FIELD EVALUATION
OF FLIGHT DECK PROCEDURES FOR FLYING CTAS DESCENTS

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ABSTRACT

Flight deck descent procedures were developed for a field evaluation of the CTAS Descent Advisor conducted in the fall of 1995. During this study, CTAS descent clearances were issued to 185 commercial flights at Denver International Airport. Data collection included questionnaire responses obtained from participating pilots and observations recorded in the cockpit during CTAS descents. Results indicate pilots' general acceptance of the procedure. Several problems were uncovered regarding clearance understanding, readbacks, and the acceptability of top of descent point and descent speed clearances in a few situations. This paper describes the descent procedures and phraseology developed to support the field test and presents the nature of the problems encountered.

BACKGROUND

The CTAS Descent Advisor

The Center-TRACON Automation System (CTAS) is a suite of decision support tools under development by NASA and the FAA to improve the efficiency of descents, aid in aircraft sequencing, and increase the rate at which aircraft can land at an airport (Erzberger, 1994). One component of CTAS, the Descent Advisor (DA), uses aircraft performance models, atmospheric forecasts, current air traffic conditions, and individual airline preferences to predict aircraft trajectories to the metering fix at the TRACON boundary (Williams & Green, 1991), (Green & Vivona, 1996). The Descent Advisor computes an arrival time at the metering fix for each aircraft that will result in aircraft arriving at the metering fix efficiently sequenced and spaced. The DA then calculates a descent trajectory and descent speed each aircraft should fly in order to meet its scheduled arrival time.
The DA provides the controller with three parameters that define these trajectories: an Assigned Descent Point, an Assigned Descent Speed and a speed and altitude crossing restriction at a metering fix. The achieved arrival time accuracies depend on how well each aircraft's actual descent path and speed match the specified trajectory.

A goal of the DA is to provide pilots with a more strategic clearance that will result in an efficient, uninterrupted descent from cruise altitude to the meter fix on the TRACON boundary. There are both positive and negative consequences to flight crews of this more strategic descent clearance. On the positive side, pilots should be able to fly more uninterrupted descents, they should receive fewer clearances, they should have fewer speed-up/slow-down clearances as they fly from sector to sector, and pilots of Flight Management System (FMS) equipped aircraft should be able to fly in VNAV (Vertical Navigation) longer. On the negative side, more information has to be communicated to pilots and if the FMS is to be used effectively this information must be communicated in time for the flight crews to program their FMS computer well before beginning their descent. In a series of simulator and field evaluations different approaches have been taken to deal with these problems.

The 1994 Field Evaluation

In the preliminary field evaluation of the DA conducted in 1994 at Denver's Stapleton International Airport (Cashion et al, 1995), the amount of information to be communicated to the flight crew was reduced by not specifying an Assigned Descent Point for FMS equipped aircraft. FMS aircraft were cleared to descend on a specified Mach/IAS speed schedule to cross a meter fix at a speed and altitude. Pilot tasks were then to program their FMS to meet these constraints and to begin their descend at the top-of-descent point calculated by their FMS. There was good pilot acceptance of this descent procedure but controllers stated that it would not be acceptable during moderate to heavy traffic conditions. Controller were uncomfortable because a clearance to descend to a crossing restriction is a pilot's discretion descent. A pilot's discretion descent give a pilot freedom to begin descent at any time following acceptance of the clearance, thus requiring the controller to protect a larger block of airspace.

Based on the experience in the 1994 field evaluation, the descent procedure was modified for the 1995 test to include an Assigned Descent Point for both FMS and non-FMS aircraft. This requirement introduced two complications for crews of FMS aircraft: 1) They had to first establish where the CTAS Assigned Descent Point was, and 2) they now had two top-of-descent points to deal with. If the CTAS Assigned Descent Point differed by more than 5 miles from their FMS calculated top of descent point, crews would need to either override the automation or negotiate with ATC in order to comply with the CTAS clearance. Because the CTAS/DA and FMS algorithms are similar, the calculated top-of-descent points of each should be close together. In order to allow maximal use of VNAV during the descent, crews were given a plus-or-minus five mile buffer from the Assigned Descent Point at which to begin their descent.

