ENHANCING PERFORMANCE THROUGH IMPROVED COORDINATION (EPIC)

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Abstract

Enhancing Performance through Improved Coordination (EPIC) is an approach to improving team performance that emphasizes identifying potential threats to coordination such as heavy workload, accelerated op tempo, or off-nominal states. Our long-term interest is in creating a coordination-aware system to promote better team performance by modeling situational properties and their relationship to crew coordination. Our current investigations focus on (1) how an automated agent could detect coordination breakdowns among teams of human operators; and (2) how to measure team coordination and performance.

Introduction

The increased use of automation has imposed new dynamics on how crewmembers work together and has changed the nature of crew communication in subtle ways. The level of coordination that an operator must sustain under an accelerated tempo is likely to increase with the amount of information that must be managed (leaving less time and attention to devote to coordination). We conducted a Needs Analysis study using as an example domain coordination within the mission crew of a Navy P-3 maritime patrol aircraft. We conducted two data collection exercises: discussions with P-3 operators at NAS Jacksonville (VP-30); and analysis of recorded crew conversations provided by NAVAIR (Bell & McFarlane, 2001). An outcome of this analysis is a top-level taxonomy of detection strategies that an automated coordination support capability could apply in recognizing or anticipating coordination breakdowns.

In this paper we present on-going work in two projects that each follow-up on our preliminary analysis. In the first project, we developed an experimental testbed to prototype an EPIC capability. In this testbed, pairs of subjects (one role-playing a pilot and the other role-playing a sensor operator) execute experimental tasks using a commercial off-the-shelf (COTS) flight simulator and a simulated sensor station. The coordination between subjects is mediated through console commands and data are captured for crew interactions as well as performance of the crew in the simulated airborne sensing task. EPIC detects lapses in coordination and takes steps to restore coordination.

In the second project, we are extending our approach and collecting additional data under a NAVAIR Training Systems Division Phase I SBIR. Our focus in this effort, just initiated, is on defining requirements for automated measurement of crew coordination and team performance by developing team performance metrics and conducting experiments to validate those metrics.

Pilot Study

We developed an experimental testbed to explore our hypothesis that more effective coordination can improve crew performance. Of special interest was the effect of higher levels of distraction on coordination and any second-order effects on performance. Collecting data relevant to this hypothesis requires: (1) a collaborative task environment in which two subjects work in coordination with one another; (2) observational mechanisms that capture and record interactions between each subject and the application as well as between the subjects; (3) a coordination support mechanism that monitors and promotes coordination among the collaborators.

Human-human coordination makes use of a rich range of communication methods, including speech, gesture, and narrative. Each of these modalities presents challenges for capturing and interpreting what is being communicated. Since the purpose of our study is limited to how coordination lapses can be detected and remediated, we designed a communications protocol that restricts the language to a limited set of commands that one subject can broadcast to the other. Subject 1 communicates a command to the pilot by constructing a phrase from primitives (*e.g.*, "turn to heading two six zero") and then transmitting the message (which results in a speech-synthesized command being broadcast to Subject 2). The resulting command set is sufficient for subjects to succeed in the experimental tasks and is readily interpreted by the system.

We also wished to define some simple detection mechanisms (indications of a possible coordination lapse) and interventions (alerts to the sensor operator). Our intent was not to derive a set of robust detection mechanisms or intervention strategies but to gather preliminary data on crew performance effects. In a later section we describe the coordination triggers and interventions we implemented for our pilot study.

Testbed

Our experimental task involves a simulated two-person air crew consisting of a pilot and a sensor operator. The job of the pilot is to control the airplane; the job of the sensor operator is to image targets appearing on a display, by guiding the pilot to maneuver the airplane in a position that optimizes the imagery. The aircraft is an RC-12 reconnaissance variant of the C-12, the military designation for the Beech 200 Super King Air (Figure 1).

Figure 1. C-12 in Simulated (left) and Real (right) Worlds.

The pilot station consists of a COTS flight simulator called X-Plane (Laminar Research), a Thrustmaster Fox Pro 2 joystick and throttle, and a Dell GX-240 Intel Pentium IV PC running Windows 2000 Professional. (Figure 2).

