily planning activities, scientists must form a consensus on the rover's intended activities. Data drives these contentious discussions, but each scientific domain has its own unique practices, methodologies, and jargon to account for which makes it difficult for those from other domains to follow. Complicating matters, most scientists are admittedly bad at simplifying their data for specialists outside of their domain. Generalists attempt to translate across domains, but they are in short supply and struggle with disparate toolsets. If scientific intent is not clearly understood by the planning committee, it will be difficult for a proposal to be granted resources and scientific opportunities may be missed. Planning may be hindered by unclear context around why a past decision was made. Further, planning around competing and complementary activities may not be able to take place at all if the intent is unclear.

“

For us to be able to communicate our ideas in a compelling way to the rest of the [scientists], the graphics need to be easy to understand for a non-specialist. If I tried to present something like this to geologists, they'd just say 'What is this noise? Take it away.' - P1

The geologist has his own kind of knowledge that comes from his expertise. The atmospheric scientists would have a different set of knowledge. Sometimes that's helpful, but also sometimes comes in the way of them seeing the data from the other person's perspective. So, how do you help them maybe step into each other's shoes? - P10



07

Data is more revealing when contextualized with other observations. Existing tools do not have this capability, hindering scientific discovery.

Context and integration of metadata can reveal unexpected findings, allowing scientists to arrive at new insights. For example, pairing temperature with rock colorization may lead to new hypotheses or present scientific opportunities that were not evident when analyzing rock colorization in isolation. Often times scientists create their own tools to analyze and visualize data in order to meet their scientific needs. These tools are not created with output integration in mind. As a result, this creates a fragmented tool ecosystem and a lack of ability to integrate datasets from multiple sources to provide context or comparative views. An example of this came to light during an interview when the participant expressed that the Mars Weather Service lacked the ability to view data over multiple days, which would allow scientists to observe weather patterns that occur temporally. These gaps in tool capabilities cause a need for workarounds that may not support efficient analyses.

“

"It would be nice if I could overlay one sol another. Like we expect that the meteorology is going to repeat kind of on a daily basis." - P1

"For meteorology, time of day is crucial. So if there were a nice way to be able to compare and contrast a couple of different days, that would be really helpful. Instead of looking at the left half of this plot and the right half. You'd have to visually try to compare this feature to that feature, and that would be awkward." - P1

"I then come up with a result... I believe my results but I believe it a lot more if I can compare it to something else." - P16



08

The use of numerous custom-built tools is "both a feature and a bug"; it makes output inconsistent, but leads to advancement through productive scientific discussions.

Every scientist has their own way of analyzing data, and they often end up building their own tools to meet their personal needs. At face value, this is problematic because the existence of multiple tools means a multitude of output forms. One scientist's output could be a visualization while another's is a data table. Additionally, although the input is the same, they may end up with completely different results through differing methodologies. The resulting output inconsistencies and the discussions around them are difficult because it takes time for different stakeholders to understand one another's output. However, these different ways of analyzing the same data helps advance science because it could lead to the detection of patterns which validates hypotheses, or to



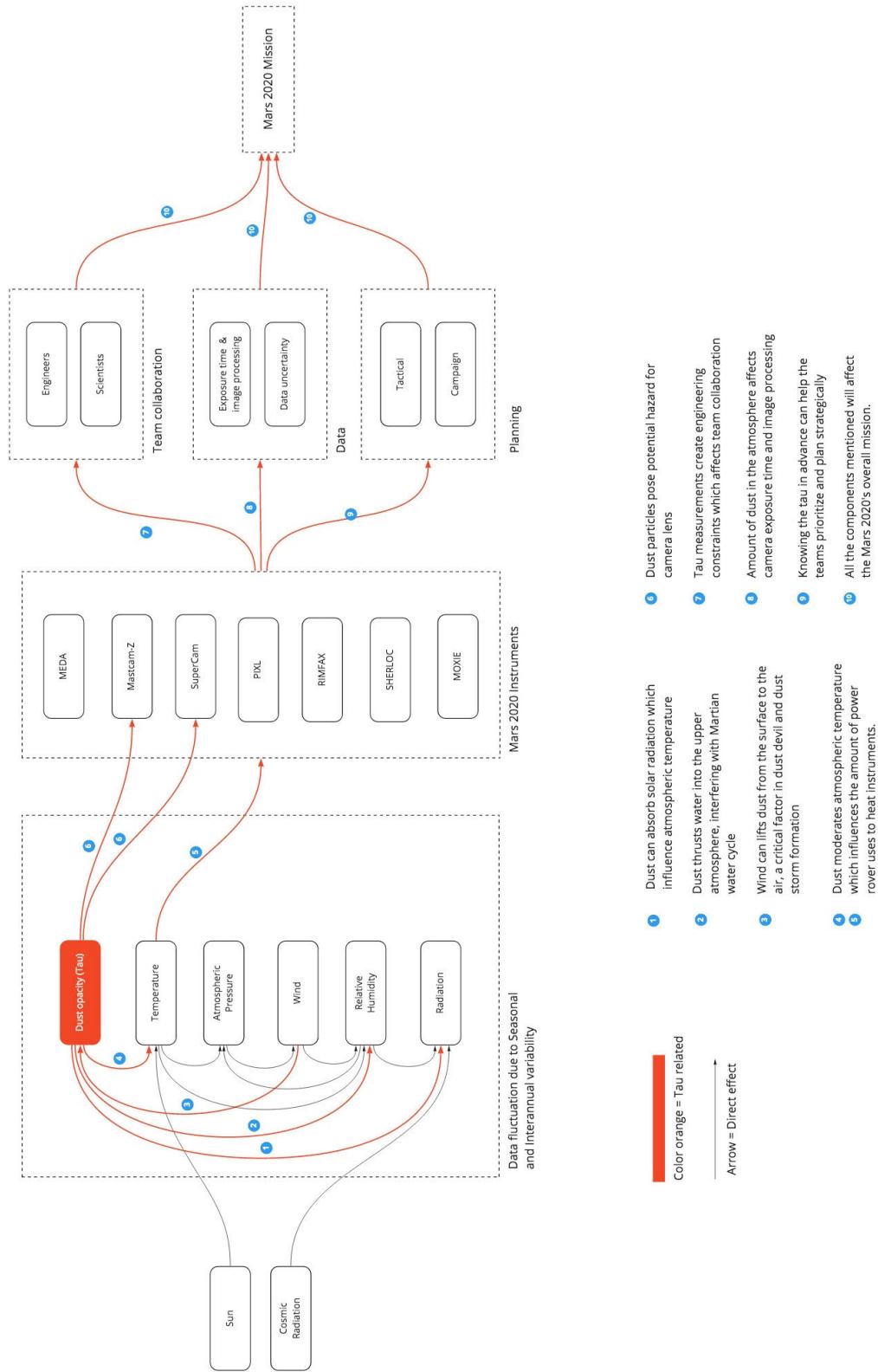
"Discrepancies aren't always bad, they just reflect that science is imperfect, we don't have all the tools, and they're not perfect. Our understanding of even how to build the tools to get the results is not perfect. So often, it's good to have healthy competition." - P14

"Sometimes, it's difficult to have the same collaborative tool because you don't use the same language. You don't have the same purpose with respect to the data, you don't have the same research code. So, you end up using your own tool because that's faster. And that's easier to customize." - P17

"For a given set of recorded data, there are definitely people giving different interpretations or different explanations, but I think that's how the science commands you in general." - P4

