



The Air Mobility Operations Simulation Environment (Air MOOSE) *Initial Design Specifications*

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Defence R&D Canada
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Chief of the Air Staff

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Abstract

The Canadian Forces (CF) air mobility community is facing a period of considerable transition over the next decade or so as its fixed wing airlift capability, represented primarily by the aging fleet of CC130 E- and H-model Hercules and a fleet of five CC150 militarized Airbus 310 aircraft, transforms into a modernized fleet with Boeing CC177 Globemaster and new J-model Hercules aircraft. There will be a wide range of operational effectiveness issues arising over this transition period, pointing to the requirement for an operational research tool to help support decisions on these issues.

It was concluded that a ‘time-and-space’ simulation of CF airlift operations was required to provide this analysis capability. This paper documents the design specifications for such a simulation tool, to be realized as the Air Mobility Operations Simulation Environment (Air MOOSE).

Résumé

La communauté de mobilité aérienne des Forces canadiennes (FC) fait face à une période de transition considérable. Au cours de la prochaine décennie, la flotte d’appareils de transport à voilure fixe, principalement représentée par les Hercules CC130 modèles E et H, et cinq avions Airbus 310 militarisés (CC150), sera remplacée par une flotte moderne consistant d’appareils Boeing CC177 Globemaster et de nouveaux Hercules modèle J. Cette période de transition donnera lieu à un bon nombre de questions d’efficacité opérationnelle, indiquant un besoin pour un outil de recherche opérationnelle qui soutiendra la prise de décisions dans ce domaine.

Il a été déterminé qu’une simulation ‘dans le temps et l’espace’ des opérations de transport aérien des FC serait requise en tant que capacité d’analyse. Ce rapport documente les spécifications relatives à la conception d’un tel outil de simulation, que l’on a surnommé « L’environnement de simulation des opérations de transport aérien », aussi désigné l’acronyme anglais « Air MOOSE ».

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Executive summary

The Air Mobility Operations Simulation Environment (Air MOOSE): Initial Design Specifications

D.W. Mason; DRDC CORA TM 2010-222; Defence R&D Canada – CORA; November 2010.

The Canadian Forces (CF) air mobility community is facing a period of considerable transition over the next decade or so as its fixed wing airlift capability, represented primarily by the aging CC130 fleet of E- and H-model Hercules and a fleet of five militarized Airbus 310 aircraft (CC150), transforms into a modernized fleet augmented with Boeing CC177 Globemasters and new J-model Hercules.

There will be a wide range of operational effectiveness issues arising over this transition period, pointing to the requirement for an operational research tool to help support decisions on these issues. The Directorate of Air Requirements, Directorate of Air Strategic Planning, and CF Air Warfare Centre will be facing questions like the following. How would operational effectiveness change if the CF had more/fewer aircraft in any given fleet? What is the operational impact of delays in new fleet delivery? Would alternate basing structures be more effective? Is the number of crews for each fleet about right? What would the operational impact be of a change in availability of a given fleet? If the projected future operational tempo increases what would be the impact on operational effectiveness? How much airlift can the CF expect to charter in the future?

The primary tool in this field is the United States Air Force (USAF) Air Mobility Operations Simulation (AMOS), which Canada acquired in 2005. It was concluded at Ref [1] that while AMOS has good utility in addressing effectiveness issues surrounding a specific operation, (an excellent mission rehearsal tool) it is not constructed to be as useful in addressing more strategic issues such as those listed above. Therefore, the decision was made to design and build a Canadian tool that modelled air mobility operations in a manner suitable for how the CF operates and can be used to support strategic level decisions on air mobility issues. This will be realized as the Air Mobility Operations Simulation Environment or 'Air MOOSE'. Air MOOSE and AMOS will comprise a strong tandem of simulations for the CF to address the full spectrum of air mobility issues that might arise in the future.

Air MOOSE will be a Monte Carlo, event-based simulation. Air transport demands will arise over time, generating a call to move a quantity of cargo and/or personnel from one location to another. Aircraft and crews will be assigned to deliver portions of the loads identified based on the priority of the particular operation and the availability of aircraft and crews.

Aircraft instantiated into the simulation can fail and require maintenance. Also, they will periodically require preventative maintenance and be unavailable for assignments during those periods. Aircrews will have flying hour limits and currency standards to meet, and will require rest periods en route. The assignment of aircraft and aircrews to missions will take place periodically on a user-determined cycle.

A range of measures of effectiveness (MOEs) will be collected by the simulation as it progresses. Multiple runs of the same scenario can be executed to generate reliable statistics on simulated missions and carry out sensitivity analyses on the input parameters.

The simulation will have a robust graphical user interface (GUI) that enables the user to easily set up the simulation, monitor its execution to verify it is operating as intended, and facilitate output of the required MOEs at the end. The interface will be based on map-like displays of the regions of the world covered by the scenario.

This document provides the detailed specifications for the Air MOOSE simulation design and will comprise a foundation document for the contracted development of the software implementation of Air MOOSE.

Sommaire

The Air Mobility Operations Simulation Environment (Air MOOSE): Initial Design Specifications

D.W. Mason; DRDC CORA TM 2010-222; R & D pour la défense Canada – CARO; Novembre 2010.

La communauté de mobilité aérienne des Forces canadiennes (FC) fait face à une période de transition considérable. Au cours de la prochaine décennie, la flotte d'appareils de transport à voilure fixe, principalement représentée par les Hercules CC130 modèles E et H, et cinq avions Airbus 310 militarisés (CC150), sera remplacée par une flotte moderne consistant d'appareils Boeing CC177 Globemaster et de nouveaux Hercules modèle J.

Cette transition engendrera un éventail de questions d'efficacité opérationnelle, d'où le besoin d'un outil de recherche opérationnelle pour aider à appuyer la prise de décisions sur ces questions. La Direction – Besoins en ressources aériennes, la Direction – Planification stratégique (Air) et le Centre de guerre aérospatial des FC seront confrontés à des questions telles que : Comment le nombre d'avions affecte-t-il l'efficacité opérationnelle? Quel serait l'impact opérationnel d'un retard dans la livraison des nouvelles flottes? Est-ce qu'une autre distribution des bases serait plus efficace? Est-ce le nombre d'équipages pour chaque flotte est à peu près juste? Quel serait l'impact opérationnel d'un changement dans la disponibilité d'une flotte donnée? Si le rythme opérationnel augmente, quel serait l'impact sur l'efficacité opérationnelle? Quels seront les besoins futurs des FC en transport commercial?