Figure 2. Experimental Testbed: Pilot's Station

The sensor station software was written for this experiment in Java, running Linux on a Dell dual processor X86[1]. The display shows a map that includes an icon representing the aircraft's current position (updated in real time by the data streamed from the flight simulator), and an icon representing the "target" that the airplane must fly over in order for the sensor operator to image it. The sensor operator's interface also provides a small control panel for creating and sending commands to the pilot, and another used for "initializing" the sensor (a distracter task in some scenarios). The sensor operator's commands to the pilot are spoken via CMU's Festival speech synthesis software. A window displays commands to the sensor operator that are generated by each scenario script. Figure 3 shows a snapshot of the sensor operator's display during a scenario.

Experimental Design

The dependent variable (performance in the simulated task) was measured varying the independent variable of workload.[2] To measure the effects of workload on coordination, we induced work for the sensor operator by introducing additional tasks during successive scenarios in the experiment.

Coordination Support

Supporting coordination in EPIC requires detection mechanisms and interventions. Detecting a coordination lapse (or imminent coordination lapse), in the general sense, involves a co-occurrence of two conditions: (1) a tactical situation that is correlated with coordination lapses, because of workload, accelerated operational tempo, threat level, or other factors; (2) an absence of coordination activity among crew members who should otherwise be coordinating.

In the task environment we defined for our experiments, we identified four situations that are likely to correlate with coordination lapses:

- failing to communicate for some elapsed time interval;
- closing on target (frequent course adjustments needed);
- straying too far off course;
- too far above or below assigned altitude (3rd scenario).

For each condition, we designed (but did not implement) a simple detection mechanism that would notify the coordination monitor of the associated condition.
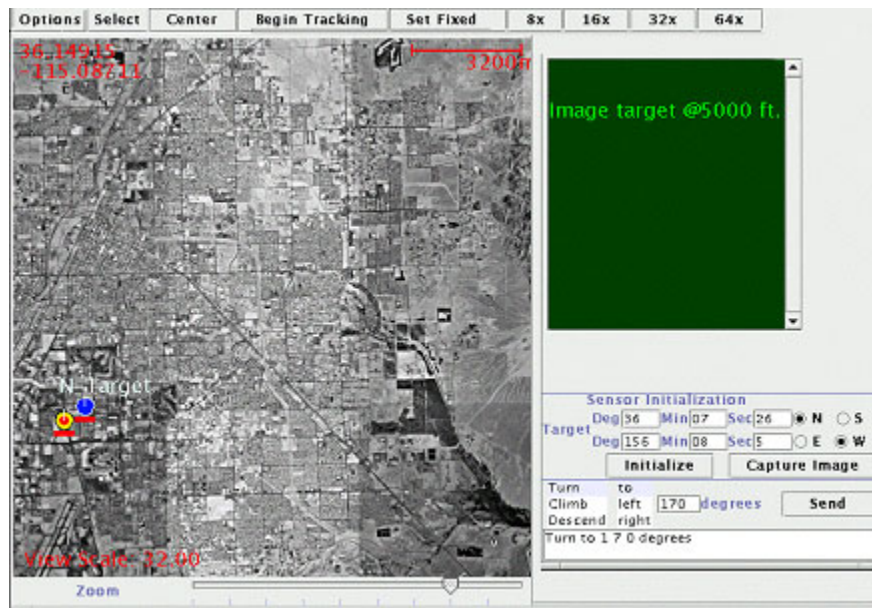
Figure 3. Experimental Testbed: Sensor Operator's Station

We defined interventions for each condition, which in all cases would prompt the sensor operator to provide the pilot with updated instructions. Table 1 lists the detection mechanisms and corresponding intervention for each.

Table 1. Detection Mechanisms and Interventions

Detection Mechanism	Intervention Alert
No comms for 30 sec.	Send update
Within 30 sec. of target	Closing on target, verify heading
More than 30° off course	Getting off course, verify heading
Altitude error > 1000 feet	Check altitude

Method

The experiment employed two subjects (one pilot, one sensor operator) and consisted of three scenarios, each lasting approximately five minutes. Each pair of subjects was given general instructions and a short briefing about the experiment (Appendix A).

