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Common Launch Acceptability Region Approach Interface Control Document (CLARA ICD)

RATIONALE

In response to a U.S. Air Force Executive Weapon Systems Review (EWSR) Task Group (TG) charter, the Society of Automotive Engineers (SAE) Common Launch Acceptability Region (LAR) Approach (CLARA) TG produced this Interface Control Document (ICD). The EWSR recognized the expensive nature of the present multiple-LAR development approaches and sought help from the SAE to standardize and document a new common LAR approach that is less expensive and time consuming. The EWSR TG recommended key characteristics upon which to base the new approach. This ICD is based on those key characteristics.

FOREWORD

Pilots', mission planners', and trainers' common objective is to deliver air-launched weapons within the weapon's performance envelope called the LAR.

The LAR is the region in space from which a released weapon could successfully guide to the target. Typically, the aircraft displays an approximation to the LAR using a mathematical model commonly referred to as the LAR Algorithm. The weapon may also run the algorithm and pass the approximation of the LAR to the aircraft.

As a result of independent attempts by aircraft manufactures, weapon manufacturers, and program offices to develop and implement a LAR Algorithm, multiple LAR approaches exist that are expensive, ill-maintained, and time-consuming.

In an effort to improve this business practice for future weapon integration projects, the U.S. Air Force EWSR formed a TG to study the feasibility of developing a Common LAR (CLAR) approach. The EWSR TG surveyed weapon and aircraft contractors to determine the best solution for the CLAR approach. The EWSR TG completed the survey and presented its recommendations to the EWSR on 4 August 1998. One recommendation was to design LAR algorithms so that weapon manufacturers or aircraft offices can make performance improvements through coefficient updates. This recommendation serves as the underlying requirement that the LAR Algorithm be coefficient-based. Another recommendation was to standardize the LAR development for all systems. The EWSR then requested the assistance of the SAE to further develop and document an approach that would standardize the development of a coefficient-based LAR process. In response, the SAE created the AS-1B5 CLARA TG (AS-1B is the Aircraft-Store Integration subcommittee under the SAE AS-1 Aircraft Systems and System Integration committee. The number five denotes the TG within AS-1B).

The CLARA TG identified four steps to develop and implement the CLAR process:

1. Develop functional and performance specifications

2. Develop interface control documents

3. Perform algorithm trade studies

4. Implement a promising set of algorithms to demonstrate feasibility

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The four functions that the CLARA TG identified are:

1. Data Space Generator
2. Truth Data Generator
3. Coefficient Generator
4. Reconstructor

External to the above four functions are the Truth Database and the LAR Algorithm which provide ancillary support to the CLARA process.

This ICD addresses the functional specifications and the interfaces of those functions.

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1. SCOPE

1.1 Introduction

CLARA identifies four functions: Data Space Generator, Truth Data Generator, Coefficient Generator, and Reconstructor. Together these four functions standardize the solution to the LAR problem. This ICD defines the logical interfaces of the four functions.

1.2 Purpose

This document specifies the CLARA interfaces of the Data Space Generator, Truth Data Generator, Coefficient Generator, and Reconstructor functions as shown in Figure 1. The weapon and delivery platform developers define the details of each function.

