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T-7A Distributed Test: Remote Testing of Prototype Aircraft

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Abstract

The T-7A is the new jet trainer aircraft for the United States Air Force. The prototype T-7A test aircraft were flown based out of a contractor test facility 2,800 km away from the Air Force test team. The combined government and contractor test team established distributed test operations that enabled engineers to monitor real-time flight test missions with telemetered data and communication in control rooms at both the contractor location and the remote government location. This paper describes the setup and capabilities of the network connection; the events used to establish distributed test operations; the concept of operations across multiple organizations; technical, organizational, and contractual challenges encountered and lessons learned; and planned future growth of this capability.

Key words: distributed test operations, remote test, real-time telemetered data, experimental flight test, T-7A Advanced Pilot Trainer

Background

The T-7A Advanced Pilot Trainer is the United States Air Force's new jet trainer aircraft. It will replace the T-38 as the primary aircraft for Undergraduate Pilot Training and Introduction to Fighter Fundamentals Pilot Training. The T-7A is a clean-sheet design aircraft with a single engine, tandem cockpit, and digital flight control system.

Test flights of the T-7A were flown by contractor test pilots, with a ground-based control room of engineers that monitored real-time data telemetered from the test aircraft and controlled the flow of test events. The engineers in the control room were led by a test conductor who communicated directly with the aircrew, while groups of specialized discipline engineers monitored specific aircraft parameters. The software used to display the real-time telemetered data was the Interactive Analysis and Display System (IADS). IADS allowed the team to design specialized displays and analysis windows to optimize data monitoring.

The initial T-7A testing was conducted on two prototype aircraft at the contractor test facility in St. Louis, Missouri, USA. The lead developmental test organization was a government test team with the Air Force Test Center, located 2,800 km away at Edwards Air Force Base (AFB), California, USA. Future T-7A testing will occur both in St. Louis and at Edwards AFB, with simultaneous testing planned for aircraft at each test location. The test team consisted of government personnel based out of Edwards AFB and contractor personnel based out of St. Louis.

To minimize travel for control room personnel, the combined test team established Distributed Test Operations (DTO). DTO refers to the streaming of real-time aircraft test data and audio from a primary test site to a remote test site. DTO was used to connect test control rooms in St. Louis and at Edwards AFB to each other, enabling the rooms to operate virtually as a single control room. In this construct, it was imperceptible to the airborne test aircrew that there were multiple control rooms, versus the standard single control room. The control room located at the same facility as the aircraft was defined as the primary control room, and the control room at the other test site was defined as the remote control room. Figure 1 shows a test conductor in the remote control room during a T-7A DTO mission.

Fig 1. Remote Control Room during DTO.

The establishment of T-7A DTO involved both technological developments and organizational agreements to align processes, techniques, and procedures between the government and contractor organizations.

Equipment Installation and Setup

The Defense Research and Engineering Network (DREN) was used to connect the contractor and government test sites. The DREN was a high-performance secure network owned by the United States Department of Defense, with service delivery points at various sites across the country. The DREN had data transfer speeds of up to 100 Gbps.

Prior to the establishment of T-7A DTO, some infrastructure updates were required. DREN delivery points already existed at Edwards AFB and near the contractor facility in St. Louis. The T-7A team sponsored the DREN installation to the contractor facility and installed the equipment required to send the mission data and communication over the DREN. This equipment included an access gateway that interfaced with the existing telemetry and communication systems; a network Ethernet switch that received information from two video encoders (for outgoing DTO), sent information to two video decoders (for incoming DTO), connected to the access gateway, and sent information to an encryptor/decryptor; and an encryptor/decryptor that encrypted outgoing data to the DREN and decrypted incoming data from the DREN. A diagram of the setup on one side of the DREN is shown below in Figure 2; the setup was mirrored on the opposite site of the DREN. The hardware installation for the T-7A DTO effort was completed in March 2020.

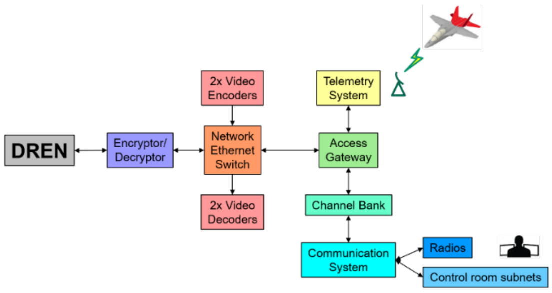

Fig. 2. Equipment Setup for DTO.