The independent variable of workload was controlled by successively increasing task complexity over three scenarios. Subjects were given instructions specific to each scenario prior to the execution of that scenario (Appendix B). The first scenario asked only that the operator provide guidance to the pilot so that the aircraft would fly directly over the target, at which time the operator captures a sensor image of that target. In the second scenario, we introduce a distracter task in order to create a potential threat to coordination, by instructing the operator to expect a message providing the Lat/Long coordinates of the target, which are then to be typed into the sensor control panel in order to "initialize" the sensor. When the aircraft comes within roughly sixty seconds of the target, the simulation provides the coordinates to the sensor operator (Figure 4,

left). In the third scenario, we introduce an additional distracter that itself requires coordination, by instructing the sensor operator to expect a message defining the altitude at which the image is to be taken (which the subject must then pass along to the pilot-subject). The altitude is provided after one minute, is revised after two minutes, and is revised a third and final time after three minutes (Figure 4, right).
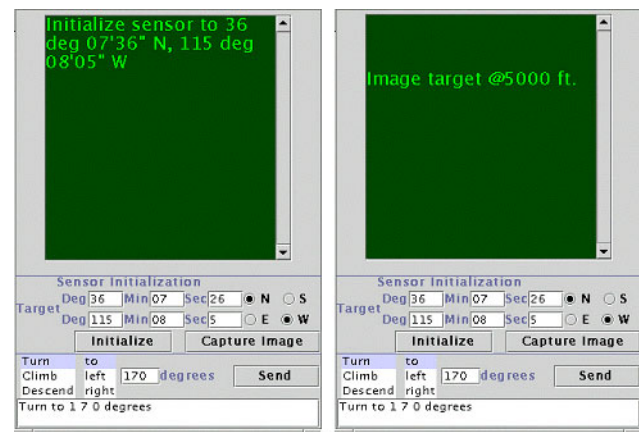

Figure 4. Sensor Initialization Distracters for Scenarios 2 & 3

Due to limited time and subject availability, we did not get to run subjects under the EPIC-enabled condition, so our goal was to validate the testbed and to baseline performance.

Four pairs of subjects were formed from among a team of professional computer scientists. Four subjects were self-selected to the pilot role because of experience flying airplanes or with flight simulators (since we did not want to

measure flying skills but instead wanted to focus on coordination). Subjects playing the sensor operator role were familiar with moving map displays and compass headings but had no experience flying airplanes and reported limited exposure to flight simulators.

Results

Performance was scored by distance to the target when the sensor operator "imaged" the target. Table 2 shows distance to target (in meters) when the sensor operator depressed the "Capture Image" button.

Table 2. Distance to Target (in meters) at Image Capture

	Scenario 1	Scenario 2	Scenario 3
Pair 1	248	224	598
Pair 2	1310	170	192
Pair 3	2233	201	1950
Pair 4	1694	766	550
Mean	-	340	823

We expected an increase in error (distance from target) with increasing scenario complexity. However, we also anticipated a practice effect that would counter the increased complexity. Treating scenario 1 therefore as a practice case, we compared performance in scenarios 2 and 3, and observed in three of four cases an increased error from scenario 2 to scenario 3. The mean similarly suggests the effects of scenario complexity on performance.

Discussion

The results from the preceding experiment provide suggestive evidence of the interplay between task complexity and task performance; since performance in this case hinged on coordination it is tempting to treat this experimental design as an approach to understanding team interaction. However true measures of team performance must go beyond task performance measures. In the remainder of this paper we report on the early stages of work we are performing under a NAVAIR Training Systems Division Phase I SBIR grant to investigate team assessment measures.

Team Assessment

The overall goal of this SBIR effort is to fully develop the EPIC intelligent team performance assessment tools. In Phase I, the goal is to define a methodology and plan for the evolutionary development of the EPIC system. Below we provide the rationale for this work and describe the planned approach.

Rationale

A key challenge faced in the development of EPIC is to perform meaningful automated assessment of team coordination performance. Team behaviors are far more difficult to characterize than task or outcome behaviors. Team behaviors can be highly asynchronous, and can reflect temporal leaps backward and forward as crew members replay past events and anticipate upcoming events. Team interactions are also less directly assignable to a discrete task, since operators naturally converse about multiple co-occurring tasks. These characteristics also make assessing team behaviors a challenge, with the additional difficulty of judging what actions might constitute good team behavior in the absence of reliable metrics. For instance, good coordination might in some cases be evidenced by a minimal level of voice communication, while in other cases steady communication among team members indicates good coordination, as was the case in the experiment described. Interaction in general might in some situations be coordination-enhancing and in others present a distraction. Team behaviors, by definition, implicate interactions between humans in all the rich modalities (e.g., speech, gesture) that are effortlessly employed by humans but that remain largely elusive to machines. These attributes also make team behaviors difficult to capture.