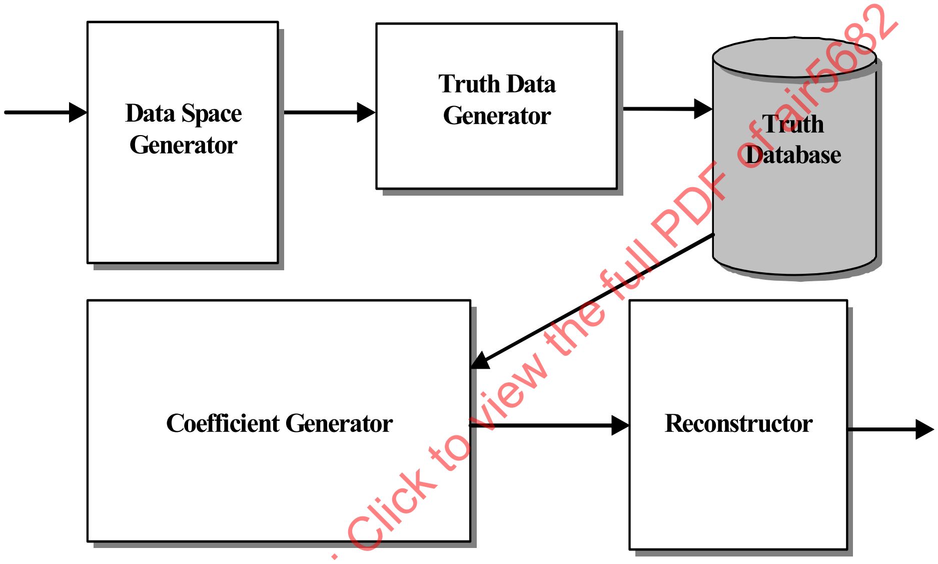

FIGURE 1 - CLARA SIMPLIFIED DIAGRAM

The Data Space Generator selects a representative set of discrete release conditions, (such as altitude, wind, speed, and release flight path angle) from a continuum of release-condition possibilities. For each set of release conditions, the Data Space Generator defines a corresponding grid of target points. The subset from the multi-dimensional space of discrete release conditions, along with their corresponding grid of target points, wind constraints, and impact angle constraints serve as the input to the Truth Data Generator. The Truth Data Generator uses the Data Space Generator output to calculate the achieved impact parameters (velocity, angles, and miss distance). The Truth Database stores the release conditions and the achieved impact parameters for each target point.

The Truth Data Generator generates impact data sets for the Coefficient Generator. The Truth Data Generator uses a model of the weapon system that predicts weapon delivery performance to a predefined accuracy. The weapon model may use Six-Degrees-Of-Freedom (6DOF) or another mathematical representation that meets the objective for the weapon system LAR.

The Coefficient Generator generates coefficients for a mathematical fitting model. This mathematical fitting model is commonly referred to as the LAR Algorithm.

The output of the Reconstructor is an approximation of the original weapon footprint data based on flight and environment conditions. The Mission Planning, Trainer Systems, and weapon delivery aircraft use this approximation.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE ACE Paper 2001-01-2953 titled “Common Launch Acceptability Region Task Group”

AIR5712 Common Launch Acceptability Region Approach (CLARA) Rationale Document

TSB 003 Rules for SAE Use of SI (Metric) Units (as issued 1965-06 and revised 1999-05)+

2.1.2 NOAA Publications

Available from U.S. Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, http://catalog.gpo.gov.

NOAA-S/T 76-1562 US Standard Atmosphere, 1976

2.2 Definitions

2.2.1 LAR and Footprint

Given a set of release, environmental, target, and mission conditions, a footprint is the area on the ground within which the weapon can impact and a LAR is the geometric region where if the weapon is released, the weapon can impact the target. A footprint is referenced to the release platform and it moves along with the release platform. A LAR is the footprint transposed to the launch plane and is referenced to the target position.

The CLAR process uses footprints; however, the implementor may choose to transpose the footprint into a LAR.

2.2.2 Training and Verification Truth Data Sets

Training Data Sets are used to develop or train the CLAR Coefficients. Verification Data Sets are used to verify that footprints generated using the CLAR Coefficients meet the defined criteria. Both Verification and Training data sets come from the same release envelope (the optimization envelope input space over which the coefficients are hypothesized to apply), but from different points within.

2.2.3 Coordinate Systems

2.2.3.1 Launch Coordinate Frame

The launch coordinate frame for launch states and aimpoint locations is an aircraft-centered, local level, right-handed coordinate system with X-axis positive forward along the horizontal component of the velocity vector, and Z-axis positive down. The origin (0,0,0) is the position of the weapon at launch.

2.2.3.2 Impact State Coordinates

The Impact State coordinate system is defined as the launch coordinate frame with the origin translated to the aimpoint (Desired Impact). Impact azimuth is positive from the X-axis toward the Y-axis and is the angle between the X-axis and the weapon velocity component in the X-Y plane at impact. Impact Angle is measured from the horizontal plane toward the Z-axis in the plane that includes the weapon velocity vector at impact.

