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ENABLING CONCEPTUAL DESIGN in a TECHNOLOGY-DRIVEN ENVIRONMENT

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ABSTRACT

A proven general purpose design modeling environment has been adapted to facilitate technology insertion in the aerospace design process. The vision, which is demonstrated here, is one of a series of steps toward the goal of developing high fidelity design trades between cost and performance at the highest level.

Two factors make this work innovative. First, we are using an advanced design modeling environment with dependency tracking, demand-driven calculations and run-time object creation. Secondly, we explore how this computer software innovation can be used to tightly integrate design scenarios with technology-driven vehicle designs.

The design scenario involves multiple sorties taken from a suite of segmented trajectories and a suite of vehicle concepts. Once a sortie-object has been formulated with a combination of a trajectory object and a vehicle object, the equations of motion are integrated to assess the fuel consumed. Any point in the trajectory can be selected to examine maneuver load requirements and the relative position of other sorties or targets in the scenario. Subsequently, the vehicle can be resized or redesigned to meet the maneuver loads and mission requirements.

EMERGING SOFTWARE CONCEPTS

Dependency Tracking: All model variables know which other model variables influence them and which quantities they influence.

Demand-Driven Calculations: Quantities are only calculated when they are needed. This is in contrast to serial programming, where the analysis proceeds according to a preprogrammed set of instructions.

Run-Time Object Creation: Compiled rules and processes can be modified on-the-fly with interpretive code.

INTRODUCTION

This paper is motivated by the AFRL Air Vehicles Directorate Vision: Provide the Air Force with the capability to develop flight vehicle technologies that exploit and maximize the benefits of all the various technology interactions.

The US Air Force has an interest in assessing the influence of emerging technologies on the battlefield. This is the raison d'etre for the US Air Force Research Laboratory (AFRL). Innovative technology assessment is successful to the degree that the technology in question has been integrated into the system. In a fully integrated system, everything influences everything else. Therefore, a good assessment of a new technology requires a redesign of the system. Therefore, the AFRL will benefit from a design modeling environment which automatically tracks complex interdependencies.

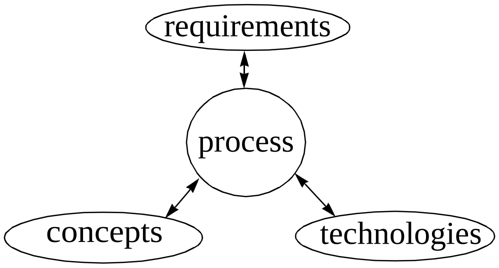

Figure (1) Three Ingredients in a Design Process

The design process is partitioned in Figure (1). The areas of responsibility are requirements, concept and technology. While the responsibility for each area is shared by all, it is important that only one entity leads. The responsibility for requirements belongs to the customer (e.g. the MAJCOMs in the USAF). The responsibility for proposing concepts belongs to the manufacturer. They have the experience and data. The responsibility for technology is in the laboratory (e.g. AFRL in the USAF). Each of these three areas of responsibility must communicate with the other two for a successful weapon system development.

As technology brokers, it is important for AFRL to put technology in the context of the requirements community and the context of the concepts community. This can be achieved in an effective design modeling environment. This paper describes some elements of this environment.

TECHNOLOGY:

Every technology which the AFRL wants to market can be modeled in the form of a design object. If technology is wrapped into design objects which are compatible with a vehicle design model (in a comprehensive design modeling environment), then technology can be readily folded into design concepts. This is the strategy for enabling conceptual design in a technology-driven environment.

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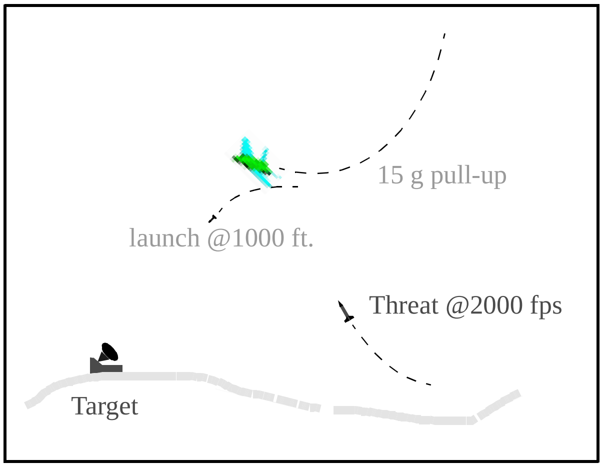

Figure (2) Schematic of a Design Scenario

REQUIREMENTS:

Consider the Suppression of Enemy Air Defenses (SEAD). From the military perspective, the requirement is simply to destroy a target. The scenario planners have numerous options to consider. Each option can be played out with a number of combative articles taken through prescribed trajectories. This is depicted in Figure (2) with an Uninhabited Combat Air Vehicle (UCAV) object launching a missile at a target with an incoming threat. Here, there are three combative articles. If we are designing the UCAV article, each scenario can generate a large set of requirements related to range (fuel), maneuver (loads), survivability (signature) and cost (manufacturing). For each requirement set, a suite of technologies can be featured. One requirement set may feature the need for signature technology in a stand-off scenario. Another requirement set my feature the need for maneuver technology in a close-in scenario.