A general response to the challenge of isolating team behaviors is to adopt the position that team skills are not what counts the most; mission performance is what matters, and team skills, while they certainly enhance mission performance, should be regarded as a means to an end. While we agree that enhancing mission performance is the ultimate aim of training, we regard team behavior as critical to mission success and under-represented in training (due in part to the challenges summarized above). Mission-related measures, which characterize end results, are usually given a high priority for data collection because they are objective, possess high face validity, and are usually easily obtained via automated systems. However, as "end results" are affected by many variables—controlled and uncontrolled—they typically suffer from lack of reliability (Lane, 1986) and thus have limited utility in deriving answers to questions addressed in research. Also, while outcome measures can signal a problem (e.g., bomb hit distance), they have restricted usefulness in diagnosing the cause of the problem (e.g., Cannon-Bowers & Salas, 1997; Dwyer, Fowlkes, Oser, Salas, & Lane, 1997). In contrast, team process measures characterize how teams perform tasks. If the observation of team processes is driven by a priori constructs and expectations, team processes can be extremely diagnostic of performance deficiencies.

Thus, our goal is to develop training technologies that help identify, diagnose, and remediate team-level behaviors. Moreover, we see this need in both traditional, instructor-led training and automated training venues. The approach we are taking to achieve this goal is described in the remainder of the paper.

Approach

Our approach is incremental, beginning with an analysis of the domain, proceeding with preliminary data collection, and concluding with the development of an EPIC framework.

Team Assessment Domain Analysis

The EPIC framework is intended to provide improved training and readiness across a broad spectrum of team training venues. In its early development, though, EPIC will be grounded in a specific application domain: naval aviation. It is our intent to establish early in the effort the specific properties of the domain as it relates to team assessment, and to understand the crew coordination processes that obtain in this domain. The outcome of this task will be a mapping from performance markers to training needs and a matrix identifying training system hard- and live-ware currently used by the naval aviation community.

In conducting our domain analysis, we are investigating patterns of coordination behaviors and trends that influence these behaviors. We see five related trends as having pronounced implications for crew coordination and team training. First, improved sensor packages are bringing more information onboard, and better communications links are pulling in data collected from other sources. As a result, operators are facing increased volumes of information. Second, aircraft roles are becoming more multi-mission and operator duties are, as a result, becoming more diverse and interdependent. Third, military and supporting agencies are emphasizing joint and coalition operations, which incur more demanding requirements for coordination among personnel from different services and nations. Fourth, military planners are focused on network-centric warfare, which will generate both a more distributed team structure and an accelerated operational tempo. Fifth, computer automation in systems continues to grow in both ubiquity and complexity. This automation requires intermittent human supervision and its presence results in a much higher rate of computer-initiated interruptions of operators. Part of our analysis is focusing on team assessment in the context of new systems, developed to enhance mission effectiveness (e.g., more powerful sensors, improved communications links). Mission systems carry implications for crew coordination but are seldom designed to support coordinated activity (Qureshi, 2000). The increased use of automation has imposed new dynamics on how crewmembers work together and has changed the nature of crew communication in subtle ways (Bowers, Deaton, Oser, Price, & Kolb, 1995). For instance, automated systems that capture the attention of an operator may compromise established coordination processes (Sheehan, 1995). Automation thus carries the risk of adverse effects on crew coordination, possibly leading to unsafe conditions (e.g., Diehl, 1991).

The outcome of the domain analysis will be a descriptive analysis of the selected domain that identifies team training and assessment needs, practices, and constraints, as well as characterizing training system hard- and live-ware currently used by the naval aviation community.

Scenario-Based Experimental Design

The domain analysis will provide background information from which we can construct a set of experimental scenarios aimed at linking crew actions to coordination behaviors and team skills. We are strongly aligned with scenario-based training as a way to ensure that instruction is focused on the skills being trained. In previous work, we developed a theoretical and methodological basis for scenario-based training, called Goal-Based Scenarios (Schank, Fano, Bell, & Jona, 1994). In the aviation domain we have demonstrated the efficacy of scenario-based training (Hitt, Jentsch, Bowers, Salas, & Edens, 2000) and the utility of tools that assist in scenario generation (Bowers, Jentsch, Baker, Prince, & Salas, 1997).

Pilot Study

We will develop experiments around our created scenarios that are likely to elicit salient behavioral cues corresponding to coordination and team skills. We have demonstrated that the study of aircrew coordination can be accomplished using low-cost flight simulators (Jentsch & Bowers, 1998). Our related work using pairs of subjects in low-fidelity flight simulation (Bowers, et al., 1995) will provide a basis for our experimental design, though the design will be improved and adjusted to fit the domain.

