Trajectory Modeling (TJM) Workshop
2-3 December 1999
Summary Report

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During the period 2-3 December 1999, the NASA Ames Research Center and the Center for Advanced Aviation System Development (MITRE/CAASD) held a workshop on the topic of trajectory modeling (TJM) for Air Traffic Management (ATM) applications. The purpose of this annotated briefing is to present the results of the workshop. Steve Green, NASA Ames, and Gene Wilhelm, MITRE/CAASD, organized and facilitated the workshop.

Report Outline

- Background
  - Action item from NASA/CAASD September off-site
  - Workshop attendees
  - Major Issues for discussion
  - Expectations: developed by the team
  - Nominal Agenda (see backup material)
- Overview of TJM Requirements Drivers
  - CTAS
  - URET
- Comparison of Approaches to Implementing TJM Components
  - URET
  - CTAS
- Future Needs for TJM Capabilities
  - Major Decision Support Tool Needs
  - Postulated TJM enhancements to support
- Pros and Cons of Single Trajectory Modeler for the NAS
- TJM Workshop Accomplishments Summary
- Next Steps

This report includes the following topic areas:
• Background: the workshop purpose, expectations, agenda, attendees, etc. are briefly reviewed.
• Overview of TJM drivers: the major drivers that motivated the TJM approach taken in CTAS (the Center-TRACON Automation System) and URET (the User Request Evaluation Tool) are addressed
• Comparison of Approaches: major commonalties and differences in the CTAS and URET TJM approaches are identified.
• Future Needs for TJM: a first-cut is made at identifying major, future application drivers for TJM capabilities
• Single Trajectory Modeler for the NAS: a preliminary list of pros and cons of a single modeler for all ATM applications is presented.
• Next Steps: near-term follow-on actions are listed.

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Action Item From NASA/CAASD Off-site

Objective: To initiate a joint activity by which the FAA is presented with a joint recommendation for evolving the trajectory modeling capability in the NAS. This first workshop will concentrate on the first bullet below; the remaining bullets will require longer-term activities.

- **Discuss the needs for trajectory modeling in all domains of the NAS. Identify what is needed, why, and when. That is: what problems need to be solved and when?**
- **Assess the current and planned NAS TJM capabilities. Identify an evolution strategy from the current plus FFP1 baseline to the future system.**
- **Work with the FAA (ASD and AUA) to establish specific requirements and implementation plan for new TJM features.**
- **Work with implementation contractor(s) to ensure technology transfer is successful.**

In September 1999, NASA Ames and CAASD held an off-site to start the process of working together more effectively to serve the interests of the FAA and the aviation community. A number of action items resulted, including the one depicted on this slide. The TJM workshop in December addressed the first of the above bullets. Follow-on actions will be necessary to begin to engage the FAA and other stakeholders on the subject of the evolution of TJM capabilities.

Attendees

- NASA
  - Steve Green
  - Banavar Sridhar
  - Dave McNally
- MITRE/CAASD
  - Gene Wilhelm
  - Dan Kirk
  - Dan Brudnicki
  - Craig Wanke
  - Bill Arthur

This slide lists the workshop attendees from NASA Ames and CAASD. Gene and Steve organized the workshop and served as facilitators. The attendees from both labs brought to the workshop many years of experience in the development of trajectory modeling and ATM applications across multiple domains.

Participants from both labs have specialized in the development and field validation of trajectory modeling and en route decision support tools (DSTs) for conflict prediction/resolution. Participants also brought unique and complimentary areas of expertise and experience.

In particular, participants from Ames brought additional experience in the areas of kinetic (force equation) trajectory modeling, precise metering conformance, and arrival metering (sequencing and scheduling).

The MITRE/CAASD participants brought additional experience in the areas of kinematic trajectory modeling, conformance modeling and sector penetration/posting, comprehensive adaptation of inter-sector/facility letters of agreement, and en route TFM applications (e.g., prediction and control of sector load).

Major TJM Issues for Discussion

Purpose: the following issues were chosen for discussion to develop a common “bi-partisan” understanding of (not necessarily agreement on) the different approaches to TJM.

Goal: to record agreements and disagreements to facilitate constructive progress.

Discussion Topics:

- What were the operational and technical factors that motivated each organization in developing their TJM approach? What are the specific design features of each TJM approach?
- What are the common and unique requirements of each operating domain (en route, terminal, transition, and TFM) that drive the current approaches?
- What are the major commonalties of the approaches? What are the major differences?

