# ADVANCED TERMINAL AREA COMMUNICATIONS LINK REQUIREMENTS


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## Abstract

The capacity of the United States' National Airspace System (NAS) must double to handle the passenger demands that are projected over the next 25 years. NASA initiated the Virtual Airspace Modeling and Simulation (VAMS) Project in 2002 with participants, including members from industry, government, and academia to develop and share ideas on revolutionary concepts to meet the future.

The constraints in the Terminal Area domain are the focus of Raytheon's VAMS concept, Terminal Area Capacity Enhancement Concept (TACEC). TACEC envisions a high level of automation and synchronization, generating optimized 4D flight profiles to land/depart multiple aircraft "simultaneously" on closely spaced parallel runways. Implementation requires infrastructure improvements such as high-speed data link, improved surveillance, integrated terminal area network, and highly automated guidance and scheduling systems. This paper focuses on the issues associated with the TACEC high-speed data link required to send flight profiles to the arrival and departing aircraft upon entering the Terminal airspace. The minimum essential uplink/downlink parameters needed to support the optimized 4D flight profiles are defined. Issues such as data rate, traffic load, and feasibility are also examined.


**TABLE OF CONTENTS**



## 1. Introduction

This paper focuses on the issues associated with the high-speed data link required by Raytheon's TACEC, a Terminal Area approach for implementation 20 years from now. We start with an overview of TACEC including a summary of the TACEC modes of operation (Initial Approach and Final Approach), and a discussion of the projected traffic within the TACEC terminal environment. The critical communication link requirements are then examined through an examination of the link characteristics and a definition of the message sets required within the Initial and Final Approach. A viable candidate solution is defined. The messages are associated with their link characteristics to define communication profiles. Finally, the profiles are associated with aircraft and ground stations within a specified region, and communication load requirements are established.

## 2. TACEC Overview

NASA's VAMS Program is addressing the challenge of increasing the future NAS capacity by developing new approaches to air traffic management. Raytheon is addressing the constraints in the terminal airspace. A preliminary concept evaluation was conducted using a simple queuing model to assess the capacity growth that could be achieved by eliminating inefficiencies in the aircraft's use of terminal airspace [1]. This study showed that additional runways will be required to meet the 2-3x demand growth.

The FAA procedure FAA 7110.65M defines the rules on use of independent or dependent runway operations. Independent operation requires 4300 feet between runways. When Precision Runway Monitoring (PRM) radar is in use, the separation can be reduced to 3000 feet. Wake vortex becomes an issue with less than 2500 feet of separation, so when aircraft land on independent runways they are not influenced by the others wake turbulence. However, adding more independent runways would require almost two square miles of land, impossible for many of urban airports that are likely to see the bulk of the capacity growth. Since land will not be available to build many more independent runways, another solution is needed.

The fundamental limit on the number of aircraft that can land or depart from a runway is their "in trail" spacing, namely how far the following aircraft must stay behind the lead aircraft as they approach the runway threshold. The vortex wakes generated at the lead aircraft's wing can pose a rolling moment hazard to following aircraft. To avoid this hazard aircraft remain far enough behind a leading aircraft to insure the wake has dissipated and can no longer pose a threat. FAA in-trail separation standards, defined in FAA7110.65M, are shown in Table 1.

**Table 1. Wake Vortex In-Trail Separation Requirements**

| | Lead Aircraft | | | |
|---|---|---|---|---|
| **Following Aircraft Gap (nm)** | **Small** | **Large** | **B757** | **Heavy** |
| Small | 2.5 | 4 | 5 | 6 |
| Large | 2.5 | 2.5 | 4 | 5 |
| Heavy | 2.5 | 2.5 | 4 | 4 |

Clearly wake vortex constrains today's operations on dependent runways, and for flights landing on the same runway. TACEC addresses the wake vortex hazard by taking advantage of the Flight Corridor concept proposed by NASA's Rossow [2]. The Flight Corridor is a defined region in space wherein the hazardous vortex rolling moment can induce no more than 5 degrees of unplanned roll. The TACEC approach to Flight Corridor/wake hazard avoidance positions the following aircraft as close as possible off the wing of the lead aircraft, thus guaranteeing a wake-free region. Thus, TACEC can significantly increase the airport's arrival (and departure) rate by nearly simultaneously landing multiple aircraft on parallel runways. However, aircraft must first be appropriately grouped together, or "staged", before entering their final approach/Flight Corridor phase. The Initial and Final Approach phases are examined further in the succeeding sections.