L'outil principal existant dans ce domaine est le « Air Mobility Operations Simulation » (AMOS) de la « United States Air Force (USAF) », auquel le Canada en a acquis l'accès en 2005. Il a été conclu à la référence [1] que, bien qu'AMOS soit utile pour résoudre les problèmes par rapport à une opération spécifique (un excellent outil de répétition de mission), il n'est pas aussi utile pour traiter des questions plus stratégiques énumérées ci-haut. Par conséquent, la décision a été prise d'examiner si un outil canadien devrait être conçu et construit pour modéliser les opérations de mobilité aérienne des FC pour appuyer la prise de décisions au niveau stratégique. Ce nouvel outil, désigné le « Air Mobility Operations Simulation Environment (Air MOOSE) », et AMOS, permettraient d'adresser l'éventail complet de questions de mobilité aérienne des FC.

Air MOOSE sera une simulation Monte-Carlo basée sur les événements. Les demandes en transport aérien seront générées au fil du temps, engendrant un appel à transporter une quantité de marchandises et / ou du personnel d'un endroit à l'autre. Aéronefs et équipages seront affectés à livrer des charges selon la priorité d'une opération et de la disponibilité.

Les aéronefs instanciés dans la simulation pourront avoir des bris mécaniques nécessitant de l'entretien. Périodiquement, ils auront de l'entretien préventif et ne seront alors pas disponibles. Les équipages ne pourront voler qu'un nombre d'heures limité, devront demeurer courant selon les normes légales, et ils auront besoin de périodes de repos en cours de route. Les aéronefs et les équipages seront affectés aux missions selon un cycle défini par l'utilisateur.

Des mesures d'efficacité (MOE) seront collectées par la simulation alors qu'elle progresse. Le même scénario pourra être exécuté plusieurs fois pour produire des statistiques fiables sur les missions simulées et effectuer des analyses de sensibilité sur les paramètres d'entrée.

La simulation aura une interface graphique pour l'utilisateur (GUI) robuste qui permettra de facilement préparer une simulation, suivre son exécution afin de vérifier qu'elle fonctionne comme prévu, et faciliter la capture des MOE à la fin. L'interface sera basée sur une carte-affiche des régions du monde couvertes par le scénario.

Ce document fournit des spécifications suffisamment détaillées sur la conception d'Air MOOSE et pourra servir de document de base pour un contrat visant au développement du logiciel requis pour créer la simulation Air MOOSE.

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1 Introduction

The Canadian Forces (CF) air mobility community is facing a period of considerable transition over the next decade or so. The fixed wing airlift capability, represented primarily by the aging CC130 fleet of E- and H-model Hercules and a fleet of five militarized Airbus 310 aircraft (CC150), will transform into a modernized fleet augmented with Boeing CC177 Globemasters and new J-model Hercules.

There will be a wide range of operational effectiveness related issues arising over this transition period. The Air Requirements and Air Strategic Planning Directorates in National Defence Headquarters and the CF Air Warfare Centre will be facing questions like the following. How would operational effectiveness change if the CF had more/fewer aircraft in any given fleet? What is the operational impact of delays in new fleet delivery? Would alternate basing structures be more effective? Is the number of crews for each fleet about right? What would the operational impact be of a change in availability of a given fleet? If the projected future operational tempo increases what would be the impact on operational effectiveness? How much airlift can the CF expect to charter in the future?

Many of these types of strategic issues will benefit greatly from the availability of a ‘time-and-space’ simulation of air mobility operations. The primary tool in this field is the United States Air Force (USAF) Air Mobility Operations Simulation (AMOS), which Canada acquired in 2005. It was concluded that while AMOS has good utility in addressing effectiveness issues surrounding a specific operation, (an excellent mission rehearsal tool) it is not constructed to be as useful in addressing more strategic issues such as those listed above [1]. It models many aspects of operations in full detail, such as airfield congestion and air-to-air refuelling, but does not permit the full breadth of all air mobility operations to be simulated over an extended period of time. Also, missions are essentially scripted, so the more demanding concurrency situations that might arise by chance cannot be simulated.

Therefore, the decision was made to design and build a Canadian tool that modelled air mobility operations in a manner suitable for how the CF operates and can be used to support strategic level decisions on air mobility issues. This will be realized as the Air Mobility Operations Simulation Environment or Air MOOSE. Air MOOSE and AMOS will comprise a strong tandem of simulations for the CF to address the full spectrum of air mobility issues that might arise in the future.

2 Air MOOSE Overview

Air MOOSE will be a Monte Carlo, event-based simulation. Air transport demands will arise over time, generating a call to move a quantity of cargo and/or personnel from one location to another. Airplanes and crews will be assigned to deliver portions of the loads identified based on the priority of the particular operation and the availability of airplanes and crews.

Some terms will have a specific meaning as simulation constructs within Air MOOSE. These terms are Scenario, Mission, Meta-Mission, Tasking, Platform, Aircraft, Aircrew, Airfield, Service Line, Chalk, Parcel and Load Element. These terms will be defined as they are introduced and will be identifiable as a special simulation construct or object by using a leading capital letter.

Aircraft instantiated into the simulation can fail and require maintenance. Also, they will periodically require preventative maintenance and be unavailable for assignments during those periods. Aircrews will have flying hour limits and currency standards to meet, and will require rest periods en route. The assignment of Aircraft and Aircrews to missions will take place periodically on a user-determined cycle.

A range of measures of effectiveness (MOEs) will be collected by the simulation as it progresses. Multiple runs of the same scenario can be executed to generate reliable statistics on simulated missions and carry out sensitivity analyses on the input parameters.

The simulation will have a robust graphical user interface (GUI) that enables the user to easily set up the simulation, monitor its execution to verify it is operating as intended, and facilitate output of the required MOEs at the end. The primary display will be based on map-like displays of the regions of the world covered by the scenario.

2.1 Scenarios

Scenario is the broad term used to describe an entire operational context for analysis. It consists of components on both the ‘demand’ side (the set of jobs to be executed) and the ‘supply’ side (various aircraft fleets, flight crews, maintenance resources, etc. available to satisfy the missions). It also includes a description of the ‘playing field’ itself, identifying the set of aerodromes around the globe to employ. Scenarios also identify the set of MOEs to be captured by the simulation.

Global parameters such as the maximum simulation execution time, the time interval between scheduling sessions, the number of iterations to be run, a random number generator seed, etc. will also be defined for each Scenario.

Each of these Scenario components will be described in further detail in the sections that follow. Section 3 covers the demand side of the simulation: Missions, Meta-Missions, and Taskings. Section 4 covers the supply side: Platforms, Aircraft, Aircrews, and Airfields.

3 The Demand Side

3.1 Missions

Mission is the term used to describe each different type of airlift operation that might arise over time as a Scenario plays out.