CONCEPTS:

Given a suite of technologies, these have to be integrated into a tight volume. It is the concept designer's job to add fidelity in the transition from historical precedence to technical innovation. The conceptual designer job starts with a lot of vision and ends with a lot of credibility. For instance the designer begins knowing how much the vehicle should weigh and cost. The job is done when the designer knows how much the vehicle will weigh and cost.

The designer may start the process with the placement of primary components. As each component is placed, the designer needs weights and balance information. Geometric conflicts are resolved. As the aerodynamic surface develops, the designer needs aerodynamic balance information. When structure is added, weights information is updated and stress constraints are assessed. All the while, technology is woven into the design. Each important metric is updated and displayed to the designer as technologically innovative components are added. The system makes the transition from what the vehicle should weigh and cost (etc.) to what the vehicle will weigh and cost (etc.). When the design is "complete", the designer has a need to look at the effect of design variations without starting over with the design. Thus, the design process should automate whatever makes sense for conducting parametric trade studies.

PROCESS:

With Technology, Requirements and Concepts playing in the same design modeling environment, AFRL can readily demonstrate and measure how their technology developments add value to the war fighter.

THE ADAPTIVE MODELING LANGUAGE

These challenges are being addressed with an emerging design modeling technology. An object-oriented environment with built-in dependency-tracking and demand-driven calculations facilitates the integration and control of all aspects of the design process depicted in Figure (3).

Reference will be made to the Adaptive Modeling Language^{TM} (AML) environment which has evolved from an in-house (Materials Directorate of the Air Force Research Laboratory) feature-based design project to a commercial product in use by industries ranging from automotive, e.g., Ford Motor and Volvo; to aerospace, e.g., Lockheed-Martin, and McDonnell-Douglas; and power generation, e.g., Zurn Balke-Durr and Siemens. AML, supports a multidisciplinary environment for interactive product-process design.

Consider the systems engineering pyramid. With dependency tracking, AML facilitates the control of a large number of design alternatives with a single set of driving requirements (feed forward). Dependency tracking can also be used to facilitate design parameterization (feed back). With demand-driven calculations, the designer can readily control when and how design information flows. AML already has built-in objects to address complex meshing and manufacturing issues. These capabilities, along with feature based geometry in a single open-access object-oriented environment make AML very attractive as a means of addressing complex air vehicle design integration.

AML incorporates a unique underlying object-oriented model for representing geometric and non-geometric features to support bi-directional constraint propagation across multiple design disciplines. Such interaction is supported between geographically dispersed teams of scientists and engineers involving experts in flight dynamics, materials and manufacturing to interactively design a new vehicle

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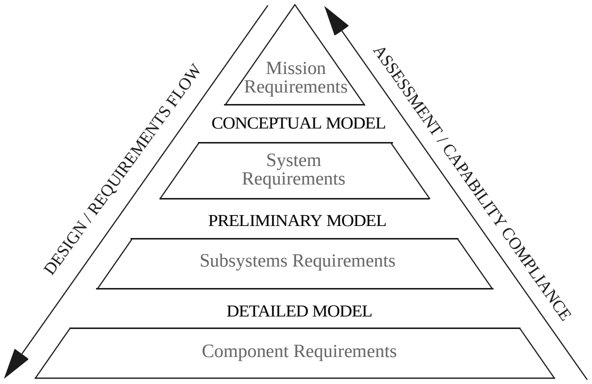

Figure (3) Systems Engineering Pyramid

BACKGROUND

In reference [1], a demonstration project was assembled in which a commercial geometric computer aided design code was used to parametrically control the geometry of the airframe outer surface and major substructures. Data was extracted with a series of configuration -dependent instructions and an aeroelastic optimization problem was accomplished for the set of parts. The process was practical for the purpose of *resizing* configuration and structural geometry. It was not a good environment for configuration *synthesis*.

In reference [2], the AML architecture was used to retain and share data with two conceptual design codes and the model in reference [1]. Again, this design process was perhaps useful for resizing a design concept. Since the participating codes were developed independently, the process had elements of redundancy and inconsistency. Also the process did not facilitate configuration *synthesis*.

In reference [3], the AML architecture was used except here its unique capabilities were utilized to create paths of data feed forward and feed back for a wing, addressing preliminary weight and cost in a conceptual design study. The process facilitates structural design *synthesis*.

Again, in reference [4], the AML architecture was used to integrate an innovative structural concept into a vehicle design concept. The emphasis here was to demonstrate how design synthesis is facilitated by the design modeling environment. This collaborative effort was shared by AFRL, Purdue University and TechnoSoft Inc.