Preparation for the 1995 Field Evaluation

A second field study, which is the focus of this paper, was conducted at the new Denver International Airport (DIA) during the fall of 1995. Two NASA-Ames teams worked together on the evaluation. The airside team developed the pilot procedures, the pilot briefing package, observed flights from the cockpit, and collected pilot questionnaire data. The groundside team worked with controllers and the Descent Advisor tool at the Denver Air Route Traffic Control Center (ARTCC) to evaluate general DA performance and develop controller procedures for using the Descent Advisor (Green & Vivona, 1996). Both teams worked collaboratively with the FAA and participating airlines to develop the clearance procedures and phraseology. The airside goals for the 1995 evaluation were to: 1) include an Assigned Descent Point for all aircraft, 2) develop clearances using standard phraseology, 3) produce a shorter briefing package than the six page package used in 1994, and 4) distribute the briefing material through normal airline channels.

The development of the procedures, phraseology and briefing material was an iterative design and test process. Multiple design meetings were held with pilots from the participating airlines and with Denver Center controllers. The procedures were evaluated in airline training simulators for FMS, non-FMS and turbo-prop aircraft. More extensive simulator evaluations were conducted in a part-task glass cockpit simulator and in a 747-400 simulator at Ames Research Center.

These simulator trials resulted in a number of changes in the procedure. For example, the navigational fix that serves as a reference for the Assigned Descent Point was different for FMS and non-FMS aircraft. For FMS equipped aircraft, the preferred reference point is the next waypoint along the route. Using a waypoint behind the aircraft results in additional workload because the waypoint has to be reentered into the aircraft's FMS. For non-FMS aircraft the preferred reference point is the VOR that they are currently using for navigation. Another type of problem occurred when the Assigned Descent Point was beyond the FMS calculated top-of-descent point. Almost all crews immediately set altitude window on their Mode Control Panels to 27,000 feet when they received the CTAS Descent Clearance. If the aircraft was in VNAV, it was now armed to automatically initiate descent at the FMS top-of-descent instead of at the cleared Assigned Descent Point. We added a caution message to the CTAS Descent Procedure Chart to alert pilots to this problem. The simulator trials also demonstrated that pilots had to receive the CTAS Descent Clearance at least 20 nm before the Assigned Descent Point in order to have time for the necessary FMS programming.

<u>Clearance Phraseology</u>. The clearance phraseology for the procedure needed to communicate to flight crews the three descent parameters provided to controllers by the CTAS/DA: the Assigned Descent Point, the Assigned Descent Speed, and the bottom-of-descent crossing restriction. A primary consideration that affected phraseology development was the fact that aircraft would be passing through two air traffic control sectors, stratified by altitude, during the CTAS/DA descent. This was a problem because a controller handling a particular sector can only issue clearances for the altitudes within that sector. This added the necessity for an intermediate clearance altitude which is part of the facility's standard operating procedure. It was decided to use three separate radio transmissions to communicate descent parameters.

An initial CTAS/DA advisory was issued while aircraft were en route approximately 150-250 miles outside of Denver. It was intended to alert crews that they would be receiving a CTAS/DA descent and to inform them of their expected bottom-of-descent crossing altitude and speed, enabling them to plan their descent profile. Underlined items in the following example clearances could vary for each aircraft.

CTAS notification. "Company 321, expect CTAS Descent, expect to cross <u>TOMSN</u> at FL190 and 250 knots, maintain <u>FL330</u>."

The second transmission cleared the crew to initiate their descent. This clearance cleared the aircraft to the low-altitude sector boundary at 27,000 feet.

Descent clearance. "Company 321, maintain FL330 until 25 miles West of FROGS, descend and maintain FL270, maintain .84 Mach and 320 knots in the descent."

The final CTAS/DA clearance cleared the aircraft to complete the descent and made explicit the bottom-of-descent crossing restriction issued in the initial "expect" advisory:

Further descent clearance. "Company 321, continue descent at 320 knots, cross TOMSN at and maintain FL190 and 250 knots."