The Air Staff of the Canadian Forces have compiled a comprehensive list of over 150 different types of Missions that the CF could be called upon to action. Examples of Missions are: deploying a Special Forces unit overseas, sustaining a deployed battle group in combat operations overseas, rotating troops on a UN peacekeeping operation, or responding to a domestic flood disaster.

Each Mission has a list of parameters to describe the nature in which it arises over time (randomly or regularly, and at what rate), the quantity of cargo and personnel that would be moved, the air embarkation and debarkation ports, the overall priority of the Mission, and preferences desired for the specific type (e.g. CC177) or general class (e.g. strategic airlift) of aircraft to assign to the Mission. Also specified might be time tolerances for executing the Mission and parameters to permit load randomization, if desired.

Parcel is the term used to describe a distinguishable subset of what the Mission has to move. Parcels are categorized as either ‘passengers’ or various classes of freight: ‘oversized’, ‘outsized’, or ‘bulk freight’. The term oversized means the item is larger than a standard freight pallet, and outsized means it is larger than what a tactical transport aircraft such as the Hercules can carry. Bulk freight catches everything else. The number of identical individual units in this Parcel is specified, as is the weight and volume of an individual unit.

The set of Missions is presumed to represent the expected range of force employment opportunities that could arise. Force generation (i.e. training flight) demands are not included in the set of Missions. They will be driven by the needs of individual Aircrews (see Section 4.3).

3.2 Meta-Missions

Some Missions will be *Meta-Missions*, meaning they don’t call up specific demands as described above, but instead initiate a sequence of other Missions. For example, a Meta-Mission might be to deliver and support a battle group overseas in a combat role for a given period of time. This Meta-Mission will determine the location and duration of the operation, schedule the deployment Mission, followed by a sustainment Mission for the force while it is deployed, followed by a redeployment Mission at the end. At regular intervals it will also schedule a troop rotation Mission.

The Meta-Mission can also temporarily redefine the home base for a selected number of Aircraft, Aircrews and service lines for the duration of that Meta-Mission. These entities will be re-assigned back to their home base after the Meta-Mission is completed. One of the duties of a Mission/ Meta-Mission will be to reschedule its next occurrence according to its defined nature (random or regular, with a frequency parameter). However, Missions generated by a Meta-Mission will be marked as ‘spawned’ and will not reschedule themselves – only the parent Meta-Mission will.

3.3 Taskings

Tasking is the term used to describe a single instantiation of a Mission. Each Mission that is not a Meta-Mission in the Scenario will have a simulation event created for it, marking the first instantiation of that Mission. This will arise at a time that is either scripted by the user or

randomized as specified. When the simulation clock reaches that point in time the Mission event is executed and a Tasking is instantiated. The Tasking parameters are set and the Tasking is placed in the queue to be dealt with at the next scheduling session. The final duty of the Mission event is to determine when to reschedule itself according to its defined parameters.

Meta-Missions will schedule all the required deployment, sustainment, redeployment, and troop rotation Mission events and mark them as ‘spawned’. When these Mission events arise they will raise a Tasking in the same fashion as other Missions.

As instantiations of a Mission, each Tasking will have run-time parameters associated with it. The completion status of the tasking will be monitored continuously as *Chalks* (individual aircraft and aircrew assignments to deliver a subset of the Parcels associated with this Tasking) are executed and Parcels are delivered. Times of these events will be recorded in calculating the various MOEs. Table 1 shows the possible Tasking states.

Table 1: Tasking Status

AC	Active Tasking.
FA	Fully assigned; all Parcels have been assigned to Chalks for delivery.
CP	Tasking completed; all Parcels delivered.
XX	Cancelled; the uncompleted tasking reached its time expiry point.

4 The Supply Side

4.1 Platforms

Air MOOSE will maintain a master list of the different types of air *Platforms* that the user may wish to instantiate into a Scenario. ‘CC130 Hercules’ and ‘CC177 Globemaster’ are possible examples.

Parameters associated with Platforms include its basic airlift class (tactical or strategic), whether it is capable of carrying oversized or outsized cargo, basic performance characteristics such as typical cruise speed and maximum transit leg distance, and its required runway length and runway surface type requirements.

The load carrying capacity of a Platform is defined as simply as possible, but it is essential to accommodate the reality of both weight and volume limitations. The maximum number of passengers possible is noted separately. Loading and unloading times also are specified.

4.1.1 Modelling Maintenance Activities

Aircraft will experience equipment failures when they fly and will subsequently require unscheduled maintenance. They will also be unavailable periodically while undergoing scheduled maintenance activities.

The mean time between failures (MTBF) of the Platform is specified, as is the expected fraction of failures that will require immediate maintenance before continuing. Remaining failures will be deemed not critical enough to require en route maintenance activity and will be repaired at home base when the aircraft returns. A mean time to repair (MTTR) value is specified.

In fact, two MTTR values will be specified, one for unscheduled maintenance en route and one for repair back at home base. Also, repair times are modelled differently in both locations. En route maintenance is simply represented as a time delay. The aircraft and aircrew wait for the aircraft to be repaired (however that is effected) and then continue their flight when the repair is completed.

At the home base, however, maintenance lines are modeled individually. The Scenario will establish a number of *Service Lines* at the home bases used for each Platform type. If no line is available when the aircraft returns to home base then it will join a queue for the Service Lines available. Aircraft can also be queued awaiting spare parts.

Scheduled maintenance is modelled with separate Service Lines and queues, and can be at a different location. This introduces the requirement to occasionally ferry aircraft, which is also represented in Air MOOSE with it's own priority established.

One of the run-time parameters associated with an instantiated Platform will be the total number of flying hours accumulated over time. Once that time exceeds a predefined limit it will enter the scheduled maintenance queue. Both long- and short-term scheduled maintenance activities can be modelled in Air MOOSE.

A service life parameter is specified for each Platform. Once an aircraft accumulates flying hours that exceed this value it will be removed from service.

4.1.2 Randomizing Times

All mean times described above are to be stochastic variables based on a suitable probability distribution, e.g., a Poisson or Triangular distribution [2]. For example, Tasking occurrences and equipment failures could be Poisson random variables, whereas repair times could be modelled using a Triangular Distribution.

It should be noted that a Triangular distribution is easier to specify when hard statistics are not available. A subject matter expert can often estimate the lower limit, upper limit, and most likely value for a random variable, whereas averages and standard deviations can be tougher to assess, especially if the distribution is quite skewed.