ARTIFACT

Atmospheric Opacity (Tau) and its impact on the Mars 2020 mission

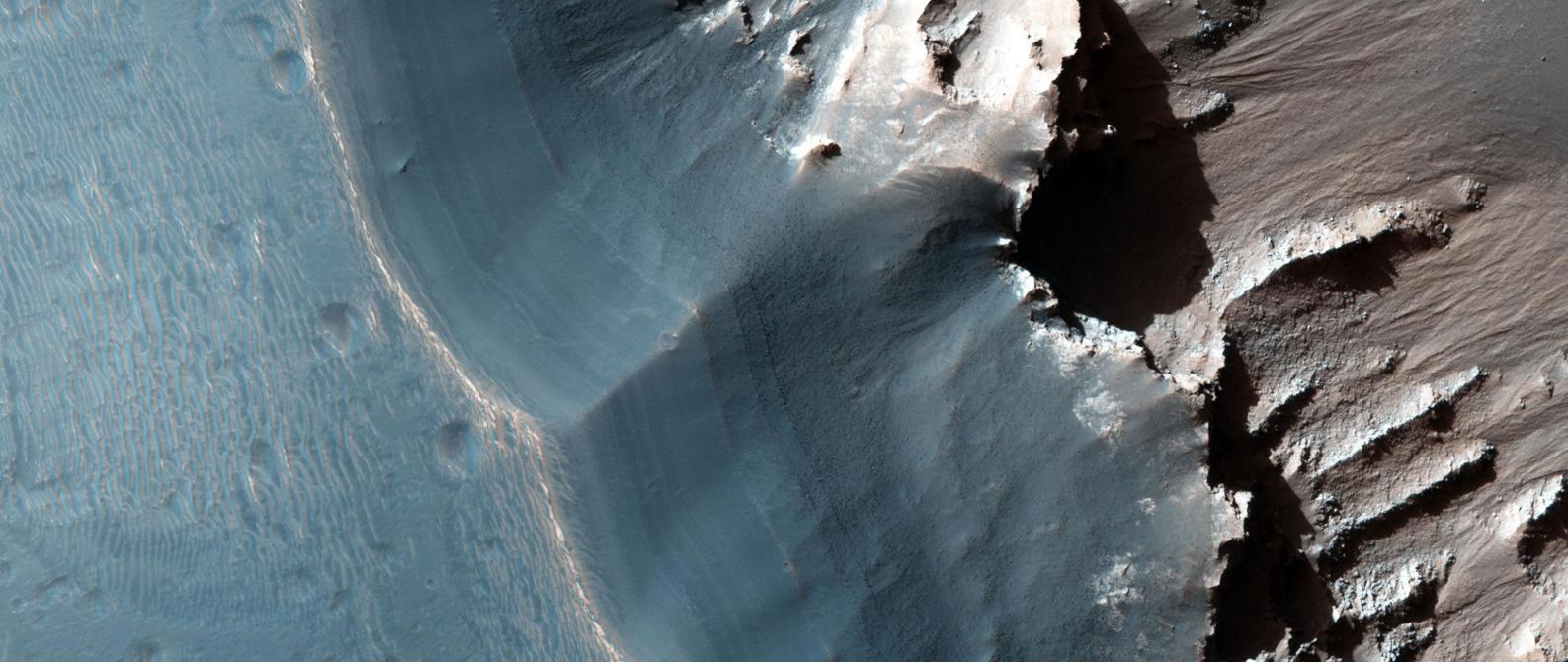




04

D i s c u s s i o n





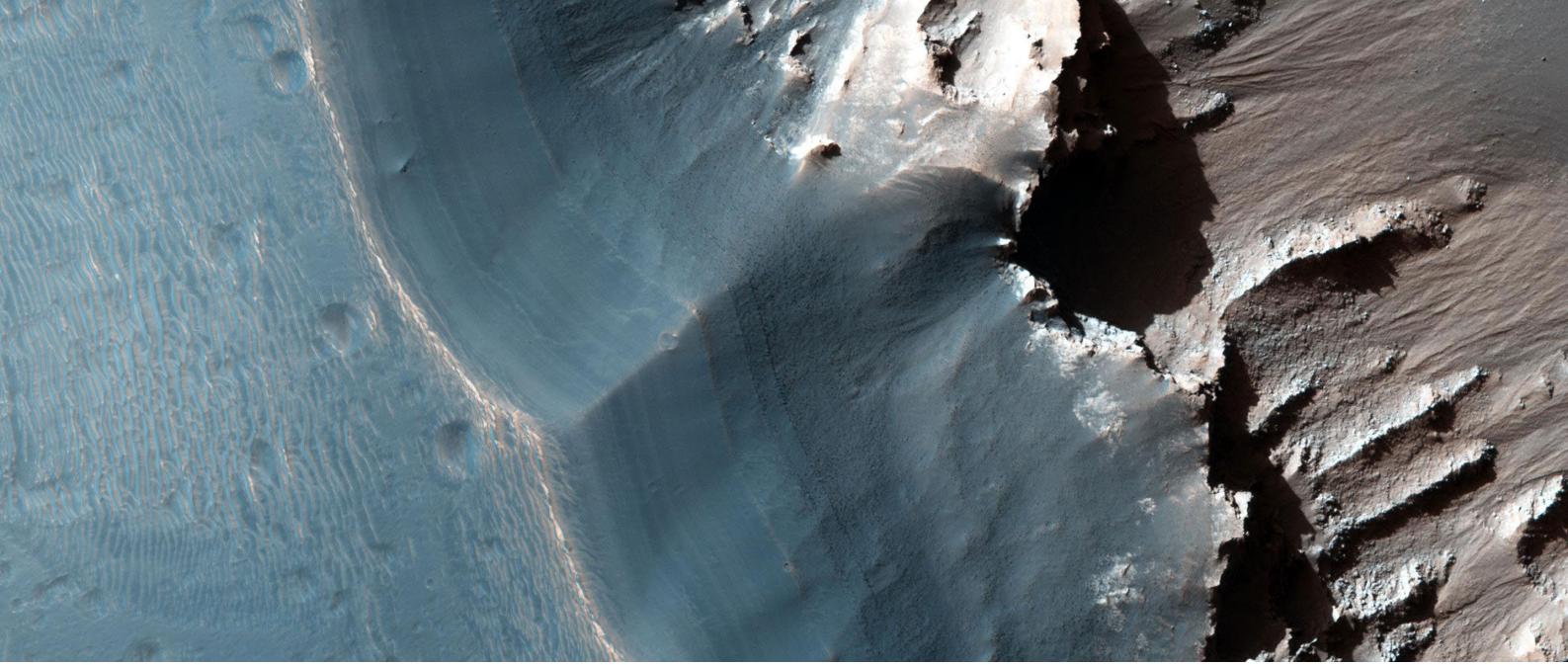
DESIGN OPPORTUNITIES

Express the impact of atmospheric opacity on instrumentation

Atmospheric opacity poses a threat to rover instruments, image exposure time, and data processing. We are interested in exploring ways to help scientists understand this impact on their work and how it pertains to the overall mission.

Use the predictability of Martian weather to help teams shift from short-term to long-term planning.

Knowing what to expect on upcoming sols makes it possible to plan instrument usage better. We want to explore how to help scientists optimize instrument selection.



DESIGN REQUIREMENTS

01 Facilitate debate

The advancement of scientific knowledge stands to benefit from disagreement as dissent breeds productive debate in order to reconcile conflicts. Our tool needs to facilitate healthy discussion between differing points of view in order to drive scientific advancement.

Insight 3, 8

02 Prioritize customization and flexibility

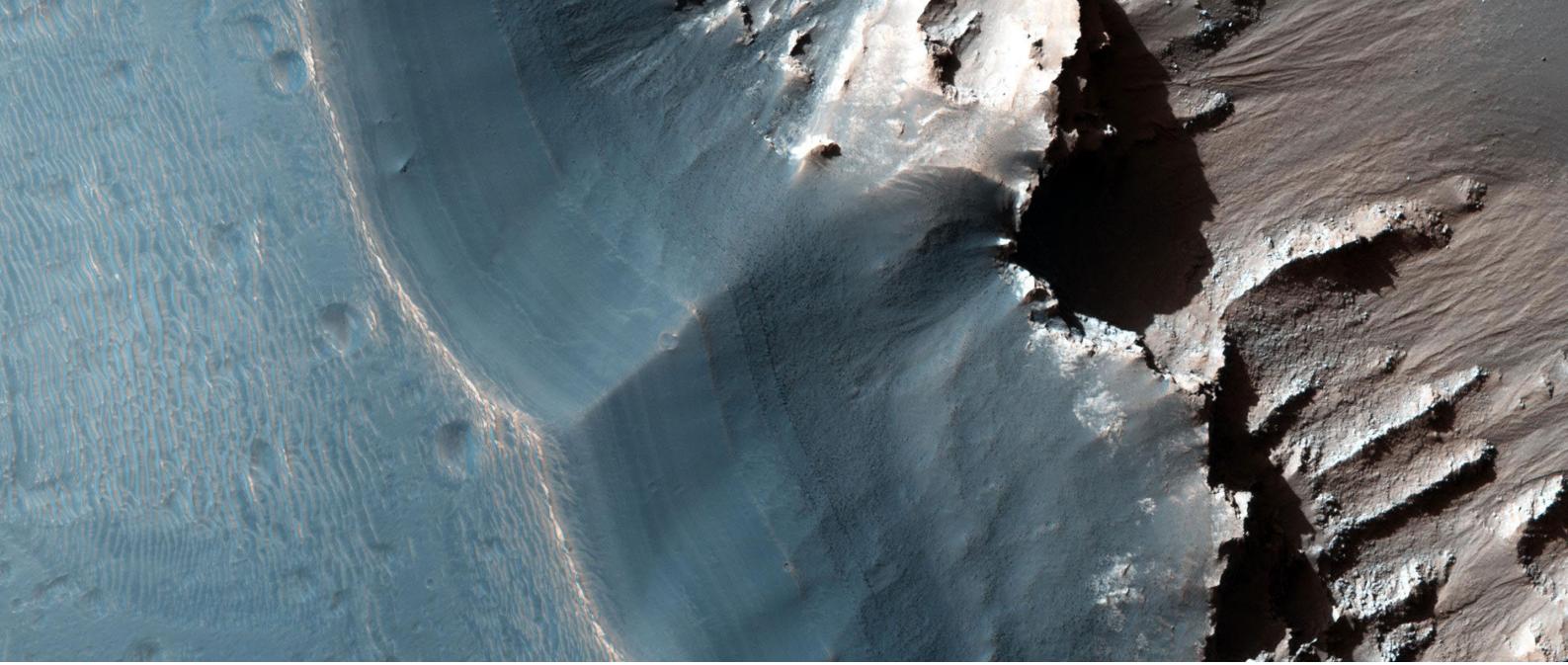
Scientific discoveries stem from finding novel ways to analyze and interpret data. To promote further exploration, the tool needs to provide scientists the ability to explore a dataset in various ways without disrupting existing work preferences.