Capabilities

During DTO, both control rooms received real-time information including: aircraft telemetered data, "hot mic" audio from the test pilots, two-way communication capability to the other control room, radio capability to the test aircraft, and live video feeds from ground stations.

Aircraft telemetered data allowed engineers in the control room to monitor aircraft parameters real-time. Hundreds of aircraft parameters were available, and discipline engineers used IADS displays to view the data relevant to their specialty. Many of these data parameters were required to monitor aircraft safety and evaluate test maneuvers. Examples of these data parameters included aircraft airspeed, pitch rate, control surface positions, engine temperature, etc.

"Hot mic" provided a one-way live audio feed from the cockpit to the control room. This allowed the aircrew to ask questions and provide comments to the control room without physically keying a microphone or radio switch.

The inter-room communication system between the two control rooms (not transmittable to the aircrew) included a "room net" with all control room participants at both locations, as well as "subnets" for subgroups of control room personnel. It was possible to use up to 24 subnets at a time, although typical missions used only five subnets. Subnets were divided up by flight test discipline (flying qualities, propulsion, subsystems, loads, etc.) to enable each discipline to speak to their counterparts in both control rooms about test point maneuvers and data quality.

Live video feeds from ground stations permitted the control room team to view the aircraft during ground operations, taxi, takeoff, and landing.

The bandwidth connection on the DREN between St. Louis and Edwards AFB was 100 Mbps. A telemetry stream of T-7A flight data was 5 Mbps, and two telemetry streams were sent across the DREN for DTO missions (one primary stream and one backup stream). The communication (radios and inter-room communication) was 1.5 Mbps. Live video was approximately 1 Mbps; only one live video stream was typically used, but the team maintained the capability to send/receive two video streams per mission. Thus, the maximum bandwidth used for a T-7A DTO mission was ~13.5 Mbps. If two DTO missions were conducted simultaneously (such as one from each test location), ~27 Mbps would be used. Thus, even at maximum expected bandwidth demand, T-7A DTO would only use about 27/100 Mbps of bandwidth; therefore, DREN bandwidth was not a limiting factor for DTO missions.

DTO Establishment and Events

Prior to conducting the first live flight test mission using DTO, a data playback event was completed as buildup. During this playback event, simulated real-time aircraft data and audio, live video, and control room communications were sent from the control room in St. Louis to a control room at Edwards AFB. While the data was a playback file, the software in the control room, IADS, treated the data as live aircraft data. Issues (discussed below) discovered during this event were investigated and corrected prior to the first live T-7A DTO flight test event, which was conducted on 30 April 2020.

As of the publication of paper (April 2022), 56 real-time DTO missions have been conducted. All of these live missions were conducted with the primary control room and aircraft in St. Louis, and the remote control room at Edwards AFB. Flight test with an aircraft at Edwards AFB is scheduled to begin in July 2022.

As risk reduction for DTO missions with Edwards AFB as the primary test site, data playback tests were conducted from a control room at Edwards AFB to a control room in St. Louis. The first test involved sending simulated live aircraft data and real live video from a control room at Edwards AFB to a control room in St. Louis. The second test evaluated the potential for simultaneous DTO missions at both test locations. Four control rooms were used for this evaluation: two at Edwards AFB and two in St. Louis. Control room 1 in St. Louis sent simulated live data and aircraft audio, live video, and live room-to-room communications to control room 2 at Edwards AFB. Control room 3 at Edwards AFB sent simulated live data and aircraft audio, live video, and live room-to-room communications to control room 4 in St. Louis. The communication connections between the control rooms were transposed initially, and the team troubleshot and corrected the issues during the checkout. There were no noticeable latency increases or issues with DREN performance; therefore, the test team does not anticipate bandwidth issues for future simultaneous DTO missions.

Latency

During flight test, the control room was required to monitor aircraft parameters to make safety-of-flight determinations, evaluate maneuver quality, and analyze data between test maneuvers. For example, to avoid ground impact during test maneuvers, the control room monitored aircraft airspeed, altitude, dive angle, bank angle, and acceleration to make “abort” calls to the pilot if the aircraft was going to exceed pre-determined safety margins.

The most pressing safety concern when establishing DTO was the latency between the aircraft and the two test sites. The team needed to ensure that the remote test site received aircraft data and could communicate a safety decision back to the primary test site with no noticeable delay, as if the remote control room was co-located with the primary control room.

The team programmed a latency measurement into the control room data displays. This latency measurement calculated the difference between the aircraft time when it sent a data package and the control room time when it received the data package.