4.1.3 Modelling Flying Rate Limitations

Platforms are usually operated with upper limits as to how much flying they can do in a given month (considered to be 30 days) or year (360 days). Such limits will be specified as Scenario inputs. Aircrews can also have similar maximum rates, including maximum flying hours in a day to ensure crew rest, but will have minimum flying rate limits as well in order to maintain their

training levels and meet currency standards. See Section 4.3 for details on how Aircrew currency and training is modelled.

Once Aircraft or Aircrew exceed a monthly or annual flying limit they will be unavailable until the next time period commences.

4.2 Aircraft

When constructing a Scenario the user will instantiate copies of Platforms into the Scenario as individual *Aircraft*.

Aircraft are assigned a tail number and a home base. They are assigned a starting age value, in terms of lifetime flying hours at the start of the simulation. They may also be assigned a future in-service date. The ability to insert Aircraft and remove life expired Aircraft will permit Air MOOSE to examine questions relating to fleet transitions.

Aircraft will have run-time status variables to monitor their operational status (Table 2) and maintenance status (Table 3). These variables will be used in determining actions as the various events are executed.

Table 2: *Operational Status of an Aircraft*

AV	Available for tasking (at home base)
AC	Assigned to a Chalk
FL	In flight
LD	Loading
UL	Unloading
MR	In unscheduled maintenance en route
MB	In unscheduled maintenance at home base
SM	In scheduled maintenance
TA	Turnaround (refuelling) en route
CR	Awaiting crew to return from rest period.
CT	Awaiting crew in transit (ferry missions)

Table 3: *Maintenance Status of an Aircraft*

OP	Operational
FL	Failure occurred, repair at end of current leg
FB	Failure occurred, repair at end of chalk
ER	Unscheduled maintenance en route
BQ	Unscheduled maintenance queue (home base)
BP	Awaiting parts (will rejoin front of BQ)
BM	Unscheduled maintenance at home base;
ST	Transit to/from scheduled maintenance facility
SQ	Scheduled maintenance queue
SM	Scheduled maintenance.

4.3 Aircrews

When operated, each Aircraft will have an *Aircrew* assigned. The Aircrew is treated as a single entity even though it may in reality have a number of different personnel within it (pilot, co-pilot, navigator, loadmaster, etc) When constructing a Scenario the user will instantiate copies of Aircrews into the Scenario for each Platform type employed, nominating each Aircrew's home base. Table 4 presents the various states that an Aircrew can be in.

For each Platform there will be some Aircrew flying rate limitations defined as well. Aircrews must fly enough in a given month or year to retain their currency, but have limits as to how much they can fly in a single month or year.

Aircrew flying rates will be assessed periodically (frequency is a Platform input) by the scheduling algorithm. If the monthly or annual training flight rate is below the expected level then a special training flight Tasking will be generated. If the Aircrew's total flying rate for the month or year is below the expected level then the Aircrew can be 'doubled up' with another crew on a Chalk.

Table 4: Aircrew Status

AV	Available for tasking (at home base)
FL	In flight as primary crew for the Chalk
FD	In flight as double-up crew
TF	In flight on a training flight
FT	In transit to/from a ferry tasking
GR	Assigned to a Chalk but currently on ground
CR	Crew resting

4.4 Airfields

Air MOOSE will simulate flights around the globe. Aircraft will either be on the ground at an Airfield somewhere or in the air flying between Airfields. Air MOOSE will maintain a master list with a limited set of parameters associated with each Airfield: International Civil Aviation Organization (ICAO) four-letter identifier, latitude, longitude, runway length, and runway surface (paved or not). This could also include landing aids such as an Instrument Landing System.

The user will import Airfields from this master list into a Scenario. Any Airfields mentioned in the Mission set would be imported automatically, as would all maintenance bases associated with the Platform set. The user can specify additional Airfields to be used as stopover bases.

5 Air MOOSE Event Structure

Air MOOSE is an event-based simulation. As simulated time progresses the next event in the event queue is executed. Figure 1 gives an overview of the Air MOOSE event structure, which comprises about 20 or so events. Included are several key calculation routines as well, including a load calculation algorithm (Annex A), and a route selection algorithm (Annex B).

The key event for matching ‘supply’ to ‘demand’ is the SCHEDULE event, which is now described in more detail.

At a regular, user-defined interval Air MOOSE will process the outstanding ‘demands’, represented by the current set of Taskings, and assign components of ‘supply’ (Aircraft and Aircrews) to address those demands, creating a *Chalk*. A Chalk is an airlift community term used to describe the sequence of flight legs required by a single aircraft with its crew to pick up its cargo, deliver it, and (usually) return to home base. Table 5 presents the states possible for a Chalk.

Table 5: Chalk Status

PL	Chalk active, but is prior to loading
LD	Parcels have been loaded onto delivery aircraft;
RF	Parcels have been unloaded, on return flight
FF	Chalk is a ferry flight
TR	Chalk is a training flight

The time between scheduling sessions is a user input and should reasonably reflect the way scheduling actually occurs in the organization being simulated. A small time between sessions (say several hours) would simulate a near real-time system where demands attempt to get satisfied as soon as they arise. A long time between sessions (say 24 hours) would simulate a day-to-day system where once the assignments have been made for the day anything new arising will have to wait until the next day to get addressed.

The scheduling algorithm selects from the three major demand sources: ferry flight demands, training flight demands, and regular ongoing Taskings. This could include a prioritized tasking or chalk, and it might be possible that some flights could satisfy more than one demand source (e.g., a ferry flight could also serve as a training flight). The highest priority demand with the oldest initiation time will be serviced first.

5.1 Ferry Flight Demand

A specific Aircraft needs to be flown from its current location to another location (usually at the start or end of periodic maintenance). If at least one Aircrew is available for this aircraft type at its home base, then select the crew with the fewest hours flown in the current month and assign it to this Chalk.