Insight 6,7,8

03 See through the same lens

Scientists are using their own tools and this could lead to misunderstandings about the meaning of their output. As a result, enabling shared mental models is crucial in order to ground conversations

Insight 2, 3, 4, 5, 6



DESIGN REQUIREMENTS

04 Show how it fits in bigger picture

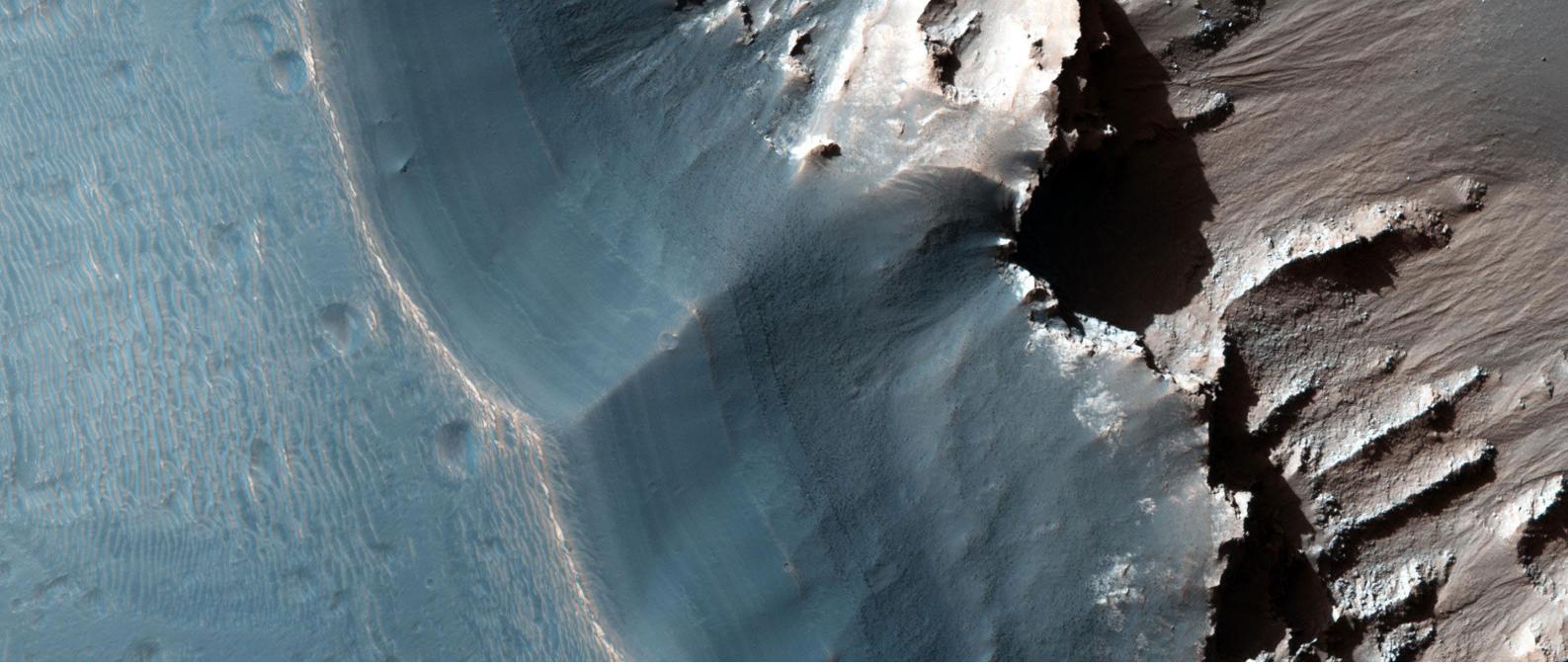
Scientists and engineers should understand how their work impacts each other and the overall mission. This can be done through contextualizing data to provide a comprehensive view of the situation.

Insight 1, 2, 3, 4, 5, 7

05 Stay transparent

Understanding the history of data is just as important as understanding what it means. To scientists, knowing the provenance of data facilitates trust, exposes caveats, and helps ground the conversations.

Insight 4, 6, 7



NEXT STEPS

- 01** Follow-up interviews with relevant experts how it fits in bigger picture
- 02** Conduct focused research on tau and its impact on instruments
- 03** Iterate design requirements as needed
- 04** Begin the ideation process



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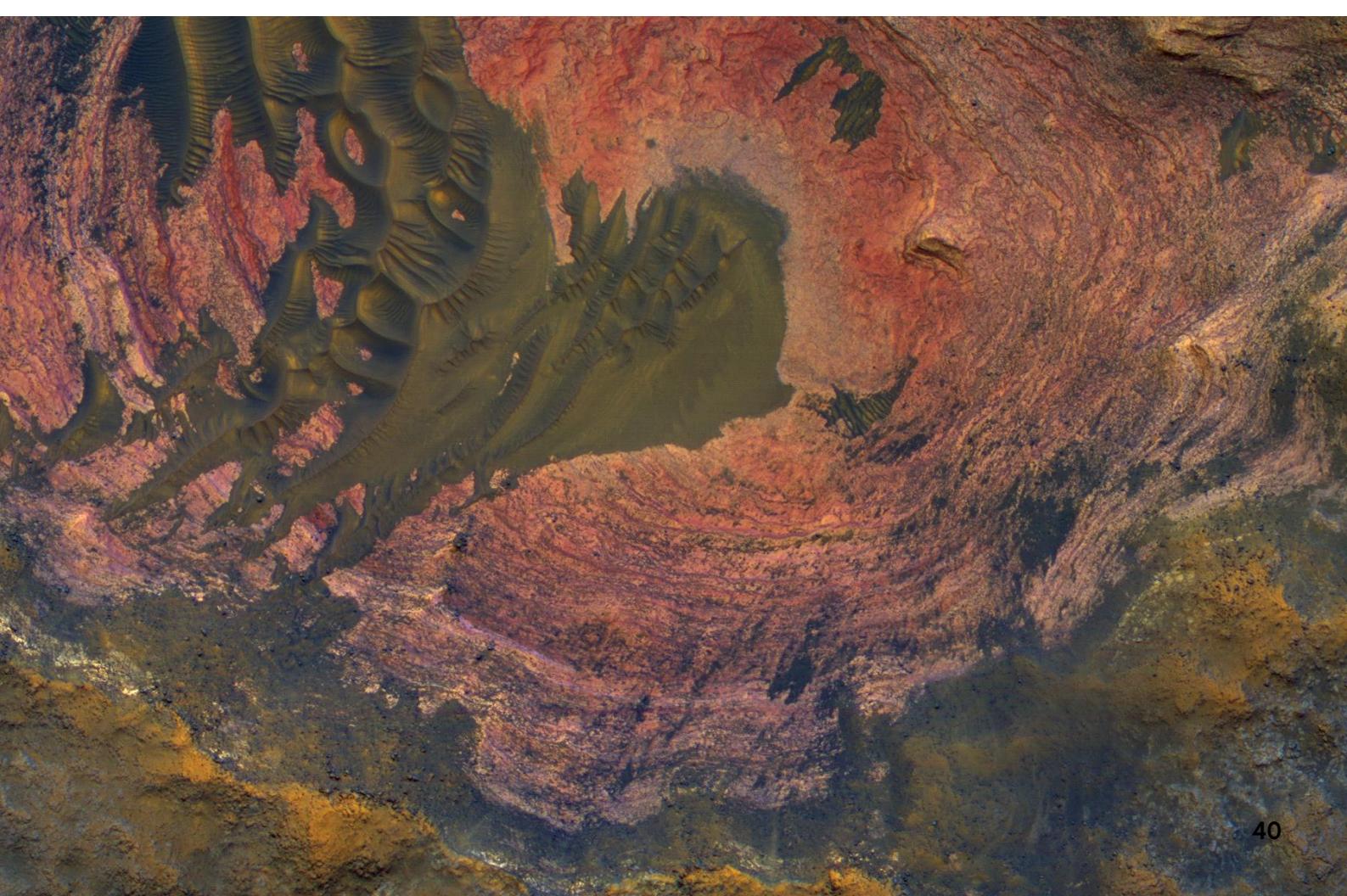
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Appendix