In reference [5], a list of functional requirements for an Aircraft Technology Assessment System (ATAS) were described. These requirements are presented in two parts. The first part describes the software requirements and the second part describes the requirements for an airframe assessment. The work presented in this paper supports the ATAS requirements.

When developing applications with dependency-tracking and demand-driven features, one needs to be aware of computational consequences. During process model development, it is important to determine which tasks should be dominated by dependency management and which tasks should be isolated for raw computational speed.

At a high level (integration), dependency-tracking and demand-driven features significantly facilitate design process development. The developer does not spend time developing a formidable flow diagram. By necessity (due to complexity) the object-code syntax is self-documenting.

At a low level (number crunching), these same features impose a computational penalty. Therefore, one would never want to put dependency tracking in the middle of a large matrix operation where computational speed of critically important.

DEVELOPMENTS

This paper builds on the work presented in Reference (4). The focus here is on (a) further development of configuration synthesis and (b) new development in trajectory modeling.

The new work on configuration synthesis allows the designer to position components in space, place sections in space, compute the intersection, interactively draw curves on a section. The value of this is the high fidelity with which one will be able to fold in geometric aspects of new technology to be evaluated. This addresses the “concepts” leg in Figure (1).

This paper also builds on the work of Reference (4) by integrating a new vehicle trajectory modeling object. The work on trajectory modeling allows one to interactively shape a mission trajectory and to fly one’s vehicle through that trajectory. The trajectory object is used by the designer to generate a number of vehicle design requirements. This addresses the “requirements” leg in Figure (1).

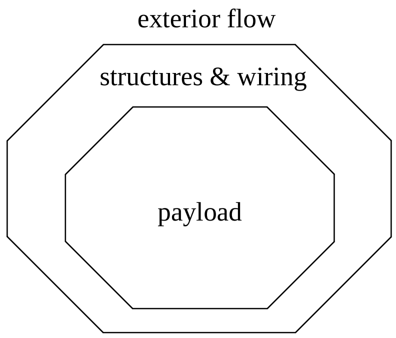

Figure (4) Nested Octagon Design Object

CONFIGURATION SYNTHESIS

While ATAS requirements in reference [5] describe what is to be done, they do not describe how it is to be done. Some results which cover this “how-to” work is described here.

Octagons were used in Reference (4) as a basic building element for this exploratory development. Nested octagons give us the ability to design with conflicting requirements. There are three types of dimensions, the inside boundary (payload, engines etc.), the exterior boundary (aerodynamic flow, signature etc.) and the space in between (structures, wiring, piping etc.). Only two of the three types can be independent. The third is dependent. The designer is allowed to switch the dependent dimension type, thus altering the order of design dependency between aerodynamics, structures and payload.

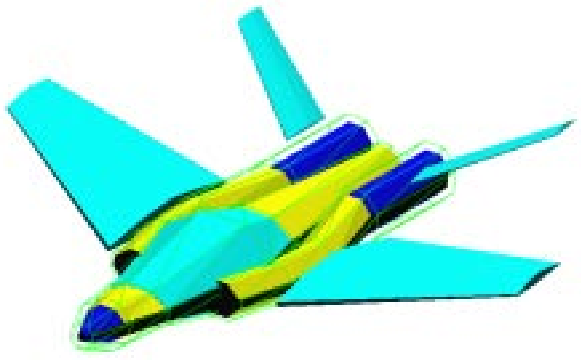

Figure (5) Internal Surface of UCAV Fuselage

These nested octagons formed octagonal prismoid pipes as shown in the vehicle concept of Figure (5).

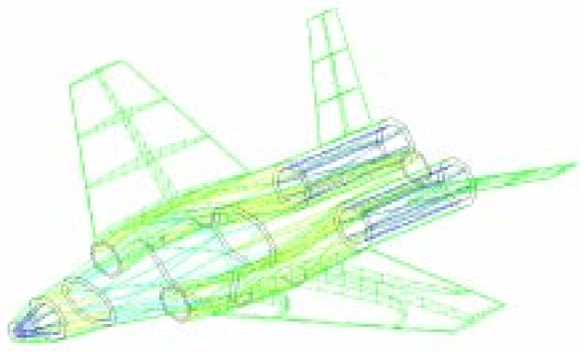

Figure (6) Structures Geometry for UCAV

The vehicle design system in Reference (4) also addressed the influence of novel structural design technology. The wing deformation was modeled as a plate and included the effect of shear deformation from the substructure. This is shown in Figure (6) with a “conventional” right wing and an “organic” left wing. The value of this modeling technique is the speed with which one can redesign the substructure without formulating a huge computational mesh system.

The next logical step is to extend the equivalent plate structural model into a compatible fuselage structures model. However, rather than formulate rapid structural modeling for the fuselage prismoids, The author addressed a pressing need to demonstrate the native capabilities of the Adaptive Modeling Language to interactively model complex fuselage geometry. A sample of what has been accomplished in fuselage modeling is presented here.