Aircraft types. Ten aircraft types from three airlines participated in the field evaluation. These aircraft consisted of three main classes: Flight Management System (FMS) equipped, non-FMS equipped, and turboprop aircraft. The particular class of aircraft affects how it is flown especially during descents. The non-FMS equipped aircraft included the Boeing 727-200 and 737-200 and the Douglas DC-10. The FMS equipped aircraft included the Boeing 757, the Boeing 737-300/500, and the Airbus A320. Turboprop aircraft included the DeHavilland Dash 8, the Embraer EMB-120, the Brasilia and the Beech 1900.

Crew briefing package. Crews were provided with a briefing package which included a Jeppesen chart (see Figure 1 for a draft of the chart for turbojet aircraft) and a Flight Manual Bulletin. The front of the chart outlined the compliance requirements of the procedure, the back of the chart described the purpose of the field evaluation and the potential benefits of CTAS/DA descents. The Flight Manual Bulletin provided an aircraft specific technique for flying the CTAS descent procedure.

THE 1995 FIELD EVALUATION

A list of candidate flights for the field evaluation was compiled based on planned entry into Denver International Airport via the two northwest meter fixes (TOMSN and RAMMS) and planned arrival times during light traffic conditions.

Scenario for a typical flight

Crews were informed by their companies of the CTAS field evaluation.

While in cruise, before entering Denver airspace, candidate flights for CTAS descents were sent a message from their company via the ACARS datalink. This was a request for aircraft and atmospheric state information, including as current weight, airspeed, wind, and temperature, for comparison with the CTAS estimates. In some cases, the CTAS predicted winds along the descent profile were uplinked to FMS-equipped aircraft for updating their VNAV descent profile. This information was used to aid CTAS in generating an accurate descent trajectory prediction for each aircraft.

Upon entering Denver ARTCC airspace, roughly 150-200 miles before initiating descent, crews were issued the initial CTAS clearance. This alerted crews to expect the CTAS descent clearance and provided the expected speed and altitude crossing restriction at the meter fix. This clearance also gave crews the opportunity to decline participation in the procedure. FMS crews were able to enter the expected crossing restriction into their FMS (LEGS page) to begin programming their flight computer for the descent.

Next, approximately 40 miles prior to the Assigned Descent Point, crews were issued the CTAS descent clearance. FMS crews finished programming their flight computers by entering the descent speed into the FMS (VNAV DESCENT page), and then cross checked the FMS computed top-of-descent point with the controller Assigned Descent Point to ensure that it was within the five mile buffer. Crews on non-FMS aircraft used the appropriate navaids to determine their top-of-descent point.

As participating aircraft approached FL270 during their descent, they were transferred to a low altitude ARTCC controller and received the CTAS continuation clearance confirming the crossing speed and altitude and allowing them to continue their descent to the TOMSN or RAMMS meter fix.

Data Collection. On arrival at Denver International Airport participating crews were met by a NASA representative who debriefed the crew and issued questionnaires. The questionnaires consisted of 29 questions soliciting feedback on pilot understanding and acceptability of the procedure as well as techniques used to fly the procedure.

RESULTS AND DISCUSSION

CTAS descent clearances were issued to 185 aircraft during the field trial. 167 pilot questionnaires were returned. Seventy-two of the flights were accompanied by a NASA cockpit observer. In addition to the questionnaires, the audio transmissions between ATC and the participating pilots were analyzed for readback errors and transaction time. Green & Vivona (1996) report results on how well the Descent Advisor was able to predict and control aircraft's trajectory to the meter fix. In terms of meter-fix arrival time, their results show an overall mean error of 0.5 seconds late with a standard deviation (sd) of 14.3 seconds. The least variation was found in FMS equipped turbojets which had a standard deviation of 11.9 seconds compared to 15.2 and 15.4 seconds for non-FMS jets and turboprops respectfully. In terms of vertical profile prediction accuracy, CTAS was able to predict the FMS jets top-of-descent within 2.4 nm. (sd = 2.5 nm.) while the bottom-of-descent was within 0.5 nm. (sd = 1.3 nm.). For non-FMS jets, CTAS was able to predict the bottom-of-descent within 3.9 nm. (sd = 4.2 nm.) while the top-of-descent was executed within 0.4 n.mi (sd = 1.4 nm.). For turboprop aircraft, the bottom-of-descent was 0.8 n.mi (sd = 1.5 nm.) while the top-of-descent was 0.8 nm. (sd = 1.5).