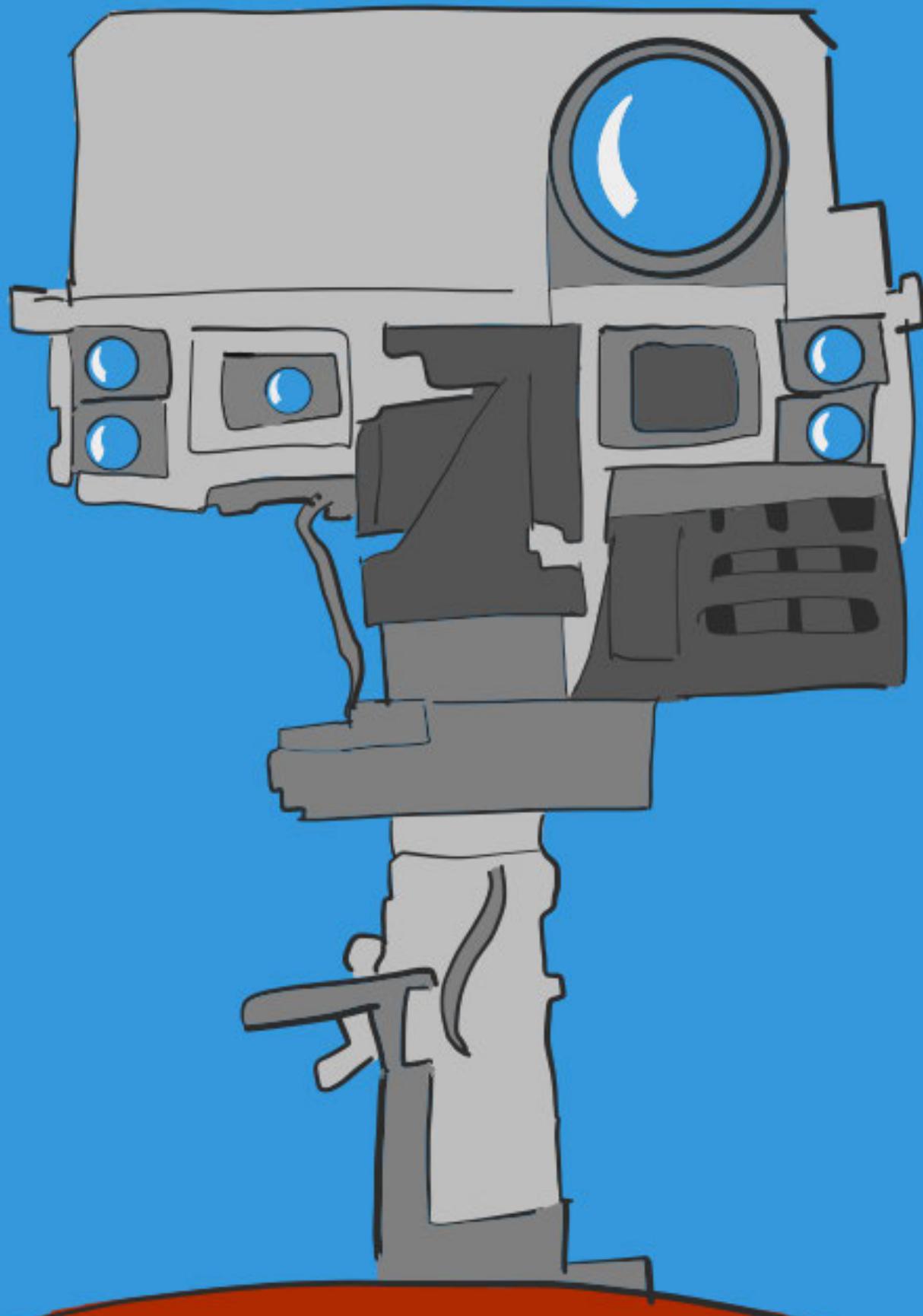


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Introduction

NASA Jet Propulsion Lab (JPL) is preparing for its upcoming mission, Mars 2020. This mission is next in NASA's long-term effort of robotic exploration on Mars with multiple scientific goals, including searching for previous signs of life on Mars, characterizing the planet's climate and geology, and preparing for potential human exploration [1].

Accurate understanding of weather on Mars is critical to the success of the mission, since there are several cases where conditions on Mars dictate where and how science experiments are conducted. For example, dust levels can dictate camera operability, atmospheric conditions can affect daily rover target planning and the sun's position can affect the timing and feasibility of operations [2].

Previous mission rovers saw long periods of inactivity due to solar-powered battery limitations. As newer rovers have longer uptime as a result of their nuclear batteries, NASA's internal policy dictates an equal amount of time planning and operating the 2020 rover. This means that planning teams need to meet a daily 5-hour planning window, requiring that all data be quickly and efficiently available [3].

Additionally, mission planning is dependant on geographically distributed teams comprised of individuals with varying skill sets and background knowledge. These teams rely on ad-hoc meetings, powerpoints, and a company-wide wiki for communication. On previous NASA missions, breakdowns in communication have caused costly delays, wasted resources, and even irreparable damage to instrumentation [4,5].

Introduction

NASA's current rover planning tool (ASTTRO) only provides location and terrain data. Our challenge is to enable the rover planning teams to meet their deadline, by creating a tool that would communicate Mars' meteorological data between distributed teams, aiding scientists and engineers in planning and decision-making processes.

Through our research activities, we aim to better understand the typical collaborative challenges that rover planners, scientists, and engineers face with a focus on how martian weather impacts their goals. Additionally, we intend to learn more about current tools being used to assess and visualize meteorological conditions and how they are integrated into the mission workflow.

Background

Past Missions

NASA's Mars Exploration Program (MEP) has a long-term and systematic plan where each mission builds upon previous research, innovations, and discoveries. The early theme of Mars exploration was to "Follow the Water" as water is a critical indication of a habitable environment [6]. When past missions found evidence that water used to exist on the Martian surface, the Mars exploration theme evolved to "Explore Habitability", with a purpose to seek additional chemical elements that were necessary for life [7].

Mars 2020

With findings from Curiosity rover, MEP marked a transition to the upcoming Mars 2020 mission, shifting the theme to "Seek Signs of Life" [6]. The Mars 2020 program has 4 long-term science goals [8].

1. Determine whether life ever existed on Mars

The rover will conduct studies on the Martian surface and seek biosignatures from rock samples.

2. Characterize the climate of Mars

The rover will look for evidence of ancient habitable environments where microbial life could have existed in the past.

3. Characterize the geology of Mars

Each layer of rock provides information about past Martian environmental conditions, revealing the history of how Mars' crust and surface evolved through time. The study could be further extrapolated to uncover the history of Earth itself. Current and future rovers will cache geological samples to be studied in the future.

4. Prepare for Human Exploration

The rover is demonstrating key technologies for using natural resources in the Martian environment for life support and fuel. It is also monitoring environmental conditions so mission planners get a better understanding of how to protect future human explorers.

Background

Workflow Challenges

Mission planning operations involve teams of scientists, rover planners, and engineers who meet a daily 5-hour planning window. The typical workflow for mission planning involves reviewing downlink data, assessing shadows, monitoring engineering components, monitoring resources, and resolving conflict [17]. Although our knowledge regarding this topic is limited due to lack of publicly available information, we see an opportunity to design a tool that could assist in daily rover planning, reducing the amount of back and forth among team members. Accordingly, we will further study this area in our user interviews.