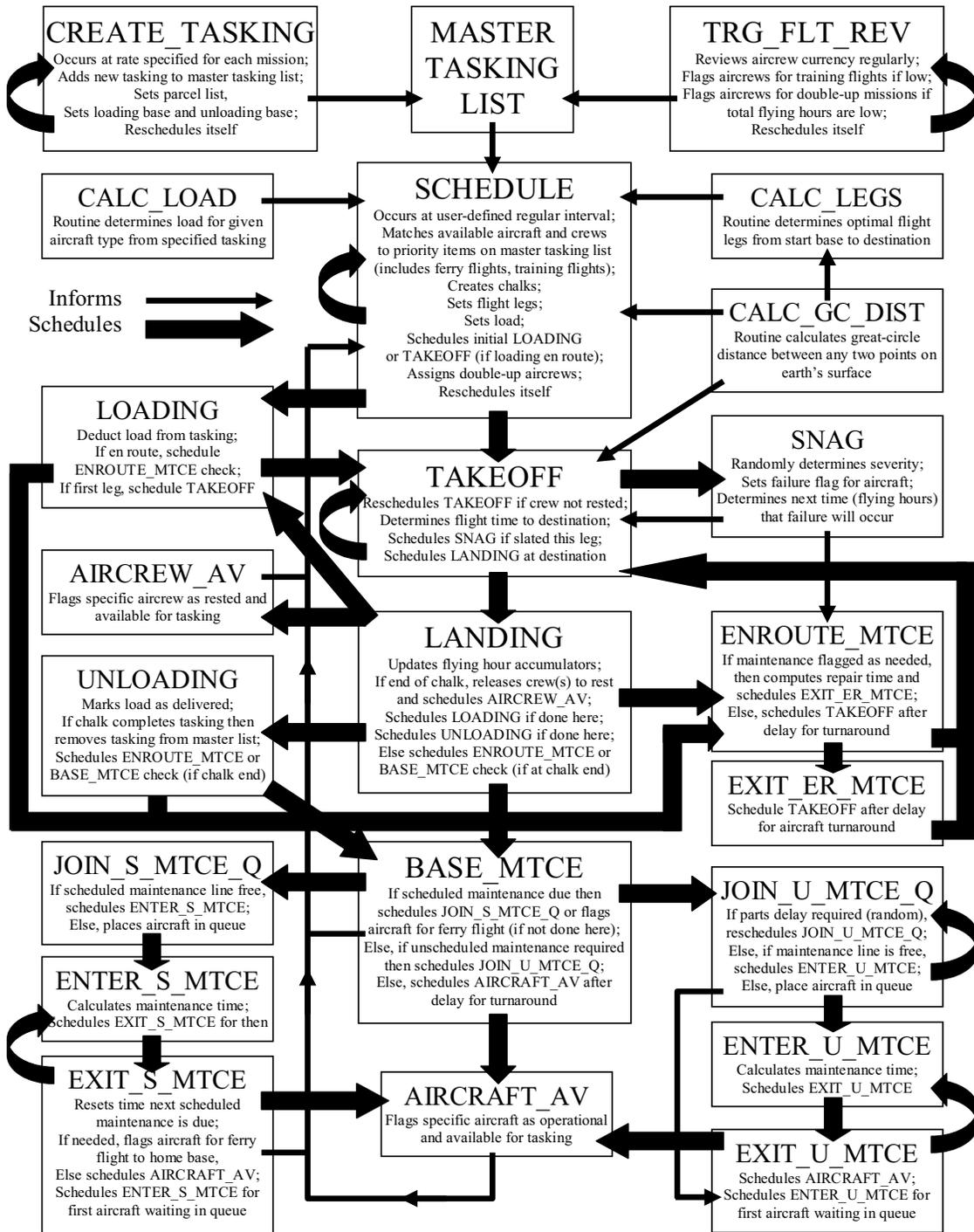


Figure 1: Air MOOSE Event Structure

If the Aircraft and Aircrew are co-located then set the Aircraft operational status to 'AC', set Aircrew status to 'GR' and schedule a TAKEOFF event to occur immediately. If the Aircrew has to come from its home Airbase then set Aircraft operational status to 'CT', set the Aircrew status to 'FT', and schedule a TAKEOFF event to occur after a calculated time delay (the formula is provided as a Scenario input).

5.2 Training Flight Demand

A specific Aircrew has been identified through the TRG_FLT_REV event to require a training flight. If the Aircrew is at its home Airbase and available and an Aircraft of the type flown by this Aircrew is available at the home Airbase then assign both to this Chalk. Set the Aircraft operational status to 'AC', the Aircrew status to 'GR', and schedule a TAKEOFF event to occur immediately.

5.3 Regular Tasking Demand

5.3.1 Identify Aircraft and Aircrew.

When a Tasking demand is being serviced, both the Aircraft and Aircrew will have to be assigned. The first step is to identify a suitable Aircraft. Find the closest available Aircraft that meets the specifications of the Tasking (either naming a particular Platform type or a generic call for 'strategic only', 'strategic preferred', 'no preference', 'tactical only', or 'tactical preferred'). If the specification indicates only a preference for a certain class of aircraft, then the other class will only be assigned if there are no aircraft of the preferred class available at any Airfield.

We determine if there is an Aircrew available for the selected Aircraft at its home Airbase and assign it to the Chalk. If no pairing of Aircraft and Aircrew is possible for this demand item, then process the next highest priority item. Otherwise the parameters associated with this new Chalk are finalized as follows.

5.3.2 Determine Load Elements

Each Parcel in the Tasking will have some number of identical and indivisible units remaining to be assigned for delivery. The algorithm in Annex A is executed to determine the *Load Elements* for this Chalk; i.e., how many units from each of the Tasking's Parcels will be delivered. The algorithm processes the Parcels looking for outsized and oversized items first (if the Aircraft is capable of handling them) and then filling in with bulk freight and passengers. Both weight and volume are monitored as the Load Elements are determined.

It may happen that no Load Elements are identified. This is possible when the Tasking is nearing full assignment and only a few Parcel types are left (for example, in a deployment where only outsized vehicles remain). If this occurs then cancel this tentative Aircraft and Aircrew assignment, mark this Aircraft type as being unsuitable for future deliveries for the remainder of this Tasking, and return to try to identify and assign a suitable Aircraft and Aircrew to this Tasking. Note that the user must ensure that the requested Aircraft types are capable of actually carrying the Parcels established for the Mission or all Taskings generated can never be completed.

5.3.3 Determine Flight Legs for the Chalk

The algorithm in Annex B will be executed to determine the outbound legs from the home base of the Aircraft to the loading point, or ‘air point of embarkation’ (APOE), from the APOE to the delivery destination, or ‘air point of disembarkation’ (APOD), and from the APOD back to home base. Only one of these segments would be calculated for ferry Taskings.

5.3.4 Schedule Chalk to Begin.

Schedule the TAKEOFF event for the first leg of this Chalk to occur immediately, unless the APOE is the same as the Aircraft/Aircrew home base in which case schedule a LOADING event for this Chalk to occur immediately.

5.3.5 Assign ‘Double-Up’ Aircrews

Once all current Taskings have been processed in priority order and all Chalks that are possible have been created, then check to see if ‘double-up’ Aircrew assignments are possible. Process the available Aircrews for each Platform type and attempt to assign those who have been flagged with low flying hours via the TRG_FLT_REV event to be a second crew on a newly created Chalk.

Finally, schedule the next occurrence of the SCHEDULE event and exit.