The major areas of focus of the workshop were: to gain an understanding of the TJM approaches taken in CTAS and URET; and to begin to define the needs that might drive the future evolution of TJM capabilities. On this page and the next, are a set of high-level topics that served to guide the discussions. Although it was not possible to thoroughly delve into each topic, the group felt that good progress was made on most. Many answers cannot be developed until current and planned research activities are completed, and until decisions are made about specific applications to be implemented in the ATM system.

A major goal was to find and document areas of agreement to support recommendations to the FAA. However, given the diversity of experience and approaches of the two labs, it was recognized that differences in opinion and perspective existed. To turn these differences into an asset, the workshop was facilitated to encourage their identification and discussion. The goal was to document any differences to support a common understanding and to facilitate further discussion if necessary.

Major TJM Issues for Discussion (concluded)

Future Directions: how should TJM evolve over time to support the NAS of the future?

- **What are the future operational and technical considerations/needs that will drive TJM enhancements?**
- **What are the pros and cons of pointing toward a single TJM for the NAS? This is often stated as a desired goal but is it realistic, necessary and cost effective? Do the differing domain requirements support the need?**
- **What are the major elements of a set of requirements for future TJM to support postulated needs?**
  - **Direct requirements: (what TJM must do)**
  - **Supporting requirements: (e.g., surveillance, winds/temp, flight/intent data)**
  - **How do we validate them? For example, how good is good enough?**

While good progress was made on most of the discussion topics, the last bullet was not discussed in any detail due to time constraints. Especially the issue of how to validate TJM requirements did not get the attention that it needed.

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Expectations

- Mutual respect
- Gain understanding of each other's approach and underlying assumptions; not a contest to decide whose is better
- Develop consensus of technical understanding
  - Identify areas of agreement
  - Disagreement is OK; document such areas to understand them
- Focus on the future: what are the future needs for TJM by domain and timeframe? What modeler requirements are needed for what purpose?
- This is a beginning, not the end; consider next steps
- Discuss: impact for future NAS system upgrades (e.g. data link, FDP); adaptation/maintenance; impact of TJM approach on problem prediction

In preparing for the workshop, the facilitators developed a set of expectations. To foster teamwork, collaboration, and contributions, the participants were engaged at the beginning of the workshop to modify and expand this set of workshop expectations.

One of the most important of these was "Mutual Respect" which was also a major theme of the September NASA/CAASD off-site that spawned this workshop. The workshop was certainly a success from that standpoint- we talked about some potentially difficult topics in a cooperative and interactive manner. Agreement was not achieved in several areas but the state of knowledge within both organizations has been advanced.

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TJM Requirements Drivers

- CTAS
  - Ops concept: ATC counterpart to the airborne FMS
    - Strategic prediction/planning at the sector/facility level
      - ~20 min for conflict detection
      - ~20-40 min for metering
  - Accuracy on the order of “seconds” required at the merge/meter fix to support:
    - Generation of active advisories
      - Requiring minimal correction
      - Facilitating efficient merge of dense traffic
    - Consideration for simultaneous metering and conflict detection/ resolution
  - FMS compatibility (interoperability)
  - With intent errors minimized (through active advisories and CHI), target accuracy requires higher fidelity that may be addressed by kinetic modeling

This slide and the next describe the high level requirements that drove the design approaches taken for CTAS and URET trajectory modeling.

The primary CTAS TJM driver was the goal to develop an ATC counterpart to the aircraft Flight Management System (FMS) and provide for a more efficient transition to/from terminal airspace. The original CTAS requirement (1985) was to provide 4D-based clearance advisories to facilitate time-based arrival metering under conditions of mixed aircraft capabilities. A high degree of accuracy was needed to advise efficient descent profiles while providing precise speeds (cruise/descent) and vectors for conflict-free metering. The accuracy was needed to: 1) minimize corrective updates while merging flights into dense arrival streams (i.e., where meter-spacing rivals separation minima); 2) support accurate meter-conformance planning/intent for conflict detection/ resolution (CD/R) while metering; and 3) be compatible with FMS capabilities (2D, 3D, and/or RTA) to maximize FMS utilization. Performance modeling was felt to be critical to the accurate prediction of vertical profiles (climb and descent) with respect to variations in aircraft type, speed profile (varied for metering), weight, non-standard atmosphere, and wind gradient with altitude.