In response to the question: "Overall, how acceptable was the CTAS Descent Procedure?", 85% of pilots rated the procedure favorably. Ninety three percent of pilots responded that the CTAS briefing package prepared them "adequately" or "completely." In regard to the *CTAS Notification Clearance*, 94% answered "no" to the question: "Was any portion of this clearance unclear or confusing?". However, 15% of pilots found portions of the *CTAS Descent Clearance* unclear or confusing. This result is supported by the 27% of pilots who answered "yes" to the question: "Were any ATC callbacks required to clarify the CTAS Descent Clearance?". This contrasts with a 93 percent favorable rating in regard to acceptability of the CTAS Descent Clearance phraseology. This points to a possible discrepancy between pilot opinion and performance in regard to CTAS phraseology. However, a number of pilot comments expressed difficulties with this clearance: "The clearance contains too much verbiage", "Had to make many readback clarifications", "Too much information in one transmission".

To determine the types of errors most common to the CTAS Descent Clearance phraseology, audio tapes of 69 ATC/pilot transactions were analyzed for readback errors and clarification requests. "Readback errors" were those transmissions in which one or more items of the clearance were incorrectly readback by pilots and included transmissions with errors of omission and/or commission. "Clarification requests" were indicated by pilot misunderstanding of any portion of the clearance. Figure 2 presents the frequency of readback errors and clarification requests. Thirty-six percent of the 69 transactions required an additional communication to either correct an error or clarify some aspect of the clearance. The total transaction time for the 69 CTAS Descent Clearances was recorded. The mean transaction time was 32 seconds with a standard deviation of 8 seconds.

These results indicate that the CTAS Descent Clearance phraseology could be improved. Although pilots rated this phraseology favorably, a number of pilots reported that it was unclear or confusing and commented that the clearance contained too much information and too many words. The 36% percent correction and clarification rate corroborates these comments. It is difficult for pilots to remember 5 or 6 pieces of information especially when presented in an unfamiliar clearance format. This finding is consistent with previous studies by Morrow and Rodvold (1993) on ATC message length indicating that pilots make significantly more readback errors and repeat or clarification requests when ATC message length exceeds 2 or 3 elements.

A complicating factor of this clearance was the requirement to include an intermediate altitude as opposed to clearing aircraft all the way to the metering fix at TOMSN. This was necessary because a sector boundary occurred at FL270. The high altitude controller could only issue clearances down to this altitude creating the need for a further descent clearance by the low altitude controller. Discussions with pilots and controllers following this field test addressed the possibility of eliminating this intermediate altitude clearance in order to shorten the clearance phraseology and simplify the procedure .

Pilots of FMS aircraft remarked that the CTAS Descent Procedure increased workload and complicated use of the FMS. Pilot comments included: "[The procedure creates the need for] additional programming of descent clearance specifics." Of particular concern to FMS pilots was the CTAS Assigned Descent Point. This required pilots to input this point into the FMS in order to compare it with their FMS computed top-of-descent point. Crews were to use their FMS computed top-of-descent point if it fell within five miles of the CTAS assigned point. Nineteen percent of crews responding reported that their VNAV top-of-descent point fell more than five miles outside of the CTAS Assigned Descent Point. If the CTAS point was more than five miles beyond the FMS top-of-descent point, crews were asked to engage altitude hold to prevent early descent at the FMS top of descent point. Pilots commented that these tasks made the procedure cumbersome and complicated the use of the FMS.

A number of pilots of non-FMS aircraft commented that the CTAS Descent Clearance referenced a VOR for the top-of-descent point calculation that was not currently in use by the crew for navigation. This required the crew to either perform mental calculations using their currently tuned VOR, or to tune in the VOR referenced in the clearance to locate the Assigned Descent Point.

Other pilot concerns expressed in the questionnaires were: feeling rushed during some portion of the procedure, being issuing of inappropriate descent speeds for their aircraft type, CTAS compatibility with weather conditions and turbulence, and the need for using speed-brakes to meet crossing restrictions

CONCLUDING REMARKS

Crews were able to execute the procedure even though they had no prior training or experience with it. The procedure was successful in allowing aircraft to fly uninterrupted descents while providing the controler with an accurate predictions of the descent trajectory and meter fix arrival times. However, several crews cited difficulties with the length of the clearance , understanding the phraseology and the ease of the procedure.