As various independent activities (either planned or underway) develop component models in AML, there exists a requirement to assimilate these various models in one environment. Component AML models which were saved can be retrieved and modified to the extent allowed by the component model.

A simple set of AML component models was constructed in order to mimic this autonomous suite. Each of these models has a simple interface to modify the component and save the model. With this set, it will be possible to motivate the development of component models because the payoff will be clear in the context of an integrated air vehicle design.

An interface-object (avo-component-interface) was constructed to control the interactive placement and orientation of autonomous component AML models within the AML model of the air vehicle. Four components are shown in Figure (7). These are the radome, the engine and two missiles.There is on-going work to develop automated weight and balance information as each component is integrated.

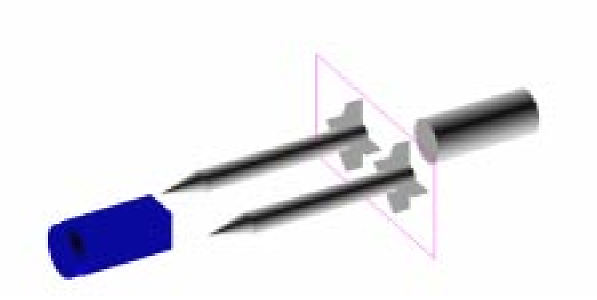

Figure (7) AML Component Models

Equally important to the weights is the aerodynamic loads based on the development of an aerodynamic surface. The aerodynamic surface will be built upon a series of curves. Some curves run down the length of the fuselage to form the aerodynamic side view and top view. A number of these curves are constrained to wrap around the components. In order to facilitate the development of cross-sectional curves, a section object (avo-section) was created. The frame is shown in Figure (7). This frame was interactively adjusted to intersect the fins of the missiles.

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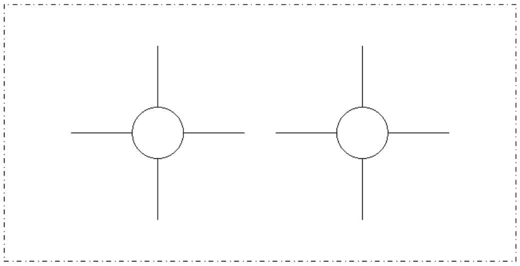

Figure (8) Component Intersection on Sketch Plane

The avo-section has two views available as sub-objects. One is the global view in Figure (7). The other is a sketch plane (global x-y plane) view. This sketch plane facilitates the intersection with any of the components or any auxiliary curve. The intersection with the missile fins is shown in the sketch plane of Figure (8).

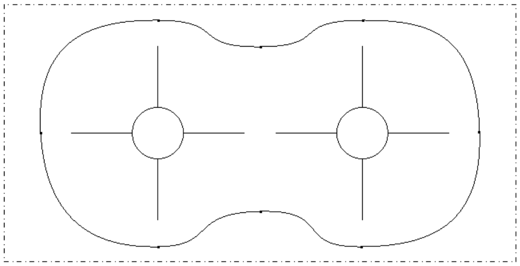

Figure (9) Sketch on Component Intersection

In Figure (9), eight points were interactively added with the mouse. These points were assigned tangency which controlled the direction and derivative of Hermitte curves.

In Figure (10), we see that the curves sketched in Figure (9) are automatically displayed in the original section of Figure (7).

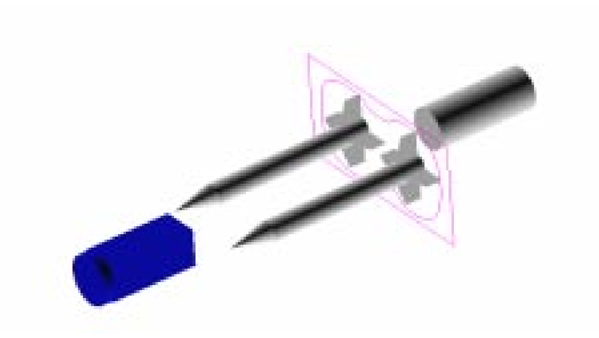

Figure (10) Global Placement of Sketched Section

Future work: constraint management so we can automate the resizing of the model. Important to keep it simple. Will deal with constrained points only. When interactive geometric modeling of the air vehicle has been sufficiently established, attention will turn back to developing a structural modeling and design capability which is compatible with the wing structures model of Reference (4).

TRAJECTORY MODELING

Here, a vehicle trajectory is described with a composite set of parametric curves along which one integrates the equations of motion. For a prescribed curve shown in Figure (11), the vehicle requirements arise in the form of thrust and normal acceleration. These requirements belong at the peak of the systems engineering pyramid shown in Figure (3) and drive the conceptual model. These top-level requirements are also a critical part of the process depicted in Figure (1). It is important that new technology developments be put in the context of the requirements community. The equations of motion (EOM) are developed here.