Weather Implications

Understanding atmospheric conditions on Mars is critical for successful rover planning. In mid-2007 a planet-wide dust storm posed a serious threat to the solar-powered Spirit and Opportunity rovers, reducing the amount of energy provided by the solar panels and necessitating the shut-down of non-essential systems while waiting for the storms to clear. Dust storms significantly reduce power on solar-dependent rovers, due to obscurement and settling of dust on the arrays [9]. This obscurement risk has been somewhat mitigated in Mars 2020 mission through the use of a nuclear power core, but meteorological data still holds significant mission planning repercussions [3].

Besides dust, there are several other weather conditions that could affect rovers' operations and long-term planning. For instance, the tau or an optical depth measurement can dictate camera operability and exposure times [10], the sun's position in the sky and its relative angle to the instrument can affect operation timelines.

Weather data is also used to determine which missions are feasible during a given period. For example, if visibility is limited due to dust particles, rover planners would delay science activities that depend on external camera data [11]. Similarly, dust storms could damage delicate instruments and rover planners would need to know when to retract them in order to increase their longevity [12].

Background

Related Technology

The Advanced Science Targeting Tool for Robotic Operations (ASTTRO), is the tool used by rover planners for target planning. It currently provides information related to the 3D terrain and rover position, but it doesn't include information about weather and atmosphere, and only limited information regarding the sun [13].

The Mars Environmental Dynamic Analyzer (MEDA) is the instrument attached to the Mars 2020 rover that will help scientists gather information about weather on Mars. MEDA measures a wide-range of variables such as wind speed and direction, temperature, humidity, and the size of dust particles in the Martian atmosphere [14].

Mars Atmosphere and Volatile Evolution (MAVEN) is a satellite developed to study the Martian atmosphere and its composition. It has recently provided significant data around the loss of water and atmosphere on Mars and the role solar storms play [15].

Deep Space Network (DSN) is a network of antennas distributed globally which provide communication links between planetary exploration spacecraft and their mission teams on Earth. Their distribution allows for 24/7 data uplink to the multiple Mars missions, including Curiosity, MAVEN, and soon the 2020 rover [16].

Initial Insights

Data visualization tools for Mars mission planning need to help scientists, engineers, and rover planners embody the rover

In order to be fully prepared for my job I need to literally be that vehicle. That's what all the visualization software I use is about. For me, it's all about intuitively being able to make decisions, because you're gonna be getting questions on the fly and you're gonna have to answer them on the fly. You're not you, you're the rover...I think of myself as the Rover so I can call the shots. I need to know where I am as the rover. It's a huge, huge part of my job.

'Liz', MEP Team Member [17]

Images and instrument data from rovers act as a decisive element in team meetings and mission planning. All individuals in the Mars team harness their "rover" skills by developing the ability to interpret downlink images retrieved directly from the rovers and orbiters. This includes images with fisheye view and those processed in RGB colors. Interpreting these unprocessed images helps the team make sense of the rover's location, its surrounding environment, atmospheric conditions, and terrain challenges before doing target calculation [18].

The team also highlights the values of plurality in data visualization. Images and data when visualized in various forms provides different contexts and layers of information. This provides the team with unexpected knowledge and aligns multiple stakeholders' point of views [19]. Teams use multiple tools to enhance this data visualization, including enhanced reality displays and bodystorming techniques to better embody the rover and enhance the shared mental model among stakeholders.

Initial Insights

Rover plays an important role in mission planning, collaboration, and defining team culture

"The techniques of being to see like a rover, being able to feel, and move, and be like a rover are all connected to the success of the team. I've argued that in order to operate robots on Mars, scientists and engineers must bring together this very complicated way not only visualizations and visual manipulations, but also this gestural and embodied relationship to the robots' experience on Mars. They do that in a particular social context, one that is oriented towards a very unique and particular model of teamwork that brings people around that robot"

Janet Veritsi, NASA Ethnographer [20]

In a flight mission, the main team is created by grouping different teams with various scientific objectives. These teams typically work separately, prioritizing individual goals and placing less emphasis on cross-functional team collaboration. Since the spacecraft has limited time, power, and memory, during the mission, these teams compete against each other for a scarce resource, creating a disjointed decision making process and a micro-political environment. This challenge was also highlighted by the past two MHCI+D projects in 2018 and 2017 [21].

In contrast, the Mars mission team has a flattened hierarchy and a single Principle Investigator. Work revolves around the rover as its capabilities play an important role in daily operations. It acts as a totem object that cultivates team dynamics and culture [22].

The Mars mission team embraces the unilateral consensus when making decisions. The team is somewhat more collaborative compared to the flight mission teams. The main challenge does not lie in competing for resources but rather, enhancing collaboration and ensuring team members are able to analyze data and produce a detailed mission plan in an efficient manner [22].

Initial Insights

Mission planning relies on a combination of new and old techniques used to reinforce shared mental models and form consensus

When we're training new rover drivers, we can really tell that they get it when you start talking about moves with the [Robotic Arm] and they start moving their own arm to kind of show you what they mean, and they say you know we're going to swing this to the left and then move their elbow [moves his elbow to the left, wrist hanging down].

'Mark', MEP Rover Driver and Trainer [23]

Scientists and engineers often utilize bodystorming in order to help visualize the actions a rover is intended to take, going as far as creating props to imitate intended target rocks and obstacles to see if a course of action is feasible. Embodying the rover in 'the right way' is considered an acquired skill that is seen as the mark of an initiated team member [24].

Daily rover planning meetings require consensus building among scientists and engineers who often have competing points of view around rover activities. Scientists are primarily focused on gathering data, while engineers focus on the health and safety of the rover. Communication at planning meetings is primarily done through annotated images which are enhanced in multiple ways and data visualizations shared on slide-decks in virtual meetings. Only when a course of action has been agreed upon the Keeper of Plan (KOP) enters the instructions into rover planning software, which is then sent to Mars via the DSN uplink [25].

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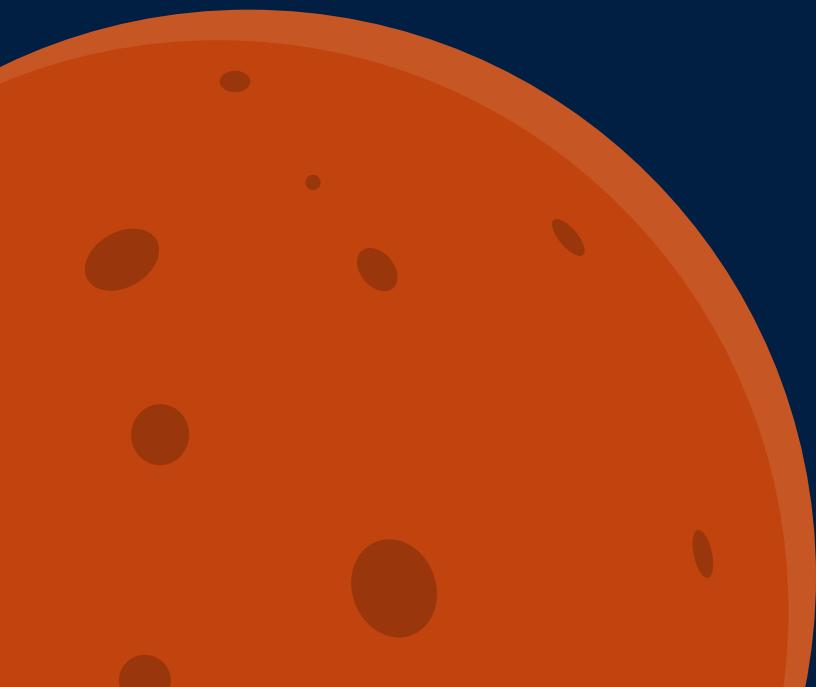
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RESEARCH PLAN



Research Questions

01

What is the typical workflow for rover mission planning and what collaborative and operational challenges do they face?

Rover operations require collaboration between rover planners, scientists, engineers and other stakeholders. Understanding their typical workflow will help us uncover any flaws which could lead to a disconnect in their mental models regarding weather.

02

What tools and technology does the mission operation team currently use, or plan to use, to collaborate and assess weather information for mission planning?

Decomposing the tools that are currently being used for mission planning, with a focus on the ones that involve weather analysis, will help us uncover any limitations with the current technology which could act as opportunities during our design process.

03

What weather information does the mission operation team need to know and how do they use this information in making time-sensitive decisions?

There are a number of different weather variables that have varying levels of impact on short-term and long-term mission planning operations. We hope to understand what weather variables the mission operations team prioritizes, how often they examine them and how they interpret them to make decisions.