2.2.3.3 Wind Coordinates

Wind shall be defined as a velocity vector in the launch coordinate frame, i.e., tail wind is defined as positive (Wind V_x).

2.2.3.4 Weapon Coordinates

Figure 2 illustrates the weapon's coordinate system. The weapon's body axis system consists of an orthogonal triad of axis, X_w, Y_w, and Z_w with origin (0,0,0) at the fixed location determined to be the optimum for that weapon (for example, at the center of mass). The X_w axis is positive in the forward direction of the weapon. The Y_w axis is positive to the right of the forward direction of the weapon. The Z_w axis is positive down through the lower side of the weapon.

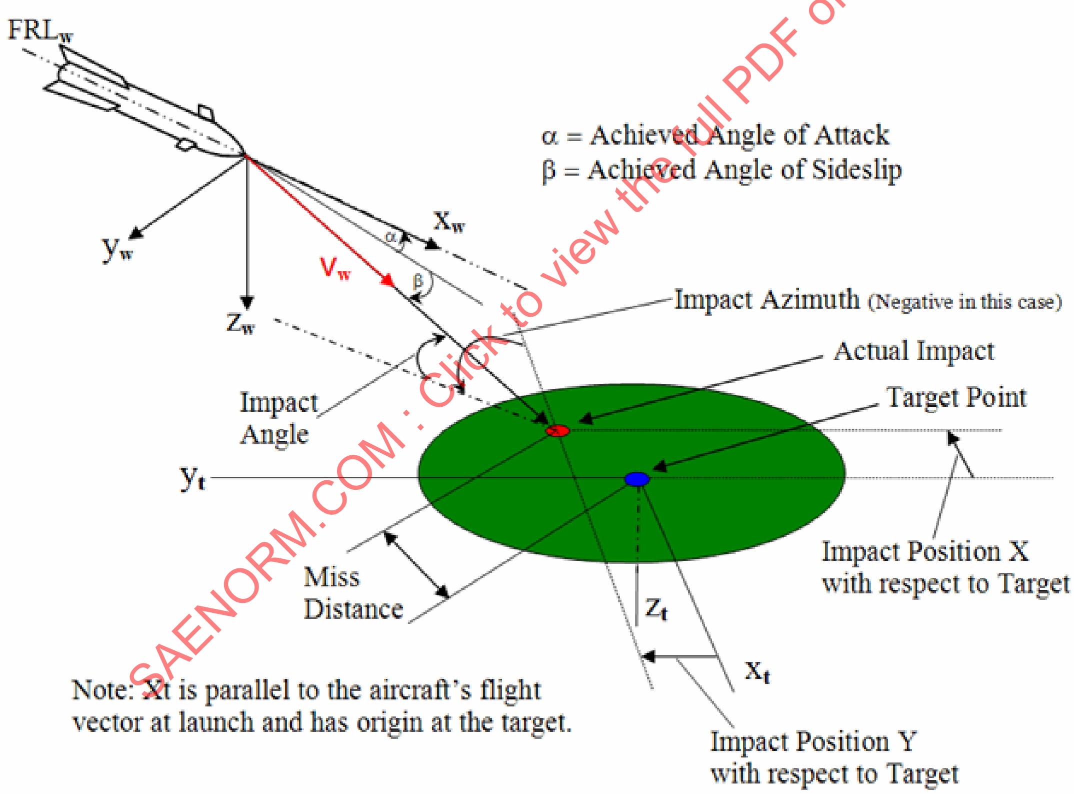

FIGURE 2 - WEAPON IMPACT RELATIVE TO TARGET

The weapon's attitude relative to the inertial velocity vector is defined by the inertial Angle of Attack (iAOA) in the weapon (X, Z) plane and the inertial Angle of Sideslip (iAOSS). The order of rotation is: iAOA and then iAOSS.

The weapon impact point (or function point - in the case of a store that does not impact) is a point some miss distance from the target point on the same horizontal plane. For consistency, this document uses target point to represent desired impact point, function point, or aimpoint. Figure 2 demonstrates weapon impact angles, velocity, and angles of attack and sideslip. Data files contain these impact parameters along with miss distance for the CLAR process to use to construct the weapon's footprint.