## 3. Initial Approach Overview

TACEC's primary objective is to land/depart multiple aircraft "simultaneously" on closely spaced parallel runways. This requires the ability to stage the aircraft upon entering the Terminal airspace. While TACEC assumes no control authority until aircraft pass the Arrival Meter Fix, knowledge of actual and intended trajectory profile is available before this event. TACEC will establish a unique track for each flight as it approaches and will maintain this track as it passes through the Terminal Airspace. Automatic Dependent Surveillance – Broadcast (ADS-B) is the preferred surveillance source and will be used for equipped aircraft. Traffic Information System – Broadcast (TIS-B) will provide the trajectory profiles of non-equipped aircraft, such as GA.

After a track is established, aircraft will be evaluated to determine if they can be paired with other aircraft. Analysis conducted in 2003 used the VAMS Airspace Concept Evaluation System (ACES) simulator, and doubled the May 17, 2002 traffic arriving and departing at 24 candidate closely-spaced parallel runways (CSPR). This analysis indicates that TACEC could achieve a doubling of airport capacity, as shown in Figure 1 [3].

After aircraft are grouped, they fly a controlled flight path specified by six to 20 waypoints that are defined by positions and time, as illustrated in Figure 2. These conflict free 4D flight paths will be generated by ground based algorithms and uplinked to the aircraft, and the aircraft's flight control system will follow the path requested. Since multiple aircraft are flying interrelated flight paths with variable error performance and with variable and unpredictable wind or other flight conditions, the waypoints not yet flown through may well need to be updated. The duration of this flight regime, in initial approach, is approximately 20 minutes. Therefore a waypoint will be passed approximately every one to three minutes. Based upon initial analysis, it appears the error budget will not be exceeded if the waypoints are updated approximately every minute. If upon further analysis, additional waypoints are needed minor waypoints could be defined that could be as close as at 20 second intervals.