It was felt that classic “intent”errors would be mitigated by a well-designed DST that supports controllers with active advisories... leaving lateral/vertical performance modeling errors as the primary error source. The reduction of these errors would then be critical to the operational success of the active DST, thus enabling an active DST to be designed to overcome classic intent errors.

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TJM Requirements Drivers (concluded)

- **URET**
  - **Ops concept: Strategic conflict detection 20 min timeframe [1-2 sector lookahead]**
  - **Driven by uncertainties in current operational environment [intent errors, input data issues…]**
  - **Conformance discussion (monitoring)**
    - **Stability of trajectory Þ stability of advisories**
    - **Interfacility comm: only send updates when trajectory changes (low bandwidth)**
    - **Connected (nav.) to separation assurance buffer (yellow alerts)**
  - **URET modeling is operationally acceptable for the designed application**

URET supports *strategic* en route sector planning and prediction, where the lookahead of 20 minutes generally extends across 1-2 sectors. Operationally, it must cover all altitude strata and, thus, all phases of flight--climb, cruise, and descent. The strategic time range is often characterized by constraints like ATC preferred routes and altitude restrictions. URET is intended to enable some of these constraints to be removed by providing for strategic notification and resolution of conflict situations.

The URET TJM was designed to allow the provision of conflict detection and resolution capabilities to the en route sector controller in the current-day NAS operational system, without modification to existing data entry procedures. As such, its development was driven by uncertainties in the controller and pilot intent, and the desire to provide a stable trajectory to facilitate controller analysis of the trajectory and derived alerts. For example, climb and descent speeds are not entered into the NAS system, and thus variations in these future, unknown speeds need not be modeled. Rather, descent speed/gradients were derived from a best-fit to empirically-observed data, and heuristics were developed to modify the predicted gradient when the observed (real-time) track data for an individual aircraft did not match the expected speed/gradient adapted for that aircraft type.

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TJM Requirements Drivers (concluded; cont'd notes)

- URET
  - Ops concept: Strategic conflict detection 20 min timeframe [1-2 sector lookahead]
  - Driven by uncertainties in current operational environment [intent errors, input data issues…]
  - Conformance discussion (monitoring)
    - Stability of trajectory ⇒ stability of advisories
    - Interfacility comm: only send updates when trajectory changes (low bandwidth)
    - Connected (nav.) to separation assurance buffer (yellow alerts)
  - URET modeling is operationally acceptable for the designed application

To provide stability in the trajectory and derived alerts, the URET TJM calculates lateral, longitudinal, and vertical conformance bounds dependent on the transitioning/turn status and navigational equipage of the aircraft. Other than modifications to the flight plan, the trajectory is modified only when one or more of these bounds are exceeded. The conformance monitoring process also allows a very significant reduction in the amount of data that must be transmitted between facilities for the interfacility conflict probe application, as position data need only be sent when an reconformance occurs (all trajectory modeling is performed locally with the ARTCC).

An additional consideration in the development of the URET TJM was the ability to handle the complex set of altitude and speed restrictions the exist in some ARTCCs. The use of tabled gradient values facilitated this process, as the gradients may be directly modified to comply with the restriction(s) and observed aircraft altitude. Finally, the computational efficiency of the TJM was a consideration, particularly for the application of a resolution process where a series of trajectories must be constructed to determine a set of conflict-free alternatives for controller selection. Again, the use of a table lookup method for determining the altitude gradients facilitated this goal.

URET modeling is operationally acceptable for strategic conflict detection and resolution via trial planning. This has been demonstrated through specific evaluation activities since 1996 and over 275,000 sector-hours of daily use operations by the end of 1999 at Indianapolis and Memphis.

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Comparison of TJM Characteristics

Characteristic	URET	CTAS (en route)
Database		
– Navigation/site adapt	ACES + DACS + NFDC	ACES
- Route processing	MD312 (emulates Host)	AK (uses Host Routing)
- Adapt processing	Manual	Manual
– Aircraft Performance	Pilot Handbook-Based – Empirically Tuned – Cross-ref Mapping	Engineering Handbook – Empirically Tuned – Cross-ref Mapping
Input		
– Track	Host + Adj Host (external)	Host + ETMS (external)
– Flight Plan Route	Flight Plan Route	Flight Plan Route
– Wind/Temp (3D grid)	RUC	RUC
Physics		
– Wind Gradient	no	yes
– Non-standard Atmos	yes	yes
– Rate of Climb/Desc (RoC/D), & Accel	Kinematic	Kinetic
– Lateral Path	Instantaneous Turn	Curved Turn
Lat/Vert Heuristics	yes (but different)	yes (but different)

ACES = internal (within facility) nav data DACS = external airway/fix database NFDC = airport database (for external)

This slide introduces a comparison of key characteristics between URET and en route CTAS (TMA, E/DA, and D2) TJM.