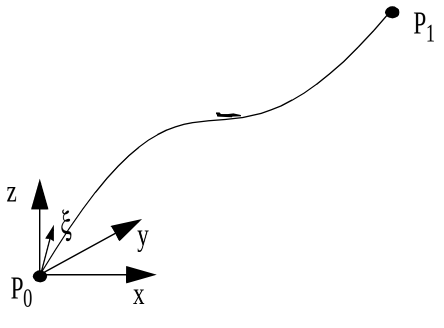

Figure (11) Vehicle Trajectory Segment

The algebraic form for a parametric $(0 < \xi < 1)$ cubic curve $\vec{P}(\xi)$ in cartesian space is

$$\vec{P}(\xi) = \vec{a_0} + \vec{a_1}\xi + \vec{a_2}\xi^2 + \vec{a_3}\xi^3 \tag{1}$$

Use $\vec{P}^{\xi}$ and $\vec{P}^{\xi\xi}$ to devise a triad of orthogonal vectors $[\hat{u}_1, \hat{u}_2, \hat{u}_3]$ along the trajectory.

$$\hat{u}_1 = \frac{\vec{P}^{\xi}}{|\vec{P}^{\xi}|} \tag{2}$$

So $\hat{u}_1$ is tangent to the velocity.

$$\hat{u}_2 = \frac{\vec{P}^{\xi\xi} \times \hat{u}_1}{|\vec{P}^{\xi\xi} \times \hat{u}_1|} \tag{3}$$

So $\hat{u}_2$ points in either along the right or left side of the vehicle depending on the sign of the normal acceleration component of $\vec{P}^{\xi\xi}$. Note that one assumes $\vec{P}^{\xi\xi}$ is not parallel to $\vec{P}^{\xi}$. If they are parallel, then one can pick any non-parallel vector. (During the process of integrating the equations of motion, one should use the last non-parallel value of $\vec{P}^{\xi\xi}$.) Finally, we compute

$$\hat{u}_3 = \hat{u}_1 \times \hat{u}_2 \tag{4}$$

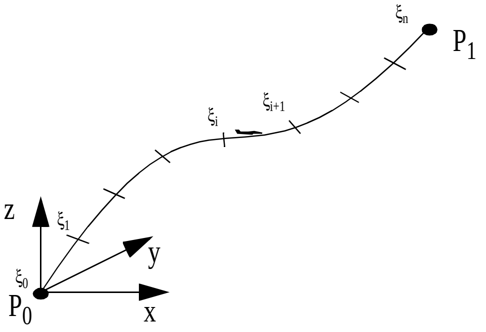

Figure (12) Partitioned Trajectory Segment

The motion of a particle along the trajectory requires a parametric description of time $t(\xi)$. A composite expression is used here. The curve is partitioned as shown in Figure (12). Use a quadratic form for $t(\xi)$ over each partition.

$$t(\xi) - t(\xi_i) = c_1(\xi - \xi_i) + c_2(\xi - \xi_i)^2 \tag{5}$$

Thus, space and time are coordinated with a single parameter ξ. $\vec{P}(\xi)$ is independently prescribed and $t(\xi)$ is dependent on the particle dynamics. The quadratic form for $t(\xi)$ is the lowest order with which the acceleration can be tracked. Note that for an accelerating particle with forward motion, $c_2 < 0$.

Differentiate equation (5) with respect to t *to* get

$$\left(\frac{d\xi}{dt}\right) = \frac{1}{[c_1 + 2c_2(\xi - \xi_i)]} \tag{6}$$

Differentiate equation (6) with respect to t to get

$$\frac{d^2\xi}{dt^2} = -2c_2\left(\frac{d\xi}{dt}\right)^3 \tag{7}$$

The velocity of a particle is described parametrically as:

$$\vec{V}(\xi) = \vec{P^{\xi}}\frac{d\xi}{dt} \tag{8}$$

Here, it will be assumed that $d\xi/dt > 0$. The acceleration of a particle is described as:

$$\vec{A}(\xi) = \frac{\partial \vec{V}(\xi)}{\partial t} = \left[\vec{P^{\xi\xi}}\left(\frac{d\xi}{dt}\right)^2 + \vec{P^{\xi}}\left(\frac{d^2\xi}{dt^2}\right)\right] \tag{9}$$

This is decomposed into the tangential and normal components

$$\vec{A}(\xi) = A^t(\xi)\hat{u}_1 + A^n(\xi)\hat{u}_3 \tag{10}$$

where

$$A^n(\xi) = \left(\vec{P^{\xi\xi}} \bullet \hat{u}_3\right)\left(\frac{d\xi}{dt}\right)^2 \tag{11}$$

and

$$A^t(\xi) = (\vec{P^{\xi\xi}} \bullet \hat{u}_1)\left(\frac{d\xi}{dt}\right)^2 + (\vec{P^{\xi}} \bullet \hat{u}_1)\left(\frac{d^2\xi}{dt^2}\right) \tag{12}$$

Note that equation (11) is simplified with $(\vec{P^{\xi}} \bullet \hat{u}_3) = 0$.