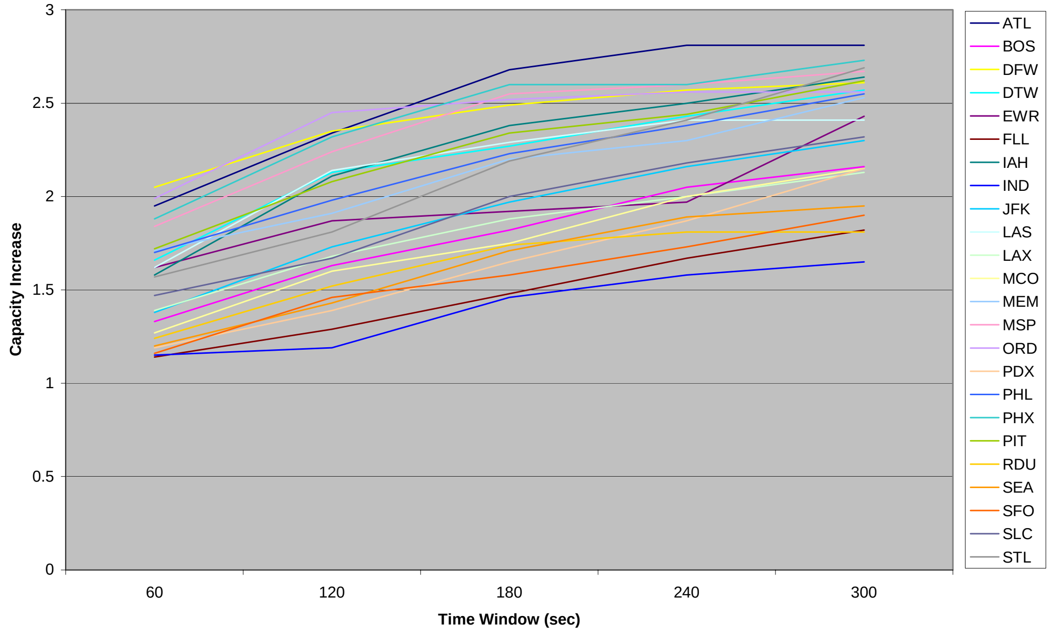



**Figure 1. TACEC Capacity Growth Potential using Closely Spaced Parallel Runways**

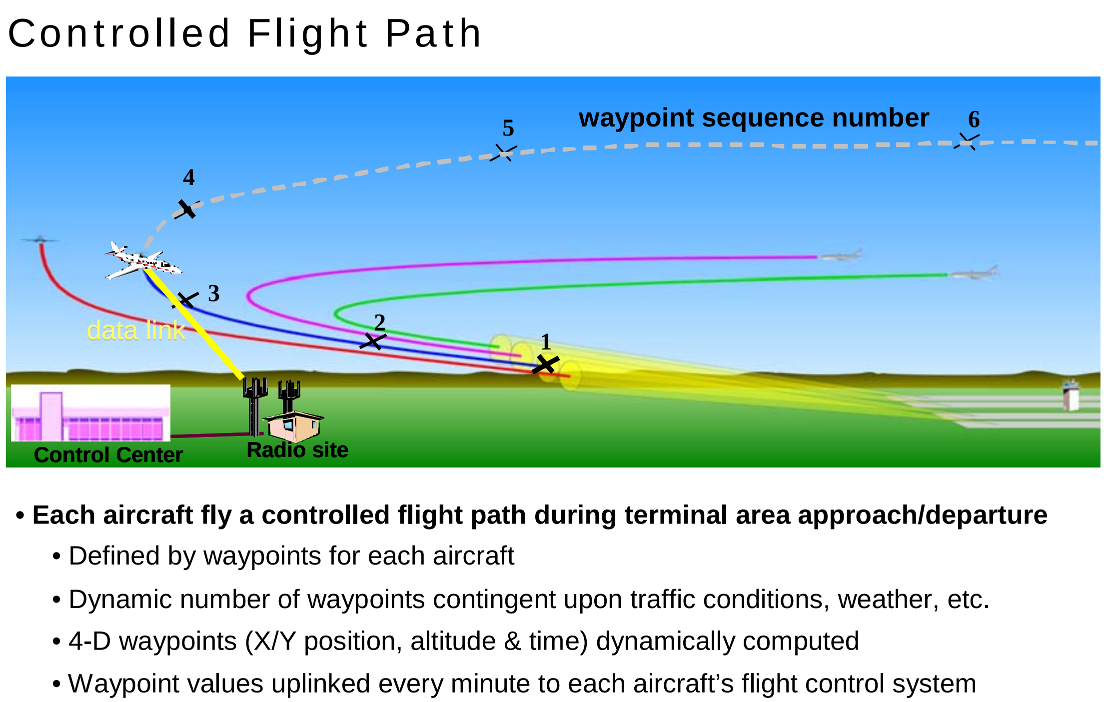
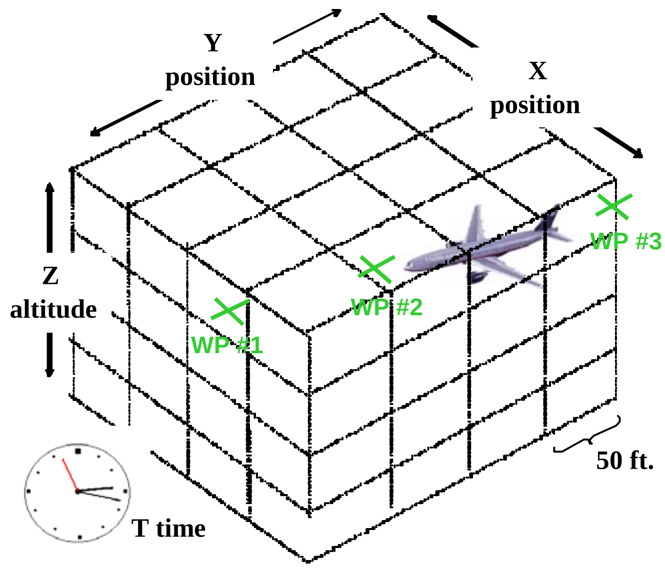