Participant Profile

Primary

- Mars rover planners/drivers
- Mars rover engineers
- Mars atmospheric scientists
- Mars principle investigator
- Mars data visualization

The main objective of our research is to uncover the typical mission planning workflow. Ideally, the primary research audience are NASA employees who participate directly in Mars rover mission planning. This includes scientists, engineers, and rover planners on the Mars 2020 mission and those who previously worked on the Spirit, Opportunity, and Curiosity rovers.

Secondary

- Air traffic controllers
- NOAA scientists (weather, climate visualization)

Learning that previous MHCI+D teams faced problems with recruitment in the past, our team chose air traffic controllers and NOAA scientists as our secondary (or backup) research audience. Similar to the work of rover planners and engineers, their work heavily revolves around planning with lots of time pressure. We believe insights derived from this audience could be translatable to our research space.

Recruitment Methods

- Systematically go through the list of NASA Mars employees and filter out potential candidates based on their job descriptions, background, and mission involvement
- Leverage Lyle's network at NASA JPL
- Snowball recruitment

Budget

16 semi-structured interviews x \$20 per participant = \$320

Study Method

SEMI-STRUCTURED INTERVIEW

1ST ROUND (8 PEOPLE)

04/15 - 05/03

Strategy

- Each interview will have a facilitator and a note-taker. The interview will be recorded and all 4 team members will attend/watch the interviews to ensure team alignment.
- The facilitator of the interview is responsible for performing research on participant's work and background to avoid asking unnecessary questions.
- After each session, the facilitator will transcribe the interview and the team will debrief and provide feedback prior to the next one.

Objective

- Pilot the primary research process.
- Learn about the mission planning workflow and the roles of scientists, engineers, and rover planners.
- Determine what kind of data and atmospheric variables are critical for planning rover mission.
- Identify the challenges that scientists and engineers when finding appropriate targets.

2ND ROUND (8 PEOPLE)

05/04 - 05/15

Objective

The objective of the second round interview is to reach 16 participants in total. Based on the insights from the first round, our team will strategize and restructure our questions accordingly.

Study Method

ITERATIVE DIAGRAMMING

FOR ALL INTERVIEWS WITH NASA EMPLOYEES

04/15 - 05/15

Overview

Understanding the workflow of the 5-hour rover planning meeting accurately is critical to the success of the project. This exercise will be used to decompose the meeting by having participants review the workflow diagram and give feedback/make adjustments. After every session, the research team will iterate on the diagram based on the insights collected.

Strategy

The iterative diagramming exercise will take place during the first half of the semi-structured interview when workflow details and challenges are the topics of discussion. Before each session, we will send the participant an image of the latest workflow process, as we understand it to be, and ask them to go through it and comment about different parts of the process. Following every session, the team will debrief and make any necessary updates to the workflow diagram.

Objective

The objective of this exercise is to ensure we have an accurate understanding of the team's workflow. Additionally, it's to help participants visualize the workflow so they can accurately answer questions about it.

Study Method

HYPOTHETICAL SCENARIO

FOR ALL INTERVIEWS WITH NASA EMPLOYEES

04/15 - 05/15

Overview

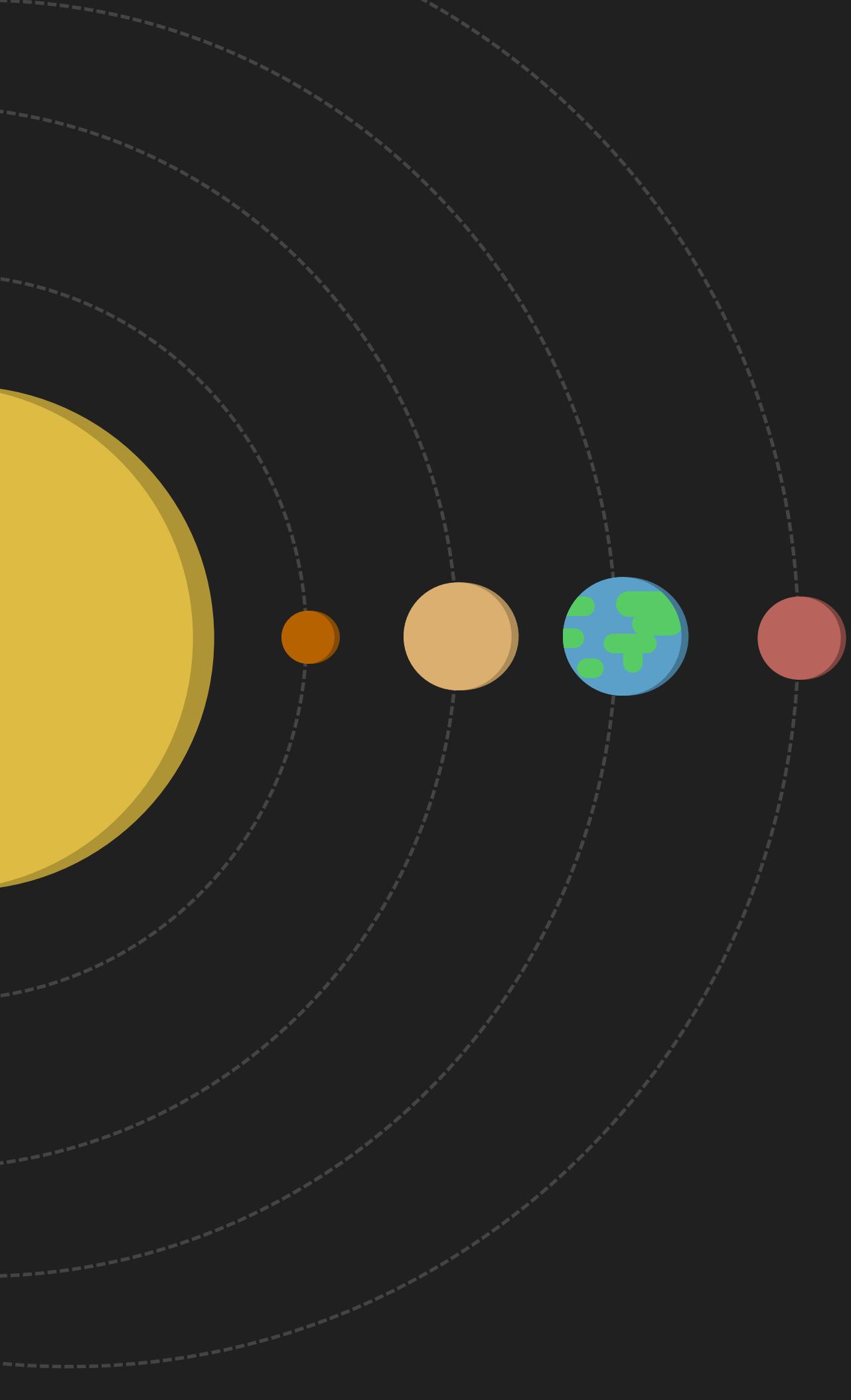
The hypothetical scenario is a form of directed storytelling meant to help draw upon past experiences of the participant in order to explain what they see as a typical or best response to a given challenge. It will also allow the researcher to compare responses across different teams within NASA to understand how those perceived best or typical responses differ. This study method isn't the primary method; it will only be conducted if time permits.

Strategy

The hypothetical scenario will be inserted in the middle of the semi-structured interview session. The activity is conducted after the facilitator learns about rover mission planning and collaboration tools from participants. After participants provide a step-by-step process or strategy to solve such problems, the facilitator will ask follow-up and weather-related questions.

Objective

Further decompose participants' mental models, team dynamics, and team dependency when it comes to solving weather-related issues.



Recruitment Kit

Introduction Email

My name is [insert name], a graduate student in the Master of Human-Computer Interaction + Design at the University of Washington.

I came across your profile at [insert text] and was fascinated by your work on [insert text]. I'd love to have a 1-hour chat with you to learn more about your work and to develop a better understanding of how weather could potentially affect rover mission planning.

For our capstone project, my team and I are working with NASA JPL to build a tool that helps scientists understand weather conditions on Mars for better rover control during the Mars 2020 mission. Besides learning more about how Martian weather affects operations, we are also interested in how scientists, rover planners, and engineers work together to plan and find valid targets. Information such as the typical workflow, decision-making process, collaboration efforts, and challenges is significantly valuable to our team.

I'm looking forward to hearing from you soon.

Thank you,
[insert name]

URL for Scheduling

<https://calendly.com/tylerla129/60min>

Consent & Gratuity Release Forms*

Hi [insert text],

As a part of our project, we are offering a \$20 Amazon gift card as a thank you for helping our team with this research. I will send you the consent and the gratuity forms shortly. Please sign them when you have a chance. Looking forward to talking to you.