6 Computer and GUI Requirements

6.1 Hardware and Software Requirements

The Air MOOSE software will run on a standard desktop PC under Microsoft Windows. The software environment for Air MOOSE will be left to the contractor to recommend. Because of the extensive amount of activity to be simulated in a typical application – scores of different airlift demands driving the activity of dozens of aircraft and associated aircrews over a simulated time period of months or years – the simulation must be fast running.

6.2 Graphical User Interface Requirements

The user will interact with the Air MOOSE simulation via a well-designed graphical user interface (GUI). The GUI will be based on a map-like presentation scheme that can show the current state of simulated airlift activity in any location in the world, including the polar regions.

The GUI will enable the user to: enter basic input data for Missions, Aircraft, Aircrews, and Airbases; easily assemble a simulation Scenario or edit a previous Scenario; select MOEs to collect during the run(s); and view simulated airlift activity as time progresses within the simulation, with the capability to ‘drill down’ to view additional detail on an individual Aircraft,

Airbase, or Tasking. It will also permit the user to: control the level of display as the simulation executes; speed up or slow down the display rate; pause or terminate execution of the simulation; and present the results to the user when execution is completed.

Superimposed on the map display, icons will reflect the identity and the current position and heading of every Aircraft in flight at that point in simulated time within the visible map region. Other icons will show the location and identity of those Airbases that are involved in the current set of Taskings. The user will be able to speed up or slow down the rate of display, including turning off the display altogether. The user will also be able to control the displayed size of icons.

Figure 2 presents a very simplistic and notional idea of the map display. The contractor will design the look and feel of the GUI and recommend the geographic information system (GIS) products and the map projection scheme to employ with Air MOOSE. One acceptable solution for the display would be to use the NASA Blue Marble imagery with an orthographic projection of the earth onto a plane from a point at infinity above a selected position on earth (which we will call the *projection point*).

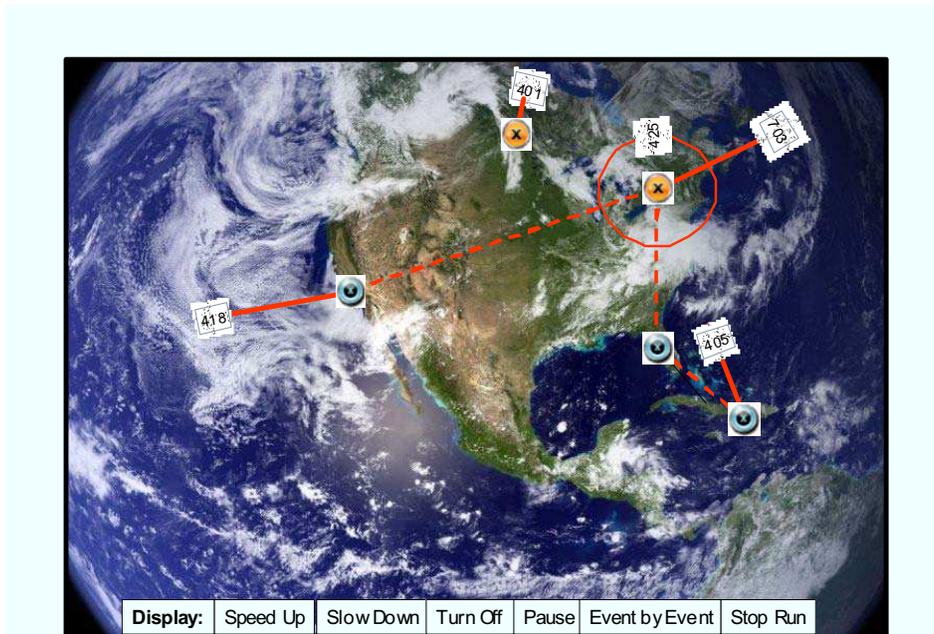


Figure 2: Notional Map Display Graphics

The user will be able to easily pan around in both latitude and longitude to different projection points using the mouse or arrow keys. The user will be able to easily zoom in or out on a given projection point using the mouse wheel (and alternate keyboard hot keys). The basic zoom and pan functionality provided by Google Earth is a good example of what is required for Air MOOSE.

The user will be able to double-click on any Airbase icon on the basic display to open a window that will show the activity graphically at that base. Figure 3 illustrates notionally what such a window might display, showing those aircraft available for tasking, those in unscheduled

maintenance or short/long term maintenance, those waiting in the queues for maintenance (including those awaiting parts), and those aircraft transiting through this base on a Chalk.

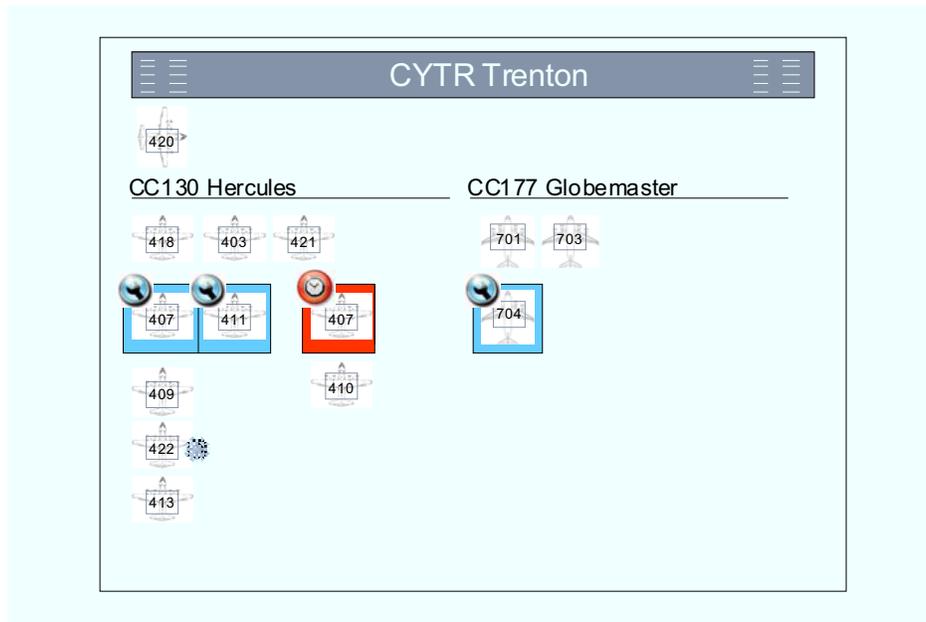


Figure 3: Notional Airbase Window Display

The user will be able to drag and dock the window at any desired location on the screen. The simulation will update any open Airbase windows as simulated time progresses.