Forward Differencing the EOM - The forward differencing process is useful where one wishes to investigate the response (velocity, acceleration and elapsed time) to constant thrust. It turns out this is not very accurate. In general, the extrapolated acceleration at $i + 1$ will not agree with the updated value in the beginning of the next step. The error is reduced with partition refinement.

There are two equations of motion representing equilibrium of forces in the $\hat{u}_1$ and $\hat{u}_3$ directions. In Figure (13), the orientation of the vehicle with respect to $\hat{u}_1$ and $\hat{u}_3$ is indicated. The $\hat{u}_3$ vector may flip up or down depending on the direction of normal acceleration. This is a point of concern that is addressed. In Figure (13), take note that the velocity, thrust and drag are assumed parallel to the $\hat{u}_1$ vector. It follows that the lift is parallel to the $\hat{u}_3$ vector.

$$T - D + \left(\vec{W} \bullet \hat{u}_1\right) = mA^t(\xi) \tag{13}$$

$$L + \left(\vec{W} \bullet \hat{u}_3\right) = mA^n(\xi) \tag{14}$$

Given the velocity and weight, equations (11), (14) and (15) provide the lift. Given the lift, the drag can be extracted from a table and equation (13) can be used to find the tangential acceleration for a given thrust

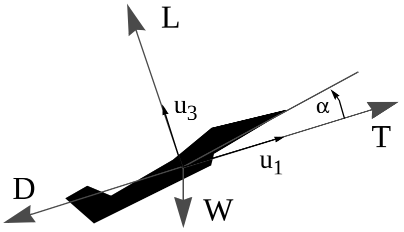

Figure (13) Fundamental Forces of Vehicle Dynamics

At this point, attention is directed at developing an approximating technique for integrating the equations of motion over the assumed trajectory $P(\xi)$. Numerical integration is applied over each partition in ξ, the same partitions used in $t(\xi)$. Consider the partition $\xi_i < \xi < \xi_{i+1}$ assuming the position, velocity and the tangential component of acceleration are known at ξ_i.

First determine the c_1 in equation (6). The initial velocity is $\left|\vec{V}(\xi_i)\right| = V_i$. From equation (8) we get

$$\left.\frac{d\xi}{dt}\right|_{\xi = \xi_i} = \frac{V_i}{\left|\vec{P_i^{\xi}}\right|} \tag{15}$$

Substitute equation (15) into equation (15) at $\xi = \xi_i$ to get

$$c_1 = \frac{\left|\vec{P_i^{\xi}}\right|}{V_i} \tag{16}$$

The constant c_2 is determined next. The initial value for the tangential component of acceleration is $A_i^t = A^t(\xi_i)$. This component of acceleration is obtained with a summation of forces in the $\hat{u}_3$ direction and then the $\hat{u}_1$ direction. From equation (12) we get

$$\left.\frac{d^2\xi}{dt^2}\right|_{\xi=\xi_i} = \frac{A_i^t - (\overrightarrow{P^{\xi\xi}} \bullet \hat{u}_1)\left.\dfrac{d\xi}{dt}\right|_{\xi=\xi_i}^2}{(\overrightarrow{P^{\xi}} \bullet \hat{u}_1)} \tag{17}$$

Substitute equations (15) and (17) into equation (7) at $\xi = \xi_i$ to get

$$\left[\frac{A_i^t - (\overrightarrow{P^{\xi\xi}} \bullet \hat{u}_1)\left.\dfrac{d\xi}{dt}\right|_{\xi=\xi_i}^2}{(\overrightarrow{P^{\xi}} \bullet \hat{u}_1)}\right] = 2c_2\left(\frac{V_i}{\left|\overrightarrow{P_i^{\xi}}\right|}\right)^3 \tag{18}$$

Solve for c_2 in equation (18).

$$c_2 = \left(\frac{1}{2}\right)\left|\frac{(\overrightarrow{P^{\xi\xi}} \bullet \hat{u}_1)\left.\dfrac{d\xi}{dt}\right|_{\xi=\xi_i}^2 - A_i^t}{(\overrightarrow{P^{\xi}} \bullet \hat{u}_1)}\right|\left(\frac{\left|\overrightarrow{P_i^{\xi}}\right|}{V_i}\right)^3 \tag{19}$$

With c_2 and c_2, the elapsed time can be computed over the interval.