*This will be sent 12-24 hours prior to the interview date

Recruitment Kit

Calendar Booking & Pre-questions

Tyler La
Mars - UW Research Team

⌚ 60 min
📍 <https://zoom.us/j/5267165613>

Thank you for helping our team with the research. Please select anywhere on the schedule to start booking. An earlier date will be ideal.

Select a Date & Time

April 2019

SUN	MON	TUE	WED	THU	FRI	SAT	
1	2	3	4	5	6	7	7:00pm
8	9	10	11	12	13	14	7:30pm
15	16	17	18	19	20	21	8:00pm
22	23	24	25	26	27	28	8:30pm
29	30						9:00pm

Pacific Time - US & Canada (2:12pm) ▾

10:00pm

Tyler La
Mars - UW Research Team

⌚ 60 min
📍 <https://zoom.us/j/5267165613>

🕒 **7:30pm - 8:30pm, Tuesday, April 16, 2019**

🌐 Pacific Time - US & Canada

Enter Details

Full Name *

Your e-mail address *

What is your area of expertise? *

Is there any material you'd like our team to go over prior to the call? (i.e, your published paper, specific research topic, terminology, etc.) *

Schedule Event

Capstone Project

Master of Human-Computer Interaction + Design

Project Brief

Mars 2020 Overview

The Mars 2020 rover mission is part of NASA's Mars Exploration Program, a long-term effort of robotic exploration of the red planet. The Mars 2020 mission addresses high-priority science goals for Mars exploration, including key questions about the potential for life on Mars. The mission takes the next step by not only seeking signs of habitable conditions on Mars in the ancient past, but also searching for signs of past microbial life itself. The Mars 2020 rover introduces a drill that can collect core samples of the most promising rocks and soils and set them aside in a "cache" on the surface of Mars. A future mission could potentially return these samples to Earth. That would help scientists study the samples in laboratories with special room-sized equipment that would be too large to take to Mars. The mission also provides opportunities to gather knowledge and demonstrate technologies that address the challenges of future human expeditions to Mars. These include testing a method for producing oxygen from the Martian atmosphere, identifying other resources (such as subsurface water), improving landing techniques, and characterizing weather, dust, and other potential environmental conditions that could affect future astronauts living and working on Mars.

Why Weather, Atmospheric and Sun Information Matter to Mars 2020

The Mars 2020 mission has a requirement to support 1:1 uplink operations —meaning that scientists and engineers may only use the same amount of time to develop instructions for the rover as it takes the rover to execute them. This differs from other Mars rovers which frequently sit idly while the ground teams plan their next move.

Scientists and rover planners must work closely together to find valid places to make targets in order to meet this timeline. There are several cases where conditions on Mars dictate where and how science experiments are conducted. To improve collaboration and enable operations teams to effectively meet the five hour timeline, you'll be conducting research and find a solution that helps scientists make valid targets with less back and forth between the rover planners. ASTTRO (The Advanced Science Targeting Tool for Robotic Operations) currently provides information related to the 3D terrain and rover position, but it doesn't currently include information about weather, atmosphere, and only includes limited information regarding the sun.

Advisors

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Research Timeline

Timeline: April 7th - June 12th

Deliverable: Submit a research report on June 12th

Audience:

- Mars scientists, rover planners, engineers (NASA JPL)
- Data visualization experts
- Weather experts
- Translational experts (i.e, air traffic controller, etc.)

Research Methods

A - Literature Review

Our team will conduct literature reviews of Martian weather, atmospheric conditions, Mars 2020 mission, and rover operations to familiarize ourselves with the research space.

B - Semi-structured Interview

We will be interviewing 16 participants (~1 hour each). Ideally, we aim for JPL scientists, engineers, and rover planners. Prior to any interview, our team will review their published work to prepare for a productive conversation.

C - Comparative analysis

We will perform comparative analysis in parallel with conducting semi-structured interviews. The objective is to assess the pros and cons of existing tools before coming up with the design.

D - Data Synthesis

Our team will then synthesize all insights collected from A,B,C to produce appropriate design principles for the design and prototyping phase. The final deliverable is a research report.

Research Ethics & Guidelines

The consent and gratuity release forms must be signed prior to any interview. We will make sure the consent form outlines clearly participants' privacy protection and permission to be recorded. Participants must understand that they don't have to answer any question that they don't feel comfortable answering and that they can exit the interview at anytime.

Sample Interview Questions

Collaboration among scientists, rover planners, and engineers

- Can you tell me more about your role and any mission you've worked on?
- Can you tell me more about the 5-hour rover planning operation?
- Can you walk me through your team's typical decision making process?
- What is the role of data visualization in rover mission planning?
- Can you tell me more about the different tools you use during mission ops?
- What are the features and capabilities that you'd like to have in a mission planning tool?
- Can you walk us through a tool that you use for analyzing data or making decisions?

Understand weather conditions on Mars

- When analyzing weather on Mars, what variables are important for rover ops?
- What types of weather events strike fear into your team? What are just inconvenient?
- What weather information would help the rover operate more efficiently on Mars that we don't understand yet?
- What don't we know about Martian weather? Where are the glaring knowledge gaps?
- How do you visualize weather data?

Data visualization

- What data viz programs do you and your colleagues typically use the most? (ie. Python, R, MatLab)
 - How do these tools integrate with the daily and end of Sol meetings?
- When using a new data visualization software, what do you find helps reduce the learning curve?
 - Is there anything you can think of that makes it harder?

Checklist

INTERVIEW PREPARATION

- Make sure the facilitator & note-taker roles are assigned
- Review participant pre-questions & review their published work (if applicable)
- Review 4 sets of interview questions and prioritize accordingly

TOOLS & TECHNOLOGY CHECKLIST

In-person Session

- Mobile phone for audio recording
- Video camera & tripod for video recording
- Additional mobile phone and camera in case of technical difficulties

Remote Session

- Email to participant with call instructions, consent and gratuity forms
- Laptop with video recording software
- Additional laptop in case of technical difficulties

Form & Data Collection

- Consent form
- Gratuity release form
- Semi-structured interview guide
- Stationary - Pen, paper, pencil, eraser

Study Method

INTRODUCTION

INTRODUCTION AND CONSENT FORM

5 MINUTES

Thank you for helping us with our research project. We are working with NASA JPL to design a tool that helps scientists understand weather conditions on Mars for better rover control during the Mars 2020 mission. Your background in _____ will help us understand _____ and provide us with insights on_____.

Before we begin, please have a look at the consent agreement we have sent you. It outlines that the interaction we will be having today will be kept anonymous, it specifies how the data collected will be used. During the interview, you do not have to answer any questions you do not feel comfortable answering and you are free to stop at any time if you don't want to continue.

Before we start, we wanted to know if it's okay for us to record audio and video of this interview.

[If YES] Thanks so much. We're starting the recording now.

[If NO] No problem, we can proceed without recording.

Do you have any question for us before we start?

SEMI-STRUCTURED INTERVIEW

30 - 40 MINUTES

ITERATIVE DIAGRAMMING [IF APPLICABLE]

10 MINUTES

HYPOTHETICAL SCENARIO [IF APPLICABLE]

10 MINUTES

WRAP-UP

5 MINUTES

Study Method

SEMI-STRUCTURED INTERVIEW

- We know that you are a [insert text] working on [insert text] but can you tell me more about your role and any mission you've worked on?

- [If NASA] How does it fit into the Mars team structure? What other teams do you collaborate with?

SET 1: ROVER MISSION PLANNING

- Can you tell me about the main highlights of your day?

- Can you tell me more about the 5-hour rover planning operation?

- What compromises (if any) do scientists make around decision making due to the time limitation?
- How much time is spent on x,y,z?
- Can you tell me more about your experience working with [scientists, engineer, rover planners]?
- How often are you collaborating with each other?
- How do you communicate with each other?
- Are there any challenges you face in the process?

- Can you walk me through your team's typical decision-making process?

- What processes reinforce shared mental models across the organization? What do you find most helpful personally?

- What is the role of data visualization in rover mission planning?

- Can you tell me about the time when you or your team use both bodystorming and data viz tool to plan for rover ops?

- Can you tell me more about the different tools you use during mission ops?

- Can you walk us through a tool that you use for analyzing data or making decisions?

- What does an ideal mission planning tool look like to you?

- What features do you want to include? Why?
- What other capabilities do you want to see? Why?