Our initial design will call for two subjects, role-playing a two-person aircrew in a low-fidelity flight simulation, engaged in performing various tasks drawn from mission phases typical of our selected domain. Scenarios will present subjects with different levels of challenge (by modulating automation, workload, distractions, ambiguities, etc.) and will be designed to elicit specific team behaviors. Data to be captured includes subjects' inputs to the flight simulation, their recorded "radio transmissions" to simulated players, and videotaped interactions with each other. Data will be coded by critical competencies and a cluster analysis will seek to identify patterns that can yield team assessment metrics.

Analytical Framework

Results from our domain analysis and pilot study will provide inputs from which we will create the analytic framework for EPIC. The framework will be grounded in an analysis of prior work in cognitive engineering and team performance, adapting our previous research in event-based approaches to training and team-dimensional training. Part of this theoretical and methodological framework will define a candidate set of team performance metrics.

EPIC will draw on the considerable body of research in event-based approaches to training (EBAT) conducted by NAVAIR Training Systems Division (Fowlkes, Dwyer,

Oser & Salas, 1998). EBAT defines instructional strategies and methods required for effective training and prescribes a structured, seven-step format that facilitates training and testing specific knowledge and skills. The process defined by EBAT will provide a skeletal framework that we will augment and tailor to our domain in refining EPIC. Another relevant model from NAVAIR Training Systems Division is Team Dimensional Training (Smith-Jentsch, Zeisig, Acton & McPherson, 1998). Research in this area has suggested that the effectiveness of training exercises can be enhanced through systematic, guided team practice. Team Dimensional Training is therefore relevant to EPIC's focus on team coordination.

Other relevant research we will examine comes from the literature on coordination, which has revealed patterns of coordination and some of the conditions under which coordination breakdowns are more likely. Activity can be coordinated by a central supervisor, by a team of cooperating peers, or by a distributed supervisory team (Palmer, Rogers, Press, Latorella, & Abbott, 1995). Studies have identified patterns that subjects exhibit while coordinating activity (e.g., Decker, 1998) and have observed subjects attenuating their coordination activity in response to the demands of the current situation (Schutte & Trujillo, 1996).

Factors that contribute to coordination failures frequently involve an increased workload or need for accelerated activity and more rapid decision-making. Often, a chain of events escalates coordination difficulties. A typical instance is when a process being monitored exhibits some anomalous behavior and the automation system begins generating alerts. The malfunction will often induce off-nominal states throughout other, related subsystems, and the operator monitoring these processes will be confronted by a growing queue of alerts, each of which taxes the operator's capacity to manage interruptions (e.g., McFarlane, 1999). Reporting and resolving these alerts introduces a heightened demand for coordination among team members, precisely when the crew is least able to sacrifice any additional attention (Woods, Patterson, Roth, & Christoffersen, 1999). Findings from these studies will help us to identify specific coordination activities that crews may be evaluated against, whether by an automated training system or by a human evaluator.

Reporting and Phase II Plan

Our domain analysis, pilot study data, and new framework will be integrated in into a coherent set of findings that will enhance our understanding of team assessment and set the stage for a broader experimental program. We will develop a detailed plan for determining the utility of our approach for both instructor-led and automated team training, and for implementing a robust technology for team assessment (automated and advisory).

General Discussion

This paper described two related efforts supporting the development of EPIC, a system supporting intelligent team performance measurement. Team coordination is becoming increasing important across a variety of military tasks and missions. At the same time it is becoming more challenging for reasons discussed in this paper such as the quantity of real time information that must be assimilated by teams and the complex nature of today's military teams. Moreover, while assessment of team performance has always been difficult, it is becoming increasingly so, for example, in the assessment of distributed teams that communicate digitally. Thus, the importance of intelligent team assessment tools envisioned for EPIC is several fold.

- Support instructors. The EPIC framework can support instructorless training or serve as an instructor assistant. The military is downsizing, and so there are reduced manning requirements. In addition, there are important team interactions that are not easily observed by humans, thus automated assessment systems are needed that can provide assistance to instructors.

- Support advanced learning. Many military tasks require a high level of adaptive performance, encompassing the assimilation of information, and the ability to recognize and react rapidly and effectively to a variety of tactical situations. There are examples of tasks that require the acquisition of advanced domain knowledge to perform well. Advanced learning has not been facilitated very well in any training or education setting (Feltovich, Spiro, & Coulson, 1993), in part because of the lack of measurement systems that address the complex skills and knowledge required.