Key databases include navigation info for site adaptation (complemented by processing for both route conversion and LOA/SOP adaptation) and aircraft performance. Although CTAS and URET both update “internal” routes and fixes based on the site’s ACES database, URET also updates its “external” airways/fixes and airports based on DACS and NFDC (currently defined manually for CTAS). URET also maintains a database of manually entered en route LOA/SOP restrictions between sectors/facilities. Whereas URET’s route processing is independent (emulates Host MD312), trial plans are based on the anticipated Host processing, CTAS currently uses the converted “AK” route directly from the Host (CTAS used to perform its own route processing). For both systems, the adaptation process (creation and update) is manual in nature (somewhat customized for each system’s routines), particularly with respect to inter-sector/facility route restrictions (LOAs and SOPs). For aircraft performance, URET uses tables of Rate-of Climb/Descent (as a function of type and weight for a nominal speed) from pilot performance handbooks and tabular acceleration data. By comparison, CTAS uses thrust/drag data from performance-engineering handbooks to dynamically compute RoC/D and acceleration as a function of aircraft type, weight, and speed. Both systems apply methods to empirically tune performance (off-line & real-time analysis) and both model unknown types by cross-referencing data of “known” types.

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Comparison of TJM Characteristics (cont'd notes)

Characteristic	URET	CTAS (en route)
Database		
– Navigation/site adapt	ACES + DACS + NFDC	ACES
- Route processing	MD312 (emulates Host)	AK (uses Host Routing)
- Adapt processing	Manual	Manual
– Aircraft Performance	Pilot Handbook-Based – Empirically Tuned – Cross-ref Mapping	Engineering Handbook – Empirically Tuned – Cross-ref Mapping
Input		
– Track	Host + Adj Host (external)	Host + ETMS (external)
– Flight Plan Route	Flight Plan Route	Flight Plan Route
– Wind/Temp (3D grid)	RUC	RUC
Physics		
– Wind Gradient	no	yes
– Non-standard Atmos	yes	yes
– Rate of Climb/Desc (RoC/D), & Accel	Kinematic	Kinetic
– Lateral Path	Instantaneous Turn	Curved Turn
Lat/Vert Heuristics	yes (but different)	yes (but different)

Regarding the real-time input data, both CTAS and URET use the Host flight plan route and Rapid Update Cycle (RUC). Both systems receive aircraft state updates (track position/velocity and mode-C altitude) for internal flights from the site's Host computer. For external flights, URET accesses track data from the Host computers at adjacent sites running URET while CTAS uses the national ETMS data.

Although both systems correct for non-standard atmospheric conditions (temperatures and altimeter setting), other physical modeling (dynamic) characteristics differ. Both systems perform airspeed-groundspeed conversions based on RUC (Rapid Update Cycle) winds/temperature, but CTAS also models the variation in climb/descent rate due to wind gradient (with respect to altitude) for constant Mach/IAS segments. [In other words, CTAS also accounts for the change in pitch angle the pilot must effect while climbing/descending (at constant Mach/IAS) through a wind that varies with altitude]. While climb/descent gradients are modeled kinematically in URET (based on tabular data for climb/descent rates derived from empirically-observed data), CTAS dynamically computes climb/descent rates (and accelerations) based on a kinematic (force) model using engineering performance data for thrust and drag. Both approaches currently reflect the influence of weight on climb/descent rate.

CTAS also reflects the significant influence of speed on climb/descent rate and acceleration. The URET tabular data currently does not reflect this speed factor, since the climb/descent speed is not known until it is observed. When the climb/descent speed and gradient is observed, the URET modeled values are appropriately modified as necessary (for the remainder of that aircraft's climb/descent profile).