This latency measurement was local to each control room, so each control room monitored the latency from the aircraft to their own control room. For aircraft operations in St. Louis, the Edwards AFB control rooms typically experienced latencies of 120-140 ms. Comparing that to the local latency in St. Louis indicated that the average latency increase due to sending data across the DREN via was 40-80 ms.

Latencies in both control rooms increased to ~300 ms when a telemetry repeater was used to relay data from the aircraft to the control room in St. Louis. However, the remote control room only suffered the standard 40-80 ms delay as compared to the primary control room. In the DTO missions to date, the latency in the remote control room was imperceptible to experienced control room personnel, and the timing of communication and data seemed comparable to the timing of a locally-executed control room mission.

A safety review board, comprised of experienced flight test professionals independent of the T-7A program, determined that latencies under 500 ms were acceptable for safety-of-flight calls for the first phase of T-7A testing. This latency threshold may change for future testing, based on the type of test and lessons learned from the first phase of DTO missions.

The latency displays on the control room data screens were programmed to alert the test conductor if the latency exceeded the 500 ms threshold. While the team has not seen latencies higher than 500 ms to date, the concept of operations mandates that if the latency exceeds the allowed threshold, the test conductor will make a “knock-it-off” or “abort” call to pause aircraft testing until the latency delay is resolved.

Concept of Operations (CONOPS)

The establishment of T-7A DTO involved both technological developments and organizational agreements to align processes, techniques, guidelines, and procedures between the government and contractor organizations. The government and contractor test teams co-authored and agreed upon a combined Concept of Operations (CONOPS) document that outlined the ground rules and procedures for DTO during flight test.

The CONOPS defined roles and responsibilities for test team members. Each control room had a test conductor who led the personnel in that control room. The test conductor at the primary test site maintained the responsibility of communicating with the test aircrew, while the test conductor at the remote test site acted as the primary communicator from the remote control room to the primary test conductor. During normal operations, the remote test conductor did not communicate directly with aircrew, enabling aircrew to communicate with a single point of contact for test information. Specialized discipline engineers could be located in either or both control rooms.

Examples of how the CONOPS brought two different organizations together to align guidelines were crew rest requirements and duty day limitations. Crew rest is mandatory off-time between duty days to ensure adequate rest before participating in aerial or control room activities. Duty day is a limitation on the amount of time spent performing official duties. The Air Force regulations and contractor standards for aircrew and control room personnel had different crew rest requirements and duty day limitations. Therefore, to ensure compliance across the combined T-7A team, the most conservative crew rest and duty day limitations from the Air Force and contractor requirements were written into the CONOPS and applied to the entire test team.

Another example of an organizational factor was resource scheduling. The CONOPS defined the scheduling processes and timelines for each test site. The test conductor at each site was responsible for scheduling resources for their respective site. The primary test conductor was responsible for preparing test cards for each mission and sending the mission materials to the remote test conductor, and the remote test conductor was responsible for distributing the materials to personnel at the remote site.

There were several types of software files required to load the IADS screens for each control room mission. Mission-specific files, prepared at the primary site, had to be sent to the remote site prior to each mission to ensure proper IADS functionality. The CONOPS outlined the required timelines for these files to be sent from the primary site to the remote site. This process also ensured version control to confirm that both sites operated with the same file revisions and viewed the same data.

Flight test briefings were led by the primary test conductor, as the overall lead personnel for flight test activities. Test team personnel at the primary site attended the briefings in-person, and personnel at the remote site called into the briefings.

The CONOPS defined the buildup approach to establish confidence in real-time safety-of-test data monitoring and communication from the remote site. The remote participants started with observation-only permissions, which allowed the test team to become comfortable with the DTO CONOPS and battle rhythm of working in/with a remote control room. The next step was progression to remote monitoring of mission-critical data to build confidence in the ability to communicate data quality or technical calls effectively across test sites. This allowed the team to identify any applicable considerations before implementing safety-of-test monitoring from the remote site. Once the combined government and contractor test team was confident in the ability to perform mission-critical monitoring from the remote site, controlled scenarios would be used to simulate making real-time safety-of-flight calls from the remote site. These scenarios were designed to exercise the necessary communication in the control rooms between both test sites, as well as communication to the aircrew that could be encountered during a live mission. Finally, the remote site would be permitted to make safety-of-flight calls real-time.