**Figure 2. Flight Path Definition During Initial Approach/Final Departure**

# Data Rate Summary

**Data sizing per waypoint**




**4 dimensional waypoints**

**Bit sizing per waypoint**

16 - X position
16 - Y position
10 - Z altitude
20 - T time
10 - WP sequence #

**72 bits or 9 bytes**

**Figure 3. Illustration of the Local Cartesian Coordinate System for Waypoint Definition**

Since this process will use a data link to reach the aircraft that are arriving and departing, one concern is whether the aircraft can or will be equipped with the necessary avionics. One approach that has been defined by the International Civil Aviation Organization (ICAO) and the certification of the necessary avionics supported by the FAA is VHF Data Link Mode 3 (VDL Mode3). It would be interesting to evaluate whether a system having similar characteristics could support this application. The essential features of VDL Mode 3 are the time division multiple access protocol providing four subchannels for user information and a separate management channel. The subchannels can be used in several modes. For this analysis we are standardizing on a mode that provides for two separate user groups that each support a shared voice and data network on one frequency.

As illustrated in Figure 3, the waypoints are defined for this analysis using a Cartesian coordinate system centered on the airport. Horizontal positions (X, Y) are based upon the typical wake vortex position uncertainty (hazard volume) of 500 ft ± 10% (50 ft.). Using 50 ft as the least significant bit and ± 100 nautical miles as the maximum range requires at least 14 bits plus sign; therefore, 16 bits are allocated for both X and Y. The vertical (altitude) position also requires 500 ft ± 10% (50 ft.) accuracy at the transition point to the final approach. A maximum altitude of 30,000 ft. with a 50 ft. least significant bit will require 10 bits for the altitude position value. For an aircraft at the typical approach speed of approximately 250 knots, the time accuracy needs to be such that the position change in the minimum time increment is consistent with the position accuracies in X, Y, and Z. Therefore, a time accuracy of 0.132 seconds is needed. For simplicity this is rounded to 0.1 seconds. The maximum time needs to exceed one day by enough to address the time through the midnight rollover without having to change the time base. We have elected to say this should be 24 hours plus 25% or 108,000 seconds or approximately 20 bits. To identify the waypoint a sequence number permitting at least 20 waypoints or 10 bits is used. The definition of each waypoint sums to 72 bits or 9 bytes of information.

In previous papers [3] the communication support for conveying the waypoint position updates to the aircraft used a fairly simplistic approach to the utilization of a VDL Mode 3 communications system operating in a 2V2D mode. In the earlier analysis we demonstrated operation using a percentage of the available data link capacity of one data channel. This earlier approach would have operated at the transport layer and was impacted by the substantial header overhead imposed by the Aeronautical Telecommunications Network (ATN) protocols. Furthermore there is a requirement for acknowledgement at the transport level from the receiver. This would have required sending a message from the aircraft which can take a relatively long time because of the reservation process the aircraft uses to obtain slots in which to transmit. Upon further consideration an alternative approach making use of the link layer of the VDL Mode 3 protocol may be more effective and useable. The communication to the aircraft is limited to the aircraft within the coverage of one ground station. There is no need to transfer the connection to the aircraft to a second ground station during the approach or departure sequence, thus the transport layer mechanisms of the ATN are not needed. An acknowledgement process is also needed to confirm that the aircraft has the necessary information and will respond to new direction.

VDL Mode 3 at the link layer is a ground station controlled process. The link layer is managed by the ground station accepting requests for data transfer from both mobile users and the ground with 4 levels of priority. The ground system schedules the use of each data burst and assigns it to either the ground or a specific mobile user. However, it must be recognized that the ground system has the ultimate power to decide who gets to send what data. This allows the ground station to schedule waypoint position updates as necessary and with a maximum delay to the next opportunity of 120 msec. There is also a built in acknowledgement scheme at the link level where the mobile user acknowledges correct reception of a message transfer in a separate sub-channel.