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Comparison of TJM Characteristics (cont'd notes)

Characteristic	URET	CTAS (en route)
Database		
– Navigation/site adapt	ACES + DACS + NFDC	ACES
- Route processing	MD312 (emulates Host)	AK (uses Host Routing)
- Adapt processing	Manual	Manual
– Aircraft Performance	Pilot Handbook-Based – Empirically Tuned – Cross-ref Mapping	Engineering Handbook – Empirically Tuned – Cross-ref Mapping
Input		
– Track	Host + Adj Host (external)	Host + ETMS (external)
– Flight Plan Route	Flight Plan Route	Flight Plan Route
– Wind/Temp (3D grid)	RUC	RUC
Physics		
– Wind Gradient	no	yes
– Non-standard Atmos	yes	yes
– Rate of Climb/Desc (RoC/D), & Accel	Kinematic	Kinetic
– Lateral Path	Instantaneous Turn	Curved Turn
Lat/Vert Heuristics	yes (but different)	yes (but different)

With regard to the lateral path, URET models turns instantaneously as an "average" representation of pilot over/undershooting. CTAS models a curved turn, like an FMS, to model the variation in path flown based on turn radius and fly-by/over waypoints.

Both systems apply customized heuristics to overcome intent errors in the lateral and vertical profiles (detailed differences are beyond the scope of this report).

Comparison of TJM Characteristics (concluded)

Characteristic	URET	CTAS (en route)
Trajectory Output	Linearly Varying Segments (of varying size)	
Trajectory Updates	Scan-based monitoring Conform-based update	Scan-based update
Comp Load (per traj)	Less	More
Level of physical modeling (RoC/D, turn)	Less	More

TJM Functions beyond basic TJM capability	URET	CTAS (en route)
Sector-penetration analysis	Internally imbedded	External
"Meet-time" using speed	External	Internally imbedded
Conformance	Internally imbedded	N/A

This chart compares an additional set of characteristics noted by the workshop participants.

Both systems essentially produce the same sort of output: a 4D trajectory prediction comprised of a piecewise continuous set of linearly-varying segments (to support fast/precise interpolation of position vs. time)

Whereas the CTAS TJM is based on continuous updates (new predictions) at each scan update, URET monitors actual vs. predicted state at each scan to determine conformance with updates reserved for re-conformance or flight plan modification.

The consensus of the workshop participants is that although CTAS TJM is considered to have a more detailed physical model, URET TJM is computationally less intensive.

Another discussion related to system characteristics focussed on how both systems evolved their TJM to include functions/capabilities that are beyond "basic" TJM capabilities. For example, to optimize URET implementation its TJM includes functions for conformance and analysis of sector/airspace penetration (external to CTAS TJM). Comparatively, CTAS imbeds its algorithms for iterating on speed profile (for flow rate/metering conformance) within its TJM. These considerations add complication to the reality of developing a common TJM process.

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Future Needs for TJM Capabilities

Domains	DST Needs/Applications	TJM Requirements
Terminal	Active Advisories for Accurate Arrival/Departure Management	Arrival – Procedures Dominate, Kinematic acceptable, Turns req'd Departure – Procedures & Performance Dominate; (Time in Term is short)
En route ATC		
– Basic Conflict Detection and Resolution (CD/R)	Conflict Probe (CP) (Arrival to Arrival too) to – flexibility, (¯ restrictions) & – capacity Conflict Resolution (CR) advisories to ¯ workload	Climb/Descent Phases Require – Accurate Intent (e.g., speed profiles from clearance or user preference) – Accurate Performance – Weight, Rate of climb/descent – ATMOS (accurate ave. wind/temp) – Cruise Intent (Speed, Lateral) – General Inter/Intra-facility adaptation – Improved tracker (velocity)
– Flow Conformance – Low density – High density	Active conformance Advisories integrated w/ CD/R ~ +/- 1 min accuracy for low ~ +/- 10 sec accuracy for high	+/- 1 min. achievable w/ above req's +/- 10 sec would also require: - ATMOS (no "large" wind error) - Speed Sensitivity - Wind Gradient
– Rte Efficiency	Advisory for Route Efficiency	Same as basic CD/R
TFM	Problem Detection (airspace, Capacity & Wx) to ¯ FR's Flow Strategy Evaluation & Problem Resolution	– Intent for Departures (wheels up, not just Push Back) – Fast NAS sim (long time horizon, accuracy not as critical as CD/R) – Add Adaptation beyond CONUS

A discussion was held on the topic of the future ATM applications needs that may well drive development of TJM capabilities. The slide summarizes the discussion of anticipated Decision Support Tool/Applications and resultant implied TJM requirements. These are broken out by the following domains: Terminal, En route conflict detection and resolution (Basic CD/R), En route Flow Conformance, and Traffic Flow Management.