While the goal of DTO was to create a single virtual control room where engineers had the same responsibilities regardless of whether they were physically located in the primary or remote control room, the T-7A combined test team did impose restrictions on training control room personnel during DTO missions. Since good instruction relies heavily on observing the student’s behavior, the decision was made to restrict formal instruction of new engineers to the same control room as the instructor. Additionally, engineers at both locations had to follow a formalized T-7A control room training plan.

Communication checks were performed prior to and during each DTO mission to ensure that the two control rooms retained communication with each other. Before each DTO mission started, the primary test conductor requested a direct “comm check” call from every engineer participant, regardless of whether the engineer was in the primary or remote control room, to ensure each engineer had operational communications. Then, prior to each test point, the primary test conductor asked for a “room ready” check-in from all participants; all discipline engineers gave a thumbs-up sign to their respective test conductor, and the remote test conductor relayed a “remote room ready” call to the primary test conductor. This process ensured that a communication check between the primary and remote control rooms was conducted prior to every test point.

A safety mitigation during flight test missions was that any control room engineer was able to make a safety-related “knock-it-off” call at any point in the flight. A “knock-it-off” call meant that the aircrew should cease aircraft maneuvering, de-conflict from any formation aircraft, and return to level flight in a safe flight envelope to evaluate further actions. This mitigation was also true for DTO missions; any participating engineer, regardless of control room, was empowered to make a safety-related “knock-it-off” call to the primary test conductor at any time.

The CONOPS described procedures to be followed if data or communication failures occurred during DTO. If telemetered data was lost in either or both control rooms, the primary test conductor would be informed immediately and relay that information to the aircrew. If communication between the two control rooms was lost, the remote test conductor or remote range control officer would use an independent telephone to call the primary control room and inform them of the communication dropout. If either test site lost monitoring of mission-critical or safety-of-test parameters, testing would be halted until the issue was resolved. Additionally, for DTO missions where the remote control room was making safety-of-flight calls, the latency to the remote control room (discussed above) was considered a safety-of-flight parameter.

In the event of an aircraft mishap, both control rooms would follow their organization’s pre-defined mishap procedures to secure data and begin the proper notification protocols. The addition of DTO participation would not change the mishap investigation responsibility.

As the test team encountered challenges and lessons learned during DTO execution, the CONOPS was updated to improve processes and increase efficiency for future DTO missions.

Challenges Encountered and Lessons Learned

Technical, organizational, and contractual challenges were encountered during the establishment of T-7A DTO. As the test team overcame many of these challenges, lessons learned were documented.

The most notable technical issue encountered to date was data dropouts to the remote control room. Data dropouts occurred twice in a single mission in August 2020. The first data dropout lasted thirty-one seconds, and the second dropout lasted three minutes and thirty-six seconds. During the dropouts, the remote control room lost aircraft telemetry and hot mic audio, but maintained communication with the primary control room and thus was able to inform the primary control room of the dropouts. The test team troubleshot the dropouts but was unable to diagnose the root cause. Data dropouts remained an item of interest for the test team, although no data dropouts occurred during the other 55 missions to date. Of note, no communication dropouts occurred on any of the 56 missions. Based on the strong performance of the data and communication via the DREN to date, the test team expects to maintain reliable communication and telemetry during future missions.

Another unexpected technical issue was radio interference from the remote site. During one DTO mission in November 2021, radio communication from a local frequency at the remote site interfered with DTO radio communications, causing confusion due to extraneous radio transitions. This radio bleed-over was immediately diagnosed as a hang-up between the data line bridging the communication channels, and the communication team was able to perform a reboot of the affected communication switch and resolve the issue.

Some challenges were both technical and organizational in nature. For example, the government and contractor test teams did not have a shared data network. As a result, transferring large files between government and contractor personnel was challenging. There were multiple file transfers required prior to every DTO mission to enable the control rooms at both locations to use the same data screens. The test team explored various file exchange services and determined that the Department of Defense (DoD) Secure Access File Exchange (SAFE) best fit this application. The team had to overcome security challenges to enable the contractor personnel to initiate file transfers with this service.

A technical issue with an organizational solution was a common file structure and naming convention was required to operate the control room displays. The IADS displays used several input files that were stored on a shared drive. Initially, the test sites had different names for their shared drives, which prevented IADS at the remote location from loading the input files. To remedy this, both locations renamed their shared drives identically, which enabled the IADS input files to load properly at both test sites.