- Support operational performance. As we have argued in this paper, the increased use of automation has imposed new dynamics on how crewmembers work together and has changed the nature of crew communication in subtle ways. The level of coordination that an operator must sustain under an accelerated tempo is likely to increase with the amount of information that must be managed (leaving less time and attention to devote to coordination). EPIC can support the identification of coordination lapses in operational systems.

- Support test and evaluation. Finally, automated performance assessment, as provided by EPIC, can be used to support test and evaluation, for example, to assess the impact of the introduction of new systems on team coordination, or the employment of new tactics, techniques and procedures.

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Appendix A. Instructions to Subjects

General Instructions (Mission Commander)

You are the Mission Commander (MC) flying in an RC-12, a twin turboprop airborne reconnaissance aircraft. You are responsible for all operations except flight (in other words, you are in charge of everything that isn't actually controlling the airplane). The mission you will perform is to image a target using your electro-optic sensor (a camera) mounted beneath the airplane. Your sensor station provides a map display that includes an ownship indicator and an icon showing the target to be imaged. You also have a

control panel for taking pictures of your target. Your sensing equipment works best when directly over the target, so the success of your mission depends on how closely you come to flying directly over the target.

Since the flight station does not display targeting information, the pilot needs your help to fly the airplane along a route that will result in a successful mission. So you need to help the pilot maneuver the airplane into a position that provides good imaging over your target.

Communication is essential. In this experiment, you "speak" to the pilot through a communications panel on your display. Through this panel you construct messages to the pilot and broadcast them via synthesized speech. If the pilot asks for a repeat of the message just press "Send" again and the message will be re-broadcast.

Each mission in this experiment lasts approximately four minutes. You will perform three missions.

General Instructions (Mission Pilot)

You are the Mission Pilot (MP) flying the RC-12, a twin turboprop airborne reconnaissance aircraft. You are responsible for flight operations. Your crewmate is the Mission Commander (MC), who is responsible for helping locate the aircraft over a target to be imaged. The MC will also control the imaging equipment and communicate with Operations on the ground. Your sensing equipment works best when directly over the target, so the success of your mission depends on how closely you come to flying directly over the target.

Your flying will involve only the cruise segment, though some basic maneuvering might be required in order to get on target. Since the flight station does not display targeting information, you can expect some help from the MC in guiding the airplane into a position that provides good imaging over your target.

Communication is therefore essential. In this experiment, the MC can "speak" to you through a communications panel that will broadcast synthesized speech. You do not communicate with the MC in this experiment (exception: If you did not understand a command, you may ask the MC to re-broadcast it).

Each mission in this experiment lasts approximately four minutes. You will perform three missions.

Appendix B. Scenario-specific Instructions

Mission Commander

Mission 1: Your RC-12 has arrived on station for a day training mission in the vicinity of MCAS Miramar. Your mission is to image a target by guiding the airplane over the target and pressing the "Capture Image" button when directly on top of the target. You get to press "Capture Image" only once so plan accordingly!

Mission 2: Your RC-12 has just departed from NAS Patuxent River for a night training mission. You have reversed your outbound course and are approaching the field. Your mission is to image a target in the vicinity.

In this scenario, your sensor station must be initialized prior to use. The procedure involves inputting target coordinates to the sensor initialization panel on your display. Your communications panel will provide these values for you to input. The procedure takes approximately fifteen seconds so be sure to plan accordingly.

Mission 3: The RC-12 is approaching Nellis AFB at dusk. Your mission is to image a target in the vicinity; you will again be required to initialize your sensor equipment.

For this mission the target must be imaged at an altitude to be specified by Operations, who will send desired altitude via a text message displayed on your console. Altitude instructions may be issued multiple times so pay attention. Note that the pilot does not have access to text messages so be sure to provide guidance regarding the appropriate altitude at which to overfly the target.

Mission Pilot

Mission 1: Your RC-12 has arrived on station for a day training mission in the vicinity of MCAS Miramar. Your mission is to image a target.

Mission 2: Your RC-12 has just departed from NAS Patuxent River for a night training mission. You have reversed your outbound course and are approaching the field. Your mission is to image a target in the vicinity.

Mission 3: The RC-12 is approaching Nellis AFB at dusk. Your mission is to image a target in the vicinity at an altitude to be specified by the Mission Commander.