Higher Order Parametric Time - Here, equation (5) is replaced with a 4th order parametric function of time. We will be able to specify velocity and tangential acceleration at both ends of the trajectory segment.

$$t(\xi) - t(\xi_i) = c_1(\xi-\xi_i) + c_2(\xi-\xi_i)^2 + c_3(\xi-\xi_i)^3 + c_4(\xi-\xi_i)^4 \tag{20}$$

Thus, space and time will be completely coordinated with a single parameter ξ. $\vec{P}(\xi)$ is independently prescribed and $t(\xi)$ is dependent on the particle dynamics. Note that for an accelerating particle with forward motion, $c_2 < 0$. First, differentiate equation (20) with respect to t

$$\left(\frac{d\xi}{dt}\right) = \frac{1}{[c_1 + 2c_2(\xi-\xi_i) + 3c_3(\xi-\xi_i)^2 + 4c_4(\xi-\xi_i)^3]} \tag{21}$$

Next, differentiate equation (21) with respect to t

$$\frac{d^2\xi}{dt^2} = -(2c_2 + 6c_3(\xi-\xi_i) + 12c_4(\xi-\xi_i)^2)\left(\frac{d\xi}{dt}\right)^3 \tag{22}$$

Expressions for velocity and acceleration were given earlier in Equations (8) and (9). Given the velocity and acceleration at two points $\xi_a = \xi_i$ and $\xi_b = \xi_i + \Delta\xi$, one can determine the c_i. This will be shown in the following section. Meanwhile, the following equations will be useful.

$$c_1 = \left(1/\frac{d\xi}{dt}\right)_{\xi_a} \tag{23}$$

$$c_2 = (-0.5)c_1^3\left(\frac{d^2\xi}{dt^2}\right)_{\xi_a} \tag{24}$$

Subsequently solve the following two equations simultaneously for c_3 and c_4.

$$[3c_3(\Delta\xi)^2 + 4c_4(\Delta\xi)^3] = \left(\frac{d\xi}{dt}\right)_{\xi_b}^{-1} - [c_1 + 2c_2(\Delta\xi)] \tag{25}$$

$$6c_3(\Delta\xi) + 12c_4(\Delta\xi)^2 = \left[\left(\frac{d^2\xi}{dt^2}\right)_{\xi_b}\left(\frac{d\xi}{dt}\right)_{\xi_b}^{-3}\right] - 2c_2 \tag{26}$$

Position and Velocity Constrained EOM - The objective is to generate a thrust and normal loads requirement. This approach is useful when trying to determine the minimum energy or minimum time to climb trajectories. For a given initial and final position, velocity and acceleration, vary the initial and final trajectory tangent. The fourth order parametric time function is required to specify the velocity and acceleration.

While the trajectory is defined by $\vec{P}(\xi)$, the position depends on $t(\xi)$. However, instead of specifying $t(\xi)$, here we initially specify a function for the velocity $V(\xi)$ over the length of the trajectory $0 < \xi < 1$.

$$V(\xi) = a_0 + a_1\xi + a_2\xi^2 + a_3\xi^3 \tag{27}$$

This, specifies the form for the tangential acceleration.

$$A(\xi) = [a_1 + 2a_2\xi + 3a_3\xi^2]\left(\frac{d\xi}{dt}\right) \tag{28}$$

Thus, given the initial and final velocity and the initial and final acceleration, the velocity and acceleration are determined at each point ξ_i, thus at the beginning and end of each trajectory partition. One could integrate equation (29) to compute the time duration.

$$dt = \frac{1}{V(\xi)}\left(\frac{dS}{d\xi}\right)(d\xi) \tag{29}$$

Here, $S(\xi)$ is the curvilinear distance traversed. $S(\xi)$ is obtained from $\vec{P}(\xi)$ with numerical integration. Therefore, there is no closed form solution for integration of equation (29).