2.2.4 Units

All units shall be metric conforming to the Society of Automotive Engineering Technical Standards Board Standard, TSB 003 as issued 1965-06 and revised 1999-05.

2.2.5 Atmospheric Model

A Standard Atmospheric Model defined in NOAA-S/T 76-1562 U.S. Standard Atmosphere, 1976 shall be used. The Standard Day is default, however it is recognized that multiple conditions may be used to model conditions at a particular location, region, or season.

2.2.6 Wind Model

A single wind model shall be used. The model shall be defined as a given wind speed at the weapon release that is linearly decayed to 0 at -1219.2m Height Above Ellipsoid (HAE) with a constant direction throughout the profile.

2.3 CLAR Acronyms and Terminology Definitions

6DOF	Six Degrees of Freedom. A mathematical model that uses the translational and rotational equations of motion, which are based upon the physical characteristics of a weapon as it interacts with the environment to estimate an impact point or approximate the LAR.
AFMSS	Air Force Mission Support System. Primary system utilized by the United States Air Force to plan missions.
Aircraft Ground Track	The direction of the aircraft's ground speed vector with respect to True North.
Atmospheric Model	A mathematical model used to predict the spatial and temporal atmospheric quantities: temperature, pressure and wind.
CLAR	Common Launch Acceptability Region. A unified or common approach to solve the LAR problem and is intended to be used with a variety of aircraft and smart weapons.
CLAR Algorithm	A formula or set of steps for solving the CLAR problem. This algorithm utilizes a geometric shape that represents the LAR with terms determined by parameters (coefficients) that influence the shape, size and location of the LAR. The dynamics of the LAR and the application of the algorithm to specific weapons will be controlled by varying the coefficients to the algorithm. The LAR may further be refined to provide only those solutions where the weapon satisfies specific mission constraints, i.e. impact angle, impact velocity and impact azimuth.
CLAR Coefficients	An input to the CLAR algorithm determined by the capabilities of the weapon with respect to release conditions, real time launch profiles, environmental conditions, target locations and impact constraints. The CLAR Coefficient Generator and a set of Training Footprints develop the Coefficients. The Coefficients when used in the CLAR Algorithm, determine the geometric boundary, which represents the ability of the weapon to reach a target, and may be further refined to represent the boundary where mission specific constraints are achieved. The Coefficients could be loaded into the aircraft via the aircraft Unique Planning Component such as AFMSS or loaded into the weapon as part of the OFP update via Common Bit Reprogramming Equipment (CMBRE). Both of which would allow timely integration of weapons and weapon modifications onto aircraft platforms without changes to the aircraft OFP or extensive testing.

CLARA	Common Launch Acceptability Region Approach. An approach to the CLAR developed by the AS-1B5 Group. The approach employs four block architecture: Data Space Generator, Footprint Generator (or Truth Model), Coefficient Generator, and Algorithm. FFBDs are utilized to decompose each block to its smallest reasonable component and ICDs are used to develop the interfaces between each of the blocks.
EWSR	Executive Weapon System Review. A Biannual Review held by the United States Air Force.
FFBD	Functional Flow Block Diagram
Footprint	The area on the ground at which the weapon will impact, given a set of release, environmental, target, and mission conditions.
Function Point	Point in space that the weapon must reach and satisfy end game parameters in order to effectively attack the target.
GNC	Guidance Navigation Control. The set of algorithms and programs that allow the weapon to successfully control the flight and navigate to a desired impact point.
Grid	A set of x y points with a given uniform spacing between them.
HAE	Height Above Ellipsoid (WGS 84)
iAOA	Inertial Angle of Attack
iAOSS	Inertial Angle of Sideslip
ICD	Interface Control Document. A document used to specify input, output and special processing between functional blocks of a system.
Impact Angle	The angle subtended between the weapon velocity vector and the horizontal plane at impact.
Impact Azimuth Defined for the Weapon	The angle subtended between true north and the tail of the weapon velocity vector at impact projected onto the horizontal plane. A zero value specifies weapon flight from North to South. A 90 degree value specifies weapon flight from East to West.
Impact Azimuth (Defined for the LAR and as used in this document)	The angle between the Aircraft Ground Track at release (along the x-axis) and the head of the weapon velocity vector at impact projected onto the horizontal plane. It is positive clockwise from the x-axis and is derived from the Impact Azimuth Defined for the Weapon by adding 180 degrees and subtracting the Aircraft Ground Track angle.
Impact Constraints	A set of desired impact conditions (impact velocity, impact angle, etc.) that must be attained by the weapon to achieve mission success, i.e. Probability of Kill (Pk).
Impact State	The set of weapon impact conditions, which include: distance from the target, impact velocity, impact angle, impact azimuth, angle of sideslip and angle of attack.
Impact Velocity	The velocity of the weapon at the time of impact.
In-Range	The set of basic release conditions that must be met if the weapon is to guide to and impact within a predefined distance from the target.
In-Zone	The set of basic release and mission conditions that must be met if the weapon is to guide to and impact within a predefined distance form the target and meet all mission parameters.