Within one VDL Mode 3 2V2D user group consisting of 1 voice and 1 data slot with up to 120 users, there is an opportunity for the ground system to send up to 62 bytes of information addressed to any one mobile user every 120 msec and one voice conversation between the approach controller providing a human monitor of the situation and the pilots in the approach pattern. The 62 bytes provide for the next 6 major waypoints to be sent to the aircraft. These 6 waypoints could define the aircraft position for the next 6 minutes or a waypoint every minute of flight. Or if appropriate a much shorter interval can be used. For instance, the next 6 waypoints could be provided for 20 second intervals with a projection into the future of 2 minutes. With an update rate of 1 per minute, up to 500 updates can be transmitted using the full capacity of the network. Using the full addressable capacity of a VDL Mode 3 user group, recently upgraded by the RTCA Special Committee 172 in the draft of a B version of DO-224A [4] to 120 users in a single 2V2D group (or 240 per frequency), sending one uplink burst for each of 120 aircraft once per minute would use 24% of the available capacity of the network. This leaves a reasonable capacity for other possible uses, such as broadcast of current weather conditions and general alerts. With a total capacity of 600 airport operations/hour and a 20 minute approach period for each aircraft, an average capacity of 200 aircraft at any time is necessary. This can be achieved using both user groups available on one VDL Mode 3 frequency which provides a total capacity of up to 240 users with a 20% margin for imbalance in arrivals vs. departures or peaking of traffic.

## 4. Final Approach Overview

The aircraft transitions into Final Approach, entering the TACEC Flight Corridors, approximately four minutes from the airport. Close-control during Final Approach is achieved by using differential GPS landing aids in conjunction with auto-land avionics similar to those used for CAT3 operation. This capability will allow all weather operation and thus will permit airports to operate at VFR level capacities during IFR conditions. Departing aircraft will be controlled in the same manner during initial departure.

The Local Area Augmentation System (LAAS) provides the necessary augmentation to the position information gained from GPS includes an internal data link with capacity to support close control of the aircraft. LAAS operates on a VHF broadcast data link known as VDB. VDB is a TDMA based scheme with 28.4 Kbps application data. While the datalink bandwidth allows for 95 unique Final Approach Segment (FAS) blocks, the actual number is limited to 48 by the number of unique Reference Path Data Selector (RPDS codes). Thus, LAAS can support up to 48 aircraft during Final Approach/Initial Departure. The differential corrections are uplinked in Type 1 messages at 2Hz. The differential reference points and FAS are uplinked in Type 2 and 4 messages, respectively, every 10 seconds. The LAAS VDB coverage is depicted in Figure 4.