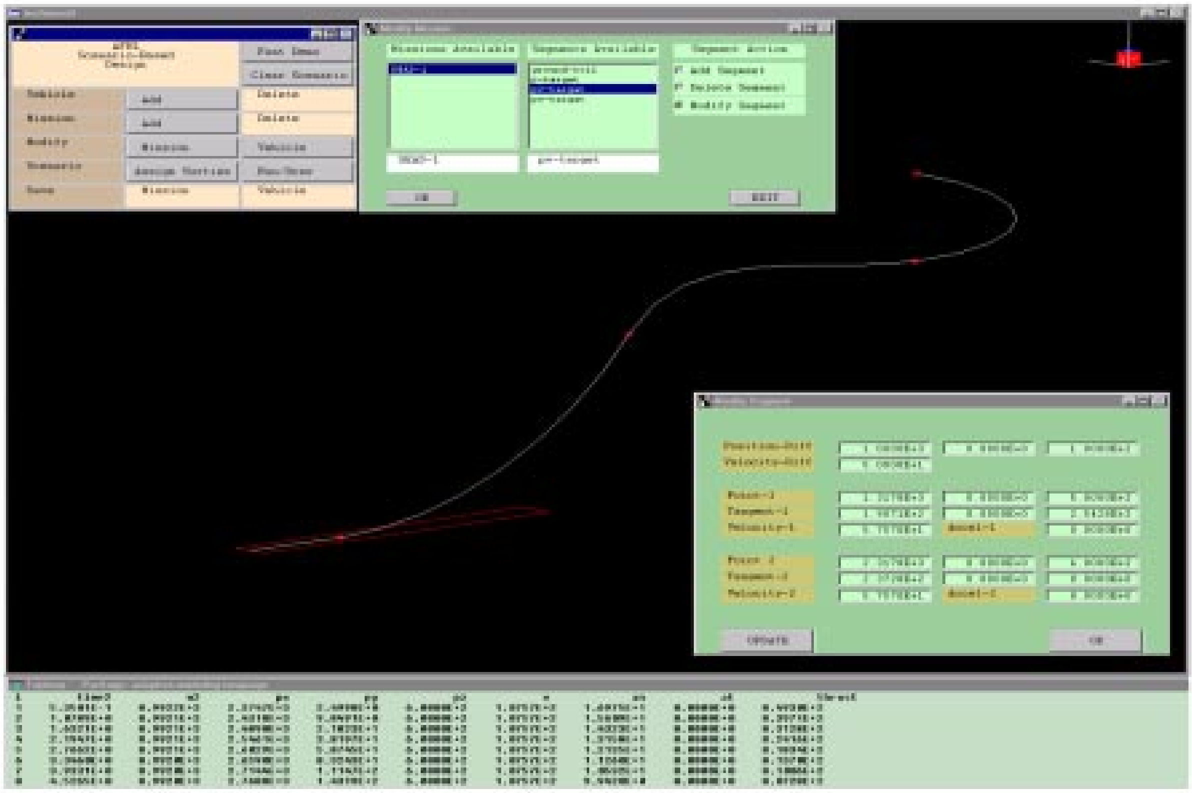

Figure (14) Interactive Scenario Interface

Therefore, we resort to the fourth order approximation for $t(\xi)$ over each partition as given in equation (20). The four coefficients c_i for $t(\xi)$ are computed for each partition. This approach allows one to compute a composite thrust requirement at each point ξ_i. The algorithm proceeds as follows.

(1) At ξ_i, the velocity and tangential acceleration are known.

> Compute $d\xi/dt$ and $d^2\xi/dt^2$.
> Use equations (23) and (24) to compute c_1 and c_2.
> Compute the lift, drag and thrust

(2) At $\xi_i + \Delta\xi$, the velocity and tangential acceleration are known.

> Compute $d\xi/dt$ and $d^2\xi/dt^2$.
> Use equations (25) and (26) to compute c_3 and c_4.
> Compute the lift, drag and thrust

(3) Use equation (20) to determine the time elapsed. This is used along with thrust to calculate the fuel consumed over the partition.

(4) Use equation (11) to compute the normal acceleration. This provides an initial requirement for maneuver load.

Scenario-Based Design Example - These equations of motion were easily programmed as part of AML objects. The mission object was joined with the vehicle object of reference (4). For this proof of concept, only one sortie (one vehicle and one mission) could be evaluated at one time. A user interface was developed in order to explore the practicality of a scenario-based design environment. Some elements of this user interface are shown in Figure (14). This figure was generated from the computer screen.

The form in the upper left is used to set up a scenario from a list of vehicle and mission objects. These vehicles can be modified at any time to the extent shown in reference (4). The form in the top-center depicts how the mission is built and saved from a number of segment legs. The bottom right form is used to control a specific leg of the mission in terms of initial and final conditions. The graphic is a perspective view of a rectangular airport and a four leg trajectory. At the bottom of Figure (14) is the time-incremented results with position, velocity, acceleration, weight (fuel consumed) and thrust required.

This simple scenario-based design example provides an element of substance to the design concept presented in Figure (1). We have all three elements wrapped in this process: requirements, concept and technology. The task is far from complete. Far more fidelity is required in the vehicle description. This is being worked on. The scenario also needs far more work beyond the trajectory modeling presented here.

Using the Trajectories - Eventually, one needs to examine a number of independent sorties in a scenario. The prescribed equations are useful for very predictable activity. However, with several interacting vehicles, the activity may become unpredictable. The trajectories should be cut short in reaction to a threat or any disturbance. Thus, the trajectories represent intention but not necessarily the deed. Given a vehicle in cruise mode, it must break away from the planned path when an incoming missile threat becomes apparent. The parametric curve must be broken and a new trajectory formed. The vehicle will follow the new trajectory until its end or until the situation changes. (Max work on this)

CONCLUSIONS

Some elements of the design process depicted in Figure (1) have been developed in the Adaptive Modeling Language. While significant work remains to be done, the author hopes the potential utility is made more clear. A technologically advanced vehicle concept and a mission can be simultaneously designed in a single scenario-based design environment. This allows the technology broker to aggressively market a product in terms which the warfighter can visualize and in the context of a vehicle concept. Ongoing work with configuration synthesis will facilitate the insertion of various technologies into a vehicle concept.

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