LAR	Launch Acceptability Region. The weapon LAR represents a geometric region or range boundary such that, if the weapon is released within the boundary, it can successfully reach the target through optimized management of weapon GNC coupled with the weapon kinematics. This boundary is often referred to as In-Range LAR. A further refinement would be a LAR that not only represents the capabilities of the weapon but also achieves certain mission constraints such as impact angle, impact velocity and impact azimuth, often referred to as In-Zone LAR.
m	Meters
Performance Measure	The performance measures used to determine the degree of fit between the set of validation footprints and the footprints generated with the CLAR Algorithm and the CLAR Coefficients. Some of the most common metrics are: (1) Percent Area Coverage or the percent of the area of the Validation Footprints that are covered by the Generated Footprints. (2) Percent False Positive or the percent area of the Generated Footprints that are not covered by the Validation Footprints. (3) Percent False Negative or the area of the Validation Footprints that are not covered by the Generated Footprints. (4) Percent Maximum Distance Threshold Outside or the percent of the maximum distance threshold that the boundary of the Generated Footprints extends beyond the Validated Footprints.
SAE	Society of Automotive Engineers
s	Seconds
Store Aerodynamics	The influence of the airflow on the dynamics of a weapon.
Store Mass Properties	The quantities that determine the dynamic behavior of the weapon and include center of gravity and moments of inertia.
Target	The object of attack by the weapon system.
TG	Task Group
TOF	Time of Fall/Time of Flight. The time from weapon release to impact.
Training Set	A set of grid data or footprints generated by the CLAR Footprint Generator that are used to develop or train the CLAR Coefficients.
Verified LAR Coefficients	CLAR Coefficients that have been verified The verification process is accomplished by generating LARs/Footprints with the CLAR Algorithm using the CLAR Coefficients for a given set of input conditions. These Generated LARs/Footprints are compared with the Verification Set. The degree of fit between the two sets is compared to an accuracy specification developed by a set of CLARA metrics. If the degree of fit meets a predefined accuracy specification then the CLAR Coefficients are considered validated, otherwise the CLAR Coefficients must be redeveloped.
Verifying Set	A set of grid data or Footprints generated by the CLAR Footprint Generator that are used to verify the CLAR Coefficients.
V_x	Velocity in the direction of the X-axis
V_y	Velocity in the direction of the Y-axis
V_z	Velocity in the direction of the Z-axis

WGS 84 — World Geodetic Survey 1984. A survey of the earth performed in 1984, to develop accurate latitudes and longitudes of given points. The earth is modeled as an oblate spheroid and the survey refined the estimates of these parameters, i.e., semi major and semi minor axis.

Wind Model — A mathematical model of the wind used to predict the temporal magnitude and direction of the wind (usually at a given altitude).

3. INTERFACES

Figure 3 provides a more detailed view of the functions and interfaces involved in the CLAR generation process. The interfaces between major dotted blocks in this diagram are generally the points where this process is divided between different contractors, different groups, or different time frames, and they are therefore the interfaces that must be defined in this document. The dotted arrows represent exchange of knowledge or control and not quantitative data. The interfaces shown from the LAR Algorithm block depict the knowledge of the chosen mathematical fitting equations.