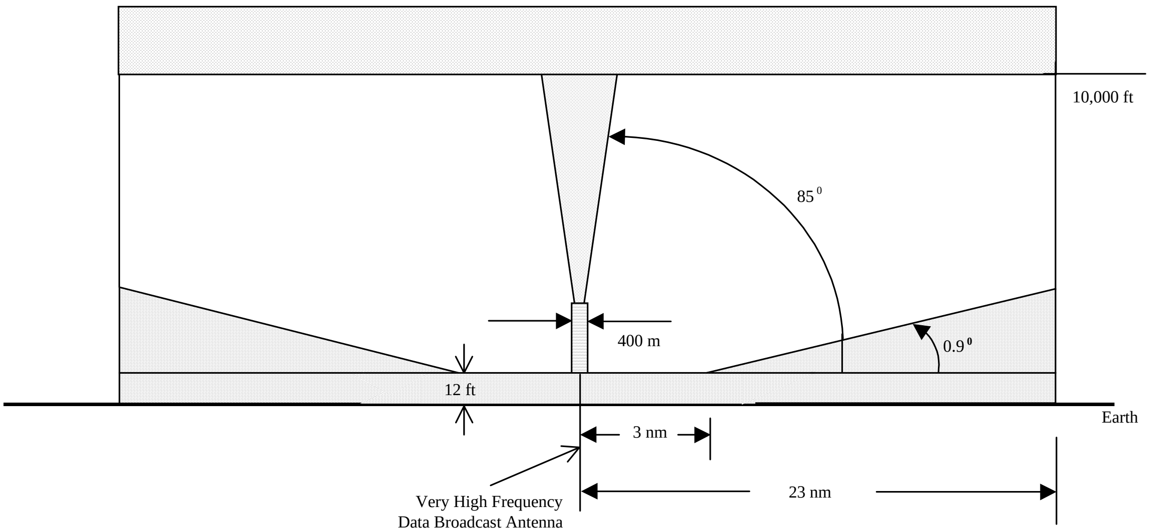



**Figure 4. LAAS VDB Coverage**

## 5.0 Traffic Loading

As shown above, by grouping aircraft onto very closely spaced parallel runways TACEC can increase airport capacity by a factor of 2.0. The spacing between groups onto and off of the same runway must adhere to today's wake vortex separation requirements. For arrivals, assuming a typical terminal airspace velocity of 140 knots, a group of Large aircraft would need to follow another Large group by 1:04, while a Large group following a Heavy group would require a spacing of 2:08. Assuming a worst case (with respect to communication loading) of one minute separation between arriving groups, with two aircraft per group, the maximum number of arrivals per hour onto one set of parallel runways would be 120 arrivals/hour. For departures, according to FAA 7110.65M the Category III groups must be separated by 6000 ft, or approximately 40 seconds. When the group is taking off behind a heavy jet or B757 the groups must be separated by 2 minutes. Again we will use the worst case assumption of 40 seconds for communication loading. With two aircraft per group, the maximum number of departures per hour off of one set of parallel runways would be 180 departures/hour. The 120 arrivals/hour and 180 departures/hour represent the busiest hours, however averaged throughout the day the number of arrivals and departures will even out.

The airport can be equipped with multiple sets of closely spaced runways, some used exclusively for arrivals and others for departures. Assume two sets are dedicated to arrivals with each handling 120 arrivals/hour. Two other sets will each handle 180 departures/hour. The total airport operations could therefore be 600 operations/hour. This is slightly higher than the 546 operations/hour that would be required at DFW if its capacity were to double and so is a reasonable worst-case across the NAS. The number of aircraft controlled by TACEC, during a 20 minute Initial Approach mode, will be 200 (80 arriving and 120 departing). As was noted above, up to 120 aircraft can be handled at any one time supporting the two 180 departure operations/hour runway pairs with a 20 minute departure window.

There will be 40 aircraft during the four minute Final Approach/Initial Departure, bringing the total number of aircraft controlled in a 24 minute TACEC Terminal Airspace to 2540. An additional 100 aircraft in the terminal area representing GA or otherwise non-equipped are included in the link analysis.

### *Messages and Links*

In addition to flight plans, TACEC also requires that surveillance data be transmitted between the ground and aircraft. ADS-B will provide surveillance of equipped aircraft, those under TACEC control. Surveillance of non-equipped aircraft will be available via TIS-B to the ground based operational algorithms and TACEC aircraft for pilot situational awareness. Accurate knowledge of the wind field is required by the ground based operational algorithms, and this information will be available at the ground station through the Integrated Terminal Weather System (ITWS) Gridded Winds Product – Terminal Winds [5]. TACEC also allows for transmission of voice, to be carried on VDL Mode-3 using the 2V/2D mode. Messages between the ground station and aircraft, along with their phase of operation, are shown in Table 2, and associated media (links) are shown in Table 3.

**Table 2. TACEC Voice and Data Messages**

| Air/Ground | Name | Kbits | Rate | Media | Phase |
|---|---|---|---|---|---|
| Air | 4D Flight Plan ACFT | 1.152 kbps | 1/min | VDL Mode 3 Data | Initial |
| Air | TACEC Final Approach ACFT | 0.74 | 2 Hz | VDB Datalink | Final |
| Air | TACEC ADS-B ACFT | 0.11 | 1 Hz | 1090 ES | Both |
| Air | TACEC ADS-B Rcv ACFT | 16.5 | 1 Hz | 1090 ES | Both |
| Air | TACEC TIS-B Rcv ACFT | 11 | 1 Hz | 1090 ES | Both |
| Air | TACEC Voice Aircraft | 1 | 0.5/min | VDL Mode 3 Voice | Both |
| Ground | 4D Flight Plan Ground | 176.64 | 1/min | VDL Mode 3 Data | Initial |
| Ground | TACEC ADS-B Ground Station | 16.5 | 1 Hz | 1090 ES | Both |
| Ground | TACEC LAAS Ground | 0.74 | 2 Hz | VDB Datalink | Final |
| Ground | TACEC TIS-B Ground to ACFT | 0.11 | 1 Hz | 1090 ES | Both |
| Ground | TACEC Voice Ground | 1 | 0.5/min | VDL Mode 3 Voice | Both |