Study Method

SEMI-STRUCTURED INTERVIEW

SET 2: WEATHER

- When analyzing weather on Mars, what variables are important for rover operation?
 - What are the must-have variables? Why?
 - Is there any other weather variable that is important to look at? Why?
 - How often should weather be studied? (how often does Martian weather fluctuate?)
 - How much time do you need to spend looking at data to interpret and analyze daily weather patterns?
- What do you think are some implications of dust storms on rovers?
- What do you think are some implications of the sun on rovers?
- What types of weather events strike fear into your team? What are just inconvenient?
- What are the limitations with the current information available regarding weather on Mars?
- What weather information would help the rover operate more efficiently on Mars that we don't understand yet?
- If possible, can you walk us through a tool that you use for analyzing data or making decisions?
- Is there any existing tool out there that does a good job at visualizing weather info that you'd recommend us looking into?
- When interpreting weather data, do you want to see all the variables being visualized or just a few selected ones? Why?
- What does an ideal weather visualization tool look like to you? Can you walk me through its capabilities and features?

Study Method

SEMI-STRUCTURED INTERVIEW

SET 3: DATA VISUALIZATION

- What do you think is the role of data visualization at NASA?
- How does this tool fit into the daily rover operation planning? (5-hour meeting)
- What data viz programs do you and your colleagues typically use the most? (ie. Python, R, MatLab)
- Can you walk us through how you use it to analyze data or to make decisions?
- How does this tool help you collaborate with other teams?
- How does it help you explain for defend for your scientific experiment?
- What are some pros and cons that you encounter when using this tool?

[IF SCIENTISTS]

- How did you learn to use this tool?
- What features do like about this tool? Why?
- What do you think could be improved?

[IF DEVELOPER]

- How do you see this tool helps scientists and other teams in terms of rover mission planning?
 - What features/capabilities would you like to add?
-
- How is the data structured?
 - How do you typically access the data for analysis?
 - Do you specialize in a specific type of dataset or do you jump across domains as needed?

Study Method

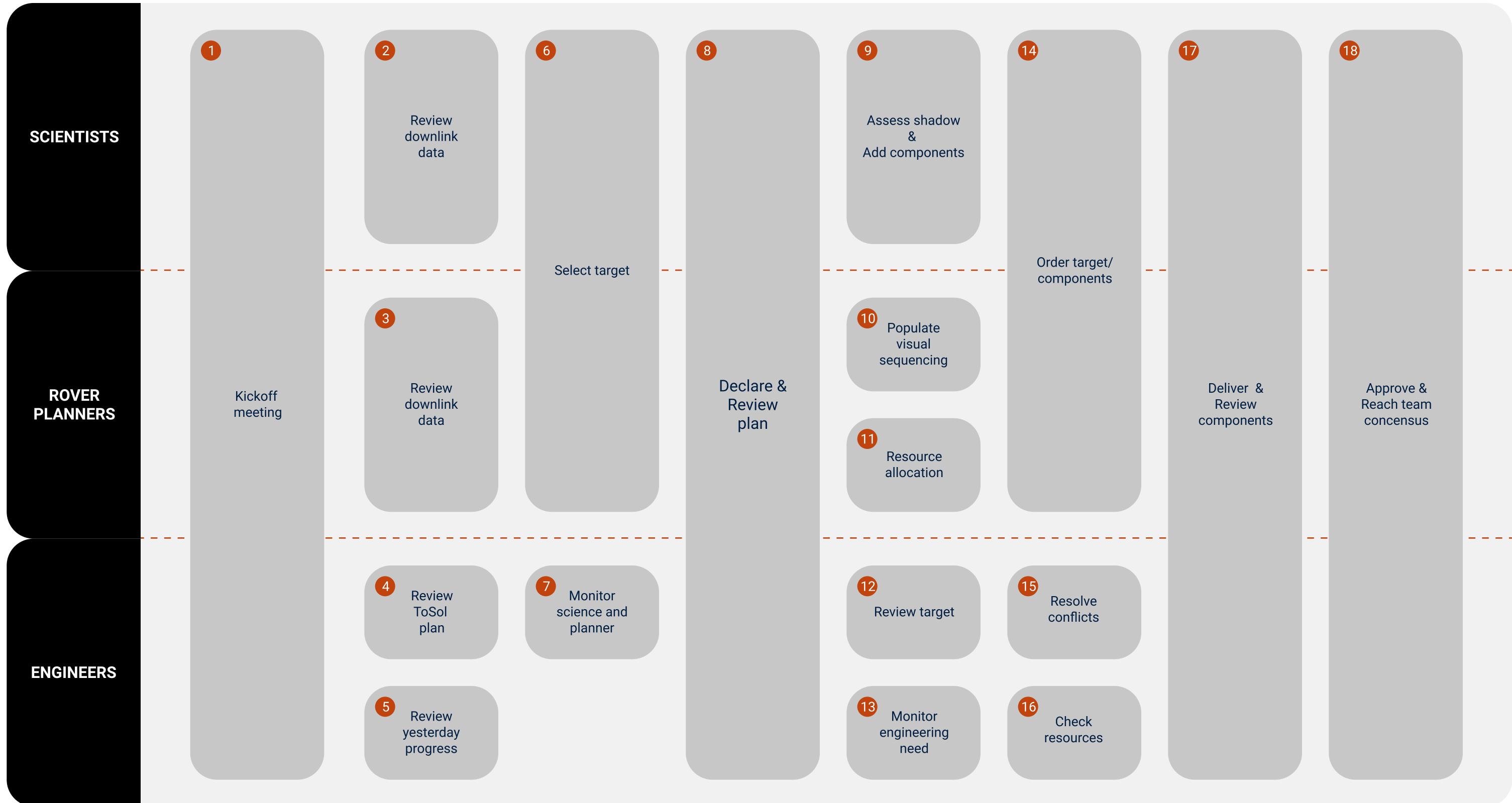
SEMI-STRUCTURED INTERVIEW

SET 4: TRANSLATIONAL INSIGHT

- Can you walk me through a typical task that you encounter? What is process like?
- What tools do you use to communicate with colleagues in different physical locations?
- There are a lot of moving parts in ATC, how do you prevent breakdowns in communication?
- What kind of planning meetings do you have? What general topics are discussed there?
- How do you and your teams make decision?
- How does weather factor into your role?
 - What meteorological information do you find vital?
 - What tools do you use to analyze meteorological data?
 - Where does the data come from?
- What processes reinforce shared mental models across the organization?
- Do you have any stories about a breakdown in communication and how it was resolved?
- Alternatively, a story where you realized that a good line of communication was vital to solving an issue?

Study Method

ITERATIVE DIAGRAMMING



Study Method

HYPOTHETICAL SCENARIO

Scenario

You've just been informed there is a previously unpredicted dust storm approaching the location of the rover. What processes do you follow? What does the overall rover mission planning team reaction look like?

Probing Questions

- How do you confirm there really is a dust storm approaching?
- Where do you find this information?
- How do you interpret this weather information?
- How do different people on the team react to it?
- How does the team make decisions in that instance?
- How often do you look at weather and atmospheric information?
- What weather variables are important in rover ops?
- What types of martian weather strike fear into your team?
- How is this info being visualized currently?
- Can you tell me about a time when weather impacted rover operations?

Wrap-up

WRAP-UP

Thank you so much for taking the time to talk to us. Your feedback is really valuable to us and will help us significantly with this project.

Do you have any additional information that you would recommend our team looking into?

Do you have any question for us?

How would you like to be credited for your contribution in our project?

Snowball Recruitment

We are still looking for more people to talk to for our project. If you know any [scientist/engineer/rover planner] that work on Mars missions, please let us know. That'd be really helpful!

[IF YES] - Do you think you could send an introduction email for us? We'd be happy to send you a blurb or an overview of our project if it helps.

Thank you once again!

Form

Consent Form

I voluntarily participate in a research project at the University of Washington. I agree that the research will be conducted via a phone call or a face-to-face interview and the session will be approximately 60 minutes in length, during which I will be interviewed by researchers from the University of Washington. Notes will be written during the interview. Both audio and video recordings of the interview will be captured, and I give my consent to be recorded.

I understand that the researcher will not identify me by name in any reports using information obtained from this interview. Subsequent uses of records and data will be subject to standard data use policies which protect the anonymity of individuals and institutions.

There are no costs or risks to me for participating in this study, however, if I feel uncomfortable in any way during the interview session, I have the right to decline to answer any question or refuse to continue participation in this study.

I have read (or someone has read to me) this form, and I am aware that I am being asked to participate in a research study. I have had the opportunity to ask questions and have had them answered to my satisfaction.

Printed Name

Signature

Date

Form

Gratuity Release Form

I acknowledge that I have received a gift card valued at \$20 for my voluntary participation in this research study.

Printed Name

Signature

Date