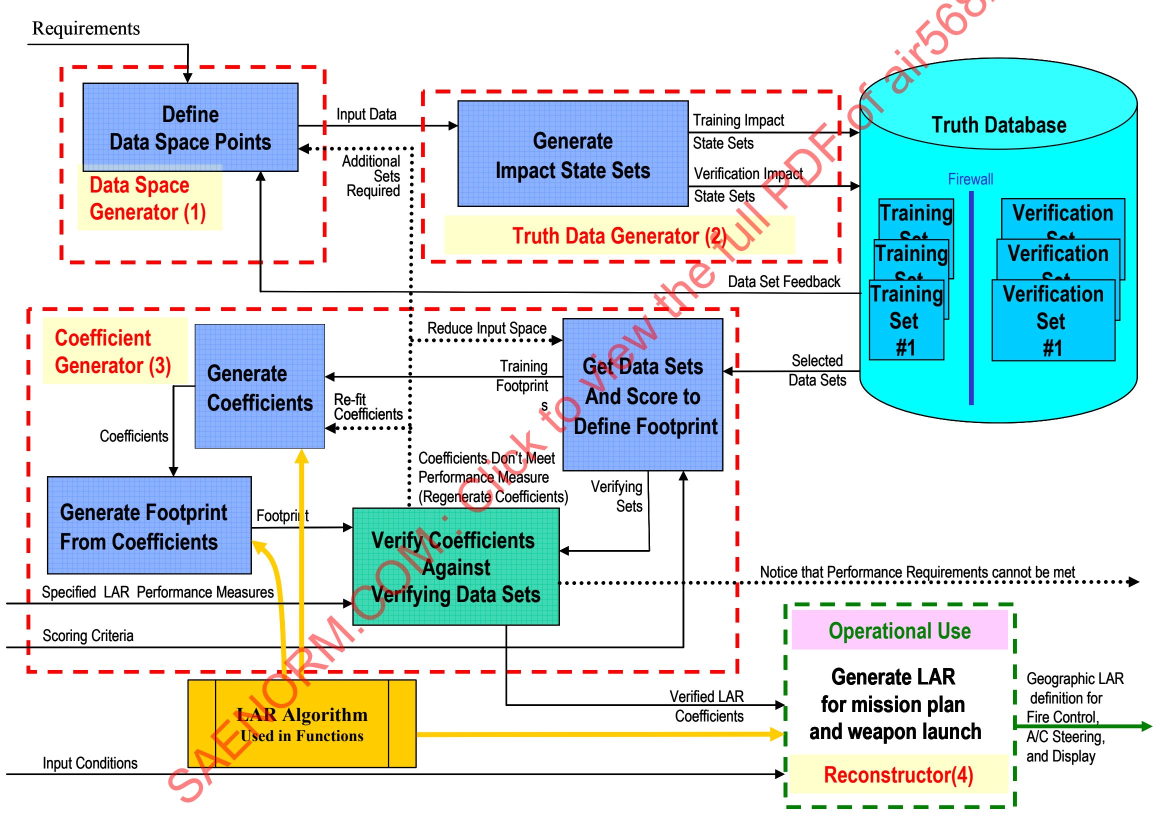

FIGURE 3 - CLAR FUNCTIONAL FLOW BLOCK DIAGRAM

3.1 Process Description

3.1.1 Data Space Generator

3.1.1.1 Overview

Figure 4 shows the inputs and the outputs to the Data Space Generator. Table 2 specifies the details of the input data while Table 3 contains the details of the output data. The Requirements consist of two parts: (1) the definition of the feasible range of continuous values that serve as the input to the four blocks, and (2) the sampling criteria that the Data Space Generator process will use to select the Training and Verification sets. The Data Set Feedback comes from the Truth Database and signifies that results from the Truth Data Generator are not sufficient to define Training and Verification Sets.