Terminal domain needs include DST automation for active advisories for efficient/precise arrival/departure management. For arrival applications (e.g., FAST), the dominant factor is the modeling of dynamic flight path patterns and turns. The relatively short vertical profile segments contribute little variation to the trajectory due to descent rate uncertainty (kinetic modeling detail adds little advantage here). Regarding departure applications (e.g., EDP), although the time to the departure fix is relatively short and the paths are dominated by dynamically defined procedures (similar to terminal arrivals), more detailed performance modeling (e.g., kinetic) may be required to predict the vertical profile's sensitivity to airspeed and wind gradient.

Future Needs for TJM Capabilities (cont’d notes)

Domains	DST Needs/Applications	TJM Requirements
Terminal	Active Advisories for Accurate Arrival/Departure Management	Arrival – Procedures Dominate, Kinematic acceptable, Turns req’d Departure – Procedures & Performance Dominate; (Time in Term is short)
En route ATC		
– Basic Conflict Detection and Resolution (CD/R)	Conflict Probe (CP) (Arrival to Arrival too) to – flexibility, (¯ restrictions) & – capacity Conflict Resolution (CR) advisories to ¯ workload	Climb/Descent Phases Require – Accurate Intent (e.g., speed profiles from clearance or user preference) – Accurate Performance – Weight, Rate of climb/descent – ATMOS (accurate ave. wind/temp) – Cruise Intent (Speed, Lateral) – General Inter/Intra-facility adaptation – Improved tracker (velocity)
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TFM	Problem Detection (airspace, Capacity & Wx) to ¯ FR’s Flow Strategy Evaluation & Problem Resolution	– Intent for Departures (wheels up, not just Push Back) – Fast NAS sim (long time horizon, accuracy not as critical as CD/R) – Add Adaptation beyond CONUS

Future en route domain TJM needs will likely include increased trajectory accuracy, particularly for transitioning aircraft. This increased accuracy will support improved conflict detection accuracy, with consequent improvement in system capacity and the reduction of ATC restrictions. These accuracy improvements may be realized in a variety of areas including: improved information on controller intent (e.g., vector maneuvers and speed), pilot intent (e.g., planned turn, speed and speed/gradient profiles), improved aircraft performance data, knowledge of aircraft weight, improved atmospheric data, and improved surveillance/tracker data.

TJM accuracy improvements will also benefit conflict resolution enhancements, by increasing the accuracy of the resolution trajectories. This, in turn, will lead to increased benefits from these enhancements, including additional reduction in controller workload.

Future Needs for TJM Capabilities (cont’d notes)

Domains	DST Needs/Applications	TJM Requirements
Terminal	Active Advisories for Accurate Arrival/Departure Management	Arrival – Procedures Dominate, Kinematic acceptable, Turns req’d Departure – Procedures & Performance Dominate; (Time in Term is short)
En route ATC		
– Basic Conflict Detection and Resolution (CD/R)	Conflict Probe (CP) (Arrival to Arrival too) to – flexibility, (¯ restrictions) & – capacity Conflict Resolution (CR) advisories to ¯ workload	Climb/Descent Phases Require – Accurate Intent (e.g., speed profiles from clearance or user preference) – Accurate Performance – Weight, Rate of climb/descent – ATMOS (accurate ave. wind/temp) – Cruise Intent (Speed, Lateral) – General Inter/Intra-facility adaptation – Improved tracker (velocity)
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– Rte Efficiency	Advisory for Route Efficiency	Same as basic CD/R
TFM	Problem Detection (airspace, Capacity & Wx) to ¯ FR’s Flow Strategy Evaluation & Problem Resolution	– Intent for Departures (wheels up, not just Push Back) – Fast NAS sim (long time horizon, accuracy not as critical as CD/R) – Add Adaptation beyond CONUS