When the cursor is hovered over any Aircraft icon - either while it is in flight and showing on the map display or on the ground and showing in an open Airbase window - a small 'mouse-over' window will appear presenting information on the type and tail number of the Aircraft, operational and maintenance status of the Aircraft, aircrew(s) aboard, Tasking the Aircraft is currently servicing, Load Elements carried, and time and name of the next event that will be executed relating to this aircraft.

The simulation will have the option of running without any graphical display to speed up the simulation run time. For software and Scenario debugging purposes the simulation will also have the option of stepping through the events one by one. The user pauses the simulation, sets the display mode to 'event by event' and resumes execution. The simulation will then pause after each event is executed and will display a text window summarizing the results of that event. The text display will simply use the full (unfiltered) Detailed Action History output for that event, as described in the Section 7 on MOEs.

7 Measures of Effectiveness

This section describes the types of measures of effectiveness (MOE) that Air MOOSE will be able to collect and present to the user at the completion of the runs. These MOEs should enable the full range of questions listed in section 1 to be addressed.

7.1 Tasking Completion Percentage

Each Tasking has a target time to close (i.e., complete) the mission, specified as a Scenario parameter for that Mission. Once this time has elapsed, Air MOOSE will record information relating to delivery relative to the Tasking requests for each mission.

7.2 Incomplete Tasking Delivery Percentage

Each Tasking that did not get completed had a percentage (less than 100%) of its Parcels delivered, calculated as the average percentage of total weight and total volume of all Parcels delivered. This MOE captures the average percentage of incomplete Taskings under this particular Mission. It gives the user insight into how close the air mobility system was able to get to complete its assigned job. If the percentage is low that might indicate that the priority of the Mission was insufficient to attract the resources required. If the percentage is high that might indicate that the Mission priority was fine but the target closure time was perhaps a bit optimistic.

7.3 Average Mission Completion Time

Of all the Taskings that were completed, what was the average closure time for that Mission, measured from the time the Tasking was initiated to when the final Chalk landed at its destination?

7.4 Aircraft and Aircrew Flying Rates

The mean monthly and annual flying rates for each Platform and for the Aircrews for each Platform will be collected. Also, the mean monthly and annual training flight rates for Aircrew will be monitored.

7.5 Detailed Action History

Air MOOSE will also offer the option of producing a detailed list of simulated actions, filtered as desired by the user. This list will be exportable into spreadsheet software using a universal format such as comma-separated values (CSV). This feature will enable a wide range of other MOEs to be captured if desired. For example, the user may wish to track the total time aircraft spent in maintenance queues of various types under various conditions. The Detailed Action History feature will also be critical in helping the user debug the software or a new scenario set.

Each time one of the simulation events is executed it will take actions according to the logic associated with that event. For example, the TAKEOFF event will: check if the assigned aircrew is sufficiently rested, and if not, reschedule the takeoff for later; determine the flight time to the destination and schedule a LANDING event for that time; and assess if the next failure for the aircraft will occur on this leg, scheduling a SNAG event if so determined.

A Detailed Action History CSV record will include the data fields listed in Table 6, and will offer the user criteria for filtering actions to determine which actions are saved and which are ignored: Note that actions within any event or routine are categorized as either ‘Enter’ (the event or routine has been initiated), ‘Calculate’ (some parameter value has been determined), or ‘Schedule’ (a future event has been scheduled)

Table 6: Detailed Action History Fields

Time	‘All’, or a define simulation time interval filter
Event	‘All’, or select subset of event types
Mission	‘All’, or select subset of Missions in Scenario
Tasking	‘All’, or define integer range of instantiations
Chalk	‘All’, or define integer range of Chalk nos.
Aircraft	‘All’, or select specific Platforms, or tail nos.
Aircrew	‘All’, or select specific Aircrew nos.
Airbase 1	‘All’, or select subset of Airbases in Scenario
Airbase 2	
Action	‘All’, or pick ‘Enter’, ‘Calculate’, or ‘Schedule’
Data 1	List data variables and values (character strings or numbers)...
Data 2 ...	

As an example, the TAKEOFF event for a CC130 departing Trenton (CYTR) on the first leg to Lyneham, England, (EGDL) of a deployment tasking to SW Asia might insert the CSV lines shown in Table 7 in a Detailed Action History (with all filters set appropriately):

Table 7: Detailed Action History Example

Time, Event, Mission, Task, Chalk, Aircraft, Aircrew, Airbase 1 & 2, Action, Data ...
8.025, TAKEOFF, SWAsiaDep, 2, 166, 312, 4, CYTR, EGDL, Enter
8.025, TAKEOFF, SWAsiaDep, 2, 166, 312, 4, CYTR, EGDL, Calculate, Rested?, Yes
8.025, TAKEOFF, SWAsiaDep, 2, 166, 312, 4, CYTR, EGDL, Calculate, Flight Time, 9.2
8.025, TAKEOFF, SWAsiaDep, 2, 166, 312, 4, CYTR, EGDL, Schedule, LANDING, 17.225
8.025, TAKEOFF, SWAsiaDep, 2, 166, 312, 4, CYTR, EGDL, Calculate, Snag?, Yes, 2.173
8.025, TAKEOFF, SWAsiaDep, 2, 166, 312, 4, CYTR, EGDL, Schedule, SNAG, 10.198

8 Conclusion

In conclusion, we have presented the design of the Air Mobility Operations Simulation Environment, which will be a 'time-and-space' simulation of CF airlift operations and will provide an operational analysis capability to the Canadian Air Force.

References

- [1] 'AMOS as an Operational Research and Analysis Tool', by S. Wesolkowski and M. Laska, DRDC CORA TN 2007-35, December 2007, Unclassified.
- [2] Stochastic Processes, by E. Parzen, San Francisco: Holden-Day, Inc., 1962.

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Annex A Chalk Load Determination

The SCHEDULE event will call upon this algorithm once a Chalk has been created, matching a Tasking with an Aircraft and Aircrew. This algorithm determines which subsets of the Parcels associated with this Tasking will be assigned as the Aircraft's load.

For each Parcel the following data variables will be known: Parcel type (outsized, oversized, bulk freight, or passengers), the number of individual units in this Parcel yet to be assigned to a Chalk (NUn), and the weight (WUn) and volume (VUn) of an individual unit.

Step 1 - Initialize the Algorithm

Set the number of load elements (NLE) to zero. The algorithm will process all available high-priority loads and outsized Parcels, followed by oversized Parcels, with bulk freight and passenger Parcels last. The order between bulk freight and passenger Parcels usually won't matter too much as all aircraft typically can carry both if required.

Set the Aircraft weight and volume capacity remaining variables, $WRem$, and $VRem$ to the full weight and volume capacity for that Platform, respectively.