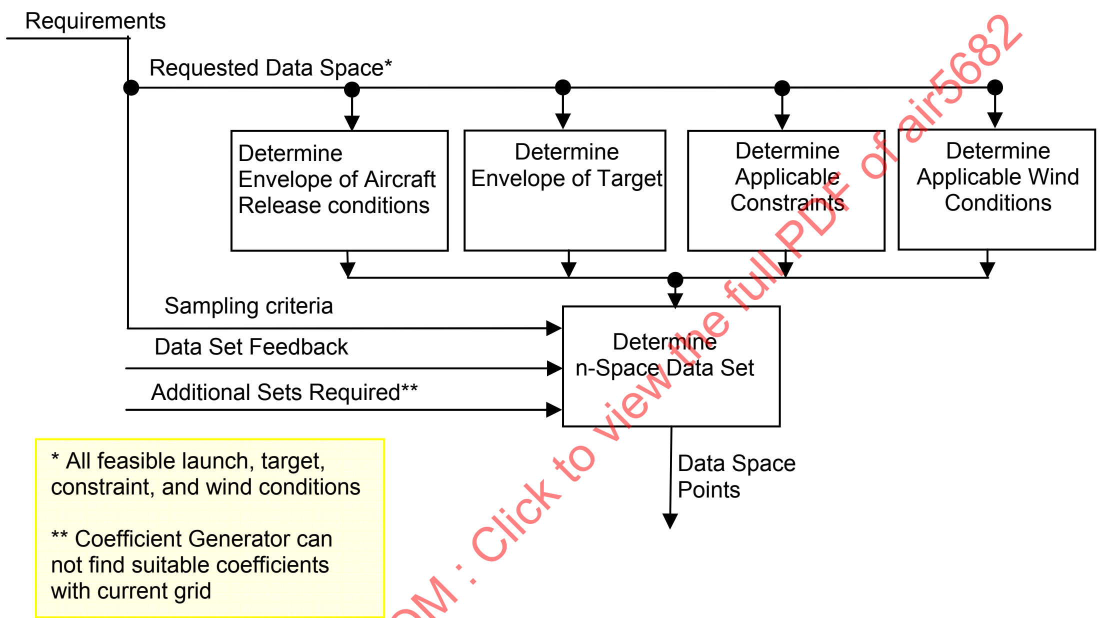

FIGURE 4 - NOTIONAL DATA SPACE GENERATOR BLOCK DIAGRAM

Additional Sets Required is feedback from the Coefficient Generator and signifies that the verification data sets do not agree with the coefficients used in the LAR algorithm. This triggers the generation of additional data sets.

The Determine n-Space Data Set block determines the reasonable combinations of discrete points from the continuum of aircraft release conditions, target conditions, impact constraints, and wind conditions. For instance, an impact angle of 90 degrees is not paired with a vertical target orientation since a weapon typically hits a vertical target from the side instead of from the top.

3.1.1.2 Functions Interfacing With the Data Space Generator

3.1.1.2.1 Interface to Truth Data Generator

The Data Space Generator defines the release, weather, and commanded impact conditions for the training and verification data sets run by the Truth Data Generator.

3.1.1.2.2 Interface to Truth Database

The Data Space Generator uses data sets from the Truth Database to verify that the training sets accurately characterize the dynamics of the impact conditions.

3.1.1.2.3 Interface to Coefficient Generator

When coefficients do not meet performance measures, the Coefficient Generator identifies a need for additional data in a specified region. Together, the Data Space Generator and the Truth Data Generator generate the additional data.

3.1.1.2.4 Data Space Generator Input and Output Files

The input file containing the information found in Table 2 and the output file containing the information found in Table 3 shall be delivered in an electronic file accompanied by a file specification document indicating the order and arrangement of the data.

3.1.2 Truth DataGenerator

3.1.2.1 Overview

The Truth Data Generator produces the training and verification data sets used by the Coefficient Generator. The training and verification sets are grid data based on truth data outputs from a Weapon Truth Model. Figure 5 is a notional depiction of a Weapon Truth Model. Table 3 and Table 4 are the Truth Data Generator inputs and outputs.