Traffic Flow Management (TFM) needs include decision support automation for detecting and solving flow problems due to excessive demand on NAS resources, severe weather events, or when flow restrictions are placed on NAS resources (e.g. sudden reduction in an airport’s arrival rate). TFM decision support is critical for minimizing delay as air traffic continues to grow. TFM problems are wide-reaching in time and space, requiring modeling of thousands of flights over prediction times of 30 minutes to 12 hours. Most flights involved have not yet departed, and thus departure time uncertainty is a dominant source of error; in future, better knowledge of runway departure times may be required. Because TFM actions are generally taken on traffic flows and not on individual flights, kinematic models provide more than enough accuracy, provided that major ATC effects are included (such as altitude and speed restrictions at facility boundaries). The accuracy improvements provided by kinetic models in climb and descent are generally not required for flow level simulations, since long-timeframe prediction errors are dominated by departure time errors and by cruise phase errors due to wind and airspeed uncertainty. In addition, due to the large number of flights involved in problems, and the need to model complex interactions between existing and proposed flow restrictions, resource capacities, and weather, care must be taken to apply trajectory models that provide sufficient accuracy while maintaining low computational requirements.

Future Needs for TJM Capabilities (cont'd notes)

Domains	DST Needs/Applications	TJM Requirements
Terminal	Active Advisories for Accurate Arrival/Departure Management	Arrival – Procedures Dominate, Kinematic acceptable, Turns req'd Departure – Procedures & Performance Dominate; (Time in Term is short)
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– Rte Efficiency	Advisory for Route Efficiency	Same as basic CD/R
TFM	Problem Detection (airspace, Capacity & Wx) to ¯ FR's Flow Strategy Evaluation & Problem Resolution	– Intent for Departures (wheels up, not just Push Back) – Fast NAS sim (long time horizon, accuracy not as critical as CD/R) – Add Adaptation beyond CONUS

For en route flow conformance, metering/spacing operations can be greatly enhanced by providing active decision support to advise conformance actions that are integrated with CD/R (to reduce the workload of corrective actions for flow and CD/R and reduce deviations / increase efficiency). Although knowledge of conformance intent will improve CD/R, spacing conformance during low-density metering is not critical to separation (spacing requirements far exceed radar separation minimums). However, in NASA's concept for high-density metering operations, where excess separation buffers will reduce flow-rate capacity, accurate trajectory planning and control (~10 sec accuracy) is critical. NASA feels that this accuracy will reduce controller workload for merging and spacing (particularly during arrival-compression situations) and increase efficiency by reducing corrective interruptions and delaying the merge (route-independent spacing as opposed to "in-trail" operations). Whereas the 1 min accuracy for low-density operations is most likely satisfied by the CD/R requirements, the high-density requirements will call for several TJM requirements. These include accurate wind predictions (with errors less than 20 knots even over small regions of airspace and time) and vertical profile predictions that reflect the influence of speed profile and wind gradient (to ensure that aircraft can accurately fly a planned 4D descent path).

CAASD has some concerns related to the above concepts. For example, there is the possibility that there could be added workload in the above high precision approach, as the controller has to issue TOD and Mach/IAS speeds, and presumably monitor those. There was not time to discuss/resolve such issues and, practically speaking, they can only be resolved through research.

Single Trajectory Modeler for NAS: Pros and Cons

PROS	CONS
Consistent info { • to same user; • Across Domains }	• Inflexible – Hard to meet all requirements across all DST applications – Harder to implement special needs for any individual application – Burden on simpler applications – Handicaps more complex applications • Challenge to evolve to it – Legacy systems • Perceived requirement for consistent information may be flawed, different requirements across applications will result in trajectory differences (consistency is not necessarily desired because it may handicap certain applications that require greater fidelity and/or update rates)
Single TJM may be necessary, but is not sufficient to make all DST ETAs the same	
Maintenance* – Software – Adaptation (NAVigation & Performance) Facilitates Integration of different DST applications	

* The first step, and possibly the first order advantage is Common Adaptation and the streamlining / automating / standardization of input-data sources.

The FAA has often debated the issue of whether a single trajectory modeler for all ATM applications should be an objective of the NAS architecture upgrade. The major goals appears to be the reduction in Operations and Maintenance (O&M) costs associated with software, adaptation, etc., and the elimination of discrepancies due to differing trajectory predictions. The workshop considered the pros and cons of a single modeler and the major results are summarized on this slide. These results must be considered to be preliminary, but they illustrate the kinds of issues that must be debated.