Step 2 - Find a Suitable Parcel

Select the next Parcel, exiting the algorithm if all have been processed. If the Aircraft assigned is incapable of handling this type of Parcel, or this Parcel has no Units left to be moved ($NUn = 0$) then move on to the next Parcel.

Step 3 - Extract the Load Element from the Parcel

All or part of this Parcel will attempt to be loaded onto the Aircraft. The number of individual Units loadable by weight, NWt , is determined by dividing the weight capacity available in the Aircraft by the weight of an individual loadable Unit, rounding down to the next integer. This value cannot exceed the number of Units available to load, of course. The number of individual Units loadable by volume, $NVol$, is determined analogously.

If the load is weight-limited then NWt will be less than $NVol$. The load will be volume-limited if the reverse holds. The number of Units to load, $NLoad$, therefore has to be the minimum of these two values. If $NLoad$ is zero then no Units from this Parcel will fit, so return to Step 2.

Increment NLE by 1 and fully identify the Load Element within the simulation, identifying the Tasking, the Parcel, and the number of Units assigned to this Chalk ($NLoad$) as variables associated with this Load Element.

Step 4 - Update Parcel and Aircraft Variables

Remove these Units from the total number yet to be assigned for this Parcel, subtracting $NLoad$ from NUn .

Reduce the amount of weight and volume left to fill on the Aircraft by subtracting $NLoad$ times WUn from the value of $WRem$, and $NLoad$ times VUn from $VRem$.

If $WRem$ or $VRem$ are zero then there is no more room on this Aircraft and exit the algorithm, although this will rarely happen unless the capacity of the aircraft happens to be an exact multiple of the weight or volume of an individual unit in a Parcel.

Return to Step 2.

Annex B Route Construction Algorithm

The SCHEDULE event will call the routine implementing this algorithm when a Chalk has been nominally established. The starting Airfield, A , and destination Airfield, Z , are given. The routine will determine the ‘optimal’ routing of flight legs to get from A to Z . Each leg must be less than the maximum distance the Aircraft type can travel in a single hop, R , and each Airfield used must be selected from that subset of Airfields that have sufficient runway length and the right surface type to support operations of the Platform. A function to calculate the great-circle distance between any two locations on Earth is assumed available.

Step 1 - Initialize the Algorithm

Set current base variable, C , to base A and number of legs, L , to 1.

Step 2 - Check if Direct Flight to Destination is Possible

If the great-circle distance between C and Z is less than the maximum leg range, R , specified for the Platform then clearly the final destination could be reached in a single hop with a direct flight. If so, then exit the algorithm with current set of legs.

Step 3 - Look for a Two-Hop Solution

If the distance between C and Z exceeds twice the maximum leg range of the Platform then a two-hop solution is not feasible, so proceed to Step 4.

Otherwise, scan each possible Airfield, X , and determine the maximum distance, $M(X)$, from that Airfield to either the start or end points (C or Z). Both of these distances need to be within the range of the Platform to be viable, so construct the subset S of Airbases X for which $M(X)$ is less than R . If this set is null then proceed directly to Step 4 as a two-hop solution is not possible with the set of Airbases employed.

The algorithm now searches set S for the Airbase, X , which is closest to the great-circle route between C and Z . This would be the most economical choice in terms of total distance travelled, and is easily identified as having the shortest total great-circle distance over both legs (from C to X plus the distance from X to Z).

Note that another alternative to minimizing total distance travelled might be to select the Airbase that has the shortest long leg, forcing the legs to be as equal in length as possible. This would also carry economic benefit as the aircraft doesn’t have to carry a heavier load of fuel (and hence burn more fuel carrying fuel), but the aircraft will have to travel further.

Finally, add in these two legs to the route before terminating the algorithm: set the Leg L destination as Airbase X ; increment L by 1; set new Leg L destination to the final destination, Z , and exit the algorithm.

Step 4 - Just Head Efficiently Towards Destination

This step will be reached if a one- or two-hop solution has been deemed impossible. Determine the set of all Airfields, S , that are within the maximum leg distance of the Platform, R , from the current base, C . Select that base X in S that is closest to the final destination Z .

If X is actually further away from Z than the current base C then declare the final destination unreachable and terminate the simulation with an appropriate error message.

Otherwise, add this leg to the trip. Set Airbase X as the Leg L destination, increment L by 1, reset the current base C to X , and return to Step 2.

List of symbols/abbreviations/acronyms/initialisms

Air MOOSE	Air Mobility Operations Simulation Environment
AMOS	Air Mobility Operations Simulation
APOD	Air Point of Disembarkation
APOE	Air Point of Embarkation
CF	Canadian Forces
CSV	Comma-separated values
DND	Department of National Defence
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
GIS	Geographic Information System
GUI	Graphical User Interface
ICAO	International Civil Aviation Organization
MOE	Measure of Effectiveness
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
NASA	National Aeronautics and Space Administration
R&D	Research & Development
UN	United Nations

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The Canadian Forces (CF) air mobility community is facing a period of considerable transition over the next decade or so as its fixed wing airlift capability, represented primarily by the aging fleet of CC130 E- and H-model Hercules and a fleet of five CC150 militarized Airbus 310 aircraft, transforms into a modernized fleet with Boeing CC177 Globemaster and new J-model Hercules aircraft. There will be a wide range of operational effectiveness issues arising over this transition period, pointing to the requirement for an operational research tool to help support decisions on these issues.

It was concluded that a 'time-and-space' simulation of CF airlift operations was required to provide this analysis capability. This paper documents the design specifications for such a simulation tool, to be realized as the Air Mobility Operations Simulation Environment (Air MOOSE).

La communauté de mobilité aérienne des Forces canadiennes (FC) fait face à une période de transition considérable. Au cours de la prochaine décennie, la flotte d'appareils de transport à voilure fixe, principalement représentée par les Hercules CC130 modèles E et H, et cinq avions Airbus 310 militarisés (CC150), sera remplacée par une flotte moderne consistant d'appareils Boeing CC177 Globemaster et de nouveaux Hercules modèle J. Cette période de transition donnera lieu à un bon nombre de questions d'efficacité opérationnelle, indiquant un besoin pour un outil de recherche opérationnelle qui soutiendra la prise de décisions dans ce domaine.

Il a été déterminé qu'une simulation 'dans le temps et l'espace' des opérations de transport aérien des FC serait requise en tant que capacité d'analyse. Ce rapport documente les spécifications relatives à la conception d'un tel outil de simulation, que l'on a surnommé « L'environnement de simulation des opérations de transport aérien », aussi désigné l'acronyme anglais « Air MOOSE ».

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