FOLLOW-ON STUDIES

A follow-on CTAS Descent Procedure study has been conducted in the 747-400 full mission simulator at Ames Research Center. This study involved several changes to the CTAS Descent Procedure used in the 1995 field trial. To shorten the clearance several modifications were introduced. The sector boundary at FL270 was eliminated permitting the high-altitude center controller to clear the aircraft all the way to the meter fix at TOMSN, thus enabling removal of this intermediate altitude element from the descent clearance. Additionally, the crossing restriction at TOMSN was removed from the phraseology and transferred to the CTAS descent chart. Thus, the clearance became: “Company 321, cleared for a Precision Descent, 32 miles west of FROGS, 320 knots.” Results using this shortened phraseology are reported in Smith, Crane & Palmer, 1997.

Upcoming studies are focused on the task of making CTAS descent clearances more compatible with FMS aircraft. These studies include the use of datalink for information exchange between air and ground. The introduction of datalink into CTAS procedures may provided another way to communicate the information that is required to specify the desired descent trajectory.

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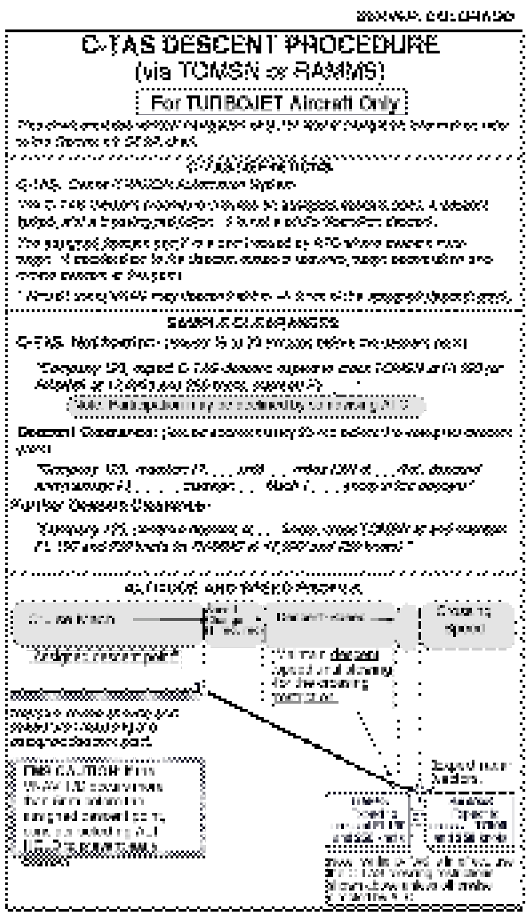

Figure 1: CTAS Descent Procedure Chart

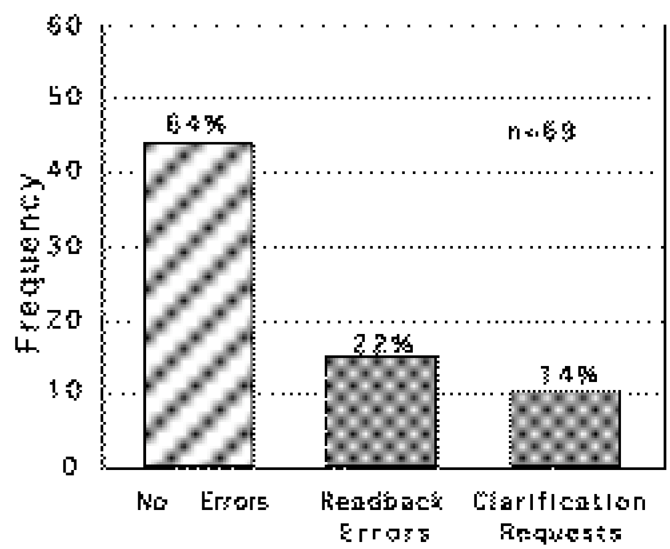

Figure 2: CTAS Descent Clearance Phraseology Analysis