One thing that the participants unanimously agreed upon: To realize an immediate and significant reduction in O&M costs, the best near-term activity would be the streamline, standardize and automate the various input sources that make up the adaptation for CTAS, URET, and other NAS systems. This includes material like: letters of agreement, standard operation practices of individual facilities, etc. The experiences of both CAASD and NASA indicate that the effort to gather, edit, format and input such data is a major cost driver for implementing CTAS or URET at a new site, or for conducting on-going maintenance for an existing site.

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Single Trajectory Modeler for NAS: Pros and Cons (concluded)

PROS	CONS
Consistent info { • to same user; • Across Domains Single TJM may be necessary, but is not sufficient to make all DST ETAs the same Maintenance* − Software − Adaptation (NAVigation & Performance) Facilitates Integration of different DST applications	• Inflexible − Hard to meet all requirements across all DST applications − Harder to implement special needs for any individual application − Burden on simpler applications − Handicaps more complex applications • Challenge to evolve to it − Legacy systems • Perceived requirement for consistent information may be flawed, different requirements across applications will result in trajectory differences (consistency is not necessarily desired because it may handicap certain applications that require greater fidelity and/or update rates)
* The first step, and possibly the first order advantage is Common Adaptation and the streamlining / automating / standardization of input-data sources.	

The list of cons focuses primarily on issues related to the software aspects of a single modeler. Although the value of software depends on its cost to develop and maintain, it also depends on the capabilities (requirements) it delivers. Requirements vary with domain/application, and over time. A “one size fits all” TJM module will be handicapped in its flexibility to deliver challenging capabilities (e.g., detailed physical modeling and update rate) for complex applications, and overkill/complication for simpler applications. There may actually be a flexibility advantage to multiple TJM modules. Another factor to consider is the transition from legacy systems which adds additional cost over and above the costs associated with developing the common TJM module.

In conclusion, the workshop consensus that the greatest challenge to implementing a single TJM would be in software, yet very significant benefits are anticipated from the adaptation aspect (which could support multiple TJM systems).

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Single Trajectory Modeler for NAS: Related Issues

- **Observation: need to resolve confusion between trajectory modeling and TJM services (e.g., sector penetration); community does not speak with one voice/definition on what "TJM" is.**
- **Future drivers for TJM postulated above are not firm**
  - **Considerable research is needed to validate functional requirements for each domain/DST-application**
  - **Performance requirements must also be validated (e.g., update rate, model fidelity)**
  - **Would be premature to decide on single modeler (or not) until more data is in… and fundamental "TJM-supporting" infrastructure is in place**

The workshop also identified the issue that there is no single definition of trajectory modeling, and one needs to be developed. For example, does TJM include just the actual modeling of the flight path, or does it include more broadly based TJM services, such as sector penetration by the flight trajectory, that are necessary to many ATM application? The group encourages dialogue with the FAA to decide on a single definition if the community decides to pursue the transition to a common TJM module.

Also, the group felt that it was premature to commit to the course of implementing a single TJM capability. Considerable study is needed to understand the long term needs and whether a single modeler is the best approach to achieving them.

Again, the initial emphasis should be placed on upgrading the data input (adaptation) process.

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TJM TIM Accomplishments

- Accomplished the first objective
  [identify TJM needs, why, when…]
  - Emphasis on key drivers for en route and TFM
  - Terminal applications may require additional expert consideration
- Made progress toward second objective
  [assess current capabilities & identify transition strategy to future]
  - Identified common TJM "infrastructure" needs
- Documented:
  - Historical drivers for CTAS and URET TJM requirements
  - CTAS/URET TJM characteristics (commonality/differences)
  - Future TJM needs vs. domain
  - Pros and Cons of single Trajectory Modeler for the NAS

This slide summarizes where we stood at the conclusion of the workshop with regard to our original objectives (slide 3). A considerable amount of progress was made on the set of questions we started out to address (slides 5/6), and many topical discussions resulted in agreement.

Based on the accomplishments of the TJM workshop, three "next steps" were identified. The workshop results and next steps were documented in this briefing and presented to the NASA/CAASD Off-site leadership via telecon on December 8.

The first step is to brief the FAA on the results of the TJM workshop at the next meeting of the IAIPT En Route Area Work Team (at Ames).

The second step is to present the FAA (via the ERAWT) with a recommendation to develop a common TJM infrastructure to support adaptation with an emphasis on the development of a streamlined process to automate the adaptation tasks.

The final step is to present the FAA (via the ERAWT) with a recommendation to initiate a study to determine future TJM requirements related to physical modeling of trajectory characteristics.