Naming conventions were not the only difference between control room setups; hardware differences also proved challenging. For example, one test site had computer monitors with a 16:9 ratio, and the other site had monitors with a 4:3 ratio. The IADS screens were initially designed to fit 16:9 ratio monitors. During the first DTO checkout, the team discovered that the displays were compressed on the narrower 4:3 monitors, rendering the displays unreadable. After collaboration, redesign, and testing, the team concluded that the displays must be initially sized to fit the smaller monitors (4:3), then scaled up for the larger monitors (16:9) to maintain readability across both monitors.

An organizational challenge was that the government and contractor sites had different processes and timelines for scheduling resources required for DTO. For example, one of the sites had significantly more flexibility in rescheduling control rooms for DTO. Both test sites reserved control rooms for DTO on planned mission days, but when factors such as weather or maintenance drove the program to reschedule flights, DTO opportunities were missed when only one test site was able to reschedule control rooms.

To minimize the effect of missed DTO opportunities due to rescheduled flights, the test team increased the number of days they requested control rooms for DTO, then canceled their control rooms on days the T-7A was not flying. However, the team was unable to reserve control rooms every day because the control rooms were shared with other test programs. A limitation of DTO is that it increases the number of resources required overall; two control rooms (one at each location) are required for each DTO mission, and the additional resource demand was a limiting factor.

Another schedule-related challenge was the test sites had a two-hour time zone difference, resulting in mission briefs as early as 0330 for the remote site. In addition to the early missions presenting physiological challenges, there were difficulties scheduling control rooms at the remote site for early morning DTO missions. Mission times outside of available control room hours were a limitation that resulted in missed DTO opportunities.

Increased organizational communication was necessary for DTO missions. For example, the addition of remote personnel meant that a significant portion of the test team was not present for any in-person mission updates – such as maintenance or weather delays – that occurred after the mission brief concluded. Therefore, proactive communication was required from the primary test conductor to the remote test conductor to convey any updates that occurred after mission brief concluded.

DTO contractual challenges were identified and overcome. The government wrote a dedicated contract for DTO support. The initial DTO contract limited the program to a maximum of eight DTO missions per month, which resulted in missed opportunities for DTO. Through execution, it became apparent that the cost of establishing DTO for a single aircraft was the same whether one, two, or three flights were observed that day; thus, the financial limitation in the contract should be based on number of days – not number of flights – of DTO missions. The follow-on DTO contract allowed for up to 20 days of DTO per month, which incorporated the improvements of counting days versus flights as well as increased the allowable count per month.

Future Growth and Conclusions

The T-7A test team intends to use DTO as part of standard operations for future testing that will occur over the next several years. This includes the continuation of missions executed in St. Louis with a remote site at Edwards AFB, adding DTO missions executed at Edwards AFB with a remote site at St. Louis, and executing simultaneous DTO missions with aircraft flying at both locations.

A future goal of T-7A DTO is fully-remote test conduct, where the test control room is independent of the aircraft location. For example, an aircraft flying in St. Louis could utilize a single control room at Edwards AFB, without a control room staffed in St. Louis. The team intends to build up to this goal over the course of a couple years, after gaining more experience with DTO missions at each test location.

The T-7A team is in the process of establishing a connection between a T-7A hardware-in-the-loop simulator in St. Louis to a simulator control room at Edwards AFB. This connection would allow personnel at Edwards AFB to participate in simulator activities via DTO when aircrew fly the simulator in St. Louis. Applications of this include flight control law development, maneuver development, mission rehearsal, and miscellaneous analysis. Flight control law development occurs when engineers are designing the software that defines how the aircraft's control surfaces will act under various flight conditions. It often involves trial and error in the simulator, and it typically occurs at least a month prior to flight test on a given software version. Maneuver development occurs when the test team uses a simulator to test and mature different aircraft maneuvers to determine which maneuvers, test conditions, and recovery procedures will result in the desired data. Maneuver development typically occurs several weeks to months prior to flight test. Mission rehearsal is completed by the test team (aircrew and control room personnel) who will execute the actual mission. It serves as a practice mission, and the engineers gather IADS data during the rehearsal to use as predictions of key parameters in the actual mission. Mission rehearsal typically occurs one to eight days prior to flight test. The capability for simulator DTO would increase participation in these critical simulator activities and reduce test team travel.

As a result of the successes of the T-7A DTO program to date, numerous other test programs across the Air Force test enterprise are planning to use DTO for upcoming testing.

T-7A DTO demonstrated successes in both technological development of capability and in organizational unity to align processes, techniques, and procedures to accomplish a common mission. The long-term capability to minimize personnel travel and participate in test missions remotely will greatly improve quality of life for test team personnel and increase the ability of both organizations to participate in flight test.

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