**Table 3. TACEC Media**

| Name | Range (Miles) | Kbps/Frequency | Effective Channels |
|---|---|---|---|
| VDL Mode 3 Data | 100 | 9.6 | 2 |
| VDL Mode 3 Voice | 100 | 9.6 | 2 |
| VDB Datalink | 20 (100) | 28.4 | 1 |
| 1090 ES (FASTE Library) | 165 | 312 | 1 |

## 6. Communication Loads

Communication profiles of the above messages and media discussed above were built in the FASTE-CNS tool. A region of 100 miles, representing one Terminal area, was defined and populated with 240 aircraft (200 in Initial Approach/Final Departure, 40 in Final Approach/Initial Departure, and 100 non-equipped/General Aviation). Ground stations were also defined representing the TACEC 4D operations for Initial Approach, LAAS operations for Final Approach, and TIS-B transmission. The Traffic Load and Number of Frequencies required for each medium are shown in Table 4.

**Table 4. Communication Load and Frequency**

| Media | Traffic Load (Kbps) | No. of Frequencies Required |
|---|---|---|
| VDL Mode 3 Data | 2.30 | 1/2 |
| VDL Mode 3 Voice | 0.64 | 1/2 |
| VDB Datalink | 1.48 | 1 |
| 1090 ES | 16.6 | 1 |

The results in Table 4 indicate that 4D Flight Plan message utilize approximate 30% of the VDL Mode 3 data link. The other links are also significantly below their limits.

## 7. Conclusion

This paper has demonstrated that the TACEC approach to Terminal Area traffic flow enhancement does provide significant improvement to the arrival and departure capacity of the terminal area. This is achieved using a communications infrastructure much of which is anticipated to be in operation, especially on the aircraft, when TACEC would be implemented. A more sophisticated approach to the definition of approach and departure flight path specification for the en-route environment has recently been published by Paielli [6]. As suggested in that paper a combination of abridged versions of the XML format definitions and the waypoint approach used in this paper will result in a more standardized definition of the aircraft trajectories while still fitting within the available communication bandwidths. Further study to adapt Paielli's approach to the Terminal Area will be undertaken shortly.

## References


[1] Arkind, K. "Maximum Capacity Terminal Area Operations in 2022," AIAA ATIO Conference, Nov. 2003

[2] Rossow, V.J. "Use of Individual Flight Corridors to Avoid Vortex Wakes," AIAA Atmospheric Flight Mechanics Conference and Exhibit, AIAA 2002-4874, August 2002.

[3] Miller, M.E and Dougherty S.P, "Communication and the Future of Air Traffic Management", IEEE Aerospace Conference, March 24.

[4] SC-172, "Signal-in-space Minimum Aviation System Performance Standards (MASPS) for Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques," RTCA/DO-224A, September 13, 2000, RTCA, Incorporated, Washington, DC.

[5] Mueller, E., Jardin, M. "4D Operational Concepts for UAV/ATC Integration," AIAA-2003-6649, 2nd AIAA Unmanned Unlimited Systems, Technologies, and Operations – Aerospace, Land, and Sea Conference, Workshop, and Exhibit, 15-18 Sept., 2003, San Diego, CA.

[6] Paielli, R. "Trajectory Specification for High Capacity Air Traffic Control," Draft NASA Publication, Sept. 2003.


## Biography


***Mary Ellen Miller*** *is Senior Principal Engineer for Raytheon Company. She has over 20 years of experience in Systems Engineering, program and technical management. Experienced in the design, development, and integration of complex systems, she strives to maximize system effectiveness and customer value. Mary Ellen has participated in and led teams in many technical domains, including Air Traffic Management, Object-Oriented Distributed Simulation, Satellite Communication, and Missile Systems. Mary Ellen holds a BSAE from the University of Michigan and a MSSE from the University of Massachusetts.*

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