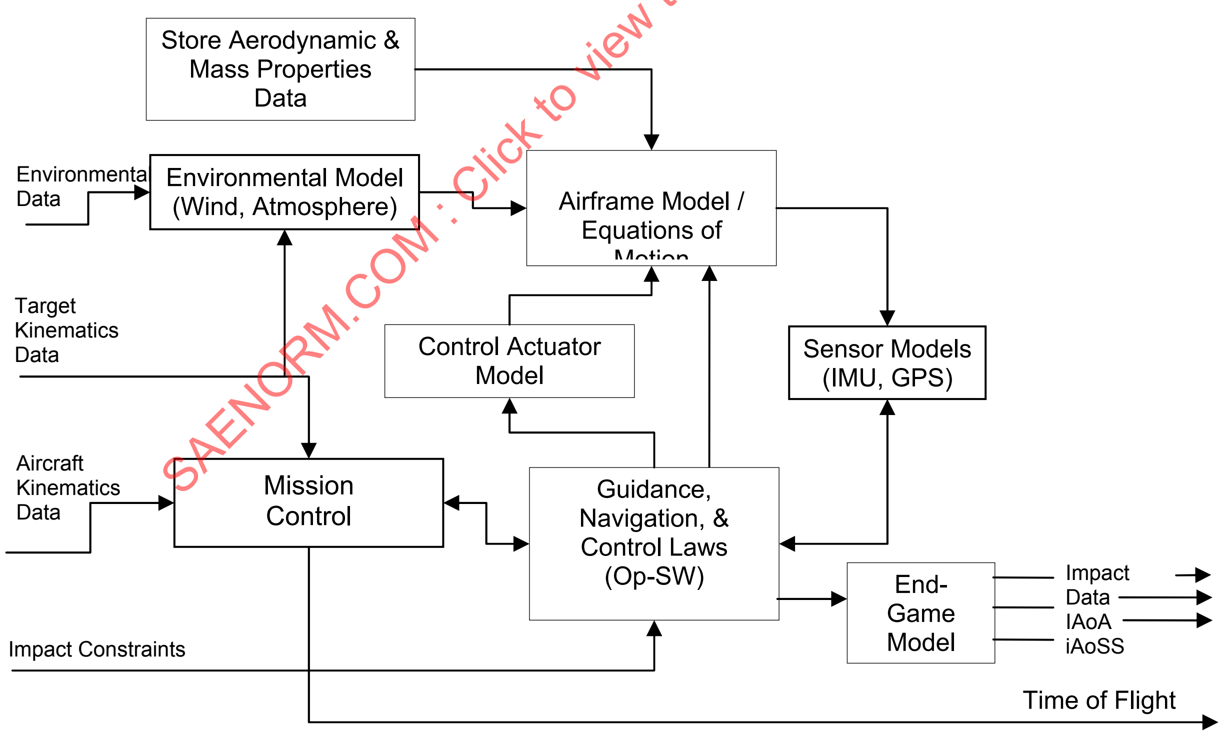

FIGURE 5 - NOTIONAL WEAPON TRUTH MODEL BLOCK DIAGRAM

3.1.2.2 Functions Interfacing With The Truth Data Generator

3.1.2.2.1 Interface to Data Space Generator

The Data Space Generator defines the appropriate number and location of input conditions necessary to properly characterize the dynamics of a set of impact states. To properly characterize the data space, the Data Space Generator may request non-uniform input conditions for the Truth Data Generator to execute. The Data Space Generator also defines the number of impact state sets used for training and verification of the CLAR Coefficients.

3.1.2.2.2 Interface to Truth Database

The Truth Database contains the impact state sets that the Truth Data Generator creates and the Coefficient Generator uses to create and verify the coefficients.

3.1.2.3 Truth Data Generator Input and Output Files

The Training and Verification files containing the information found in Table 4 shall be delivered in an electronic file accompanied by a file specification document indicating the order and arrangement of the data.

3.1.3 Coefficient Generator

3.1.3.1 Overview

The Coefficient Generator generates coefficients by building training and verification footprints from data extracted from the Truth Database, fitting a geometric shape to the training footprints, and defining the coefficients using the LAR Algorithm. It then verifies the coefficients against the verification sets by creating footprints based on the coefficients at the verification set conditions and confirming these verification footprints meet criteria.

Figure 6 shows the notional representation of the coefficient generation process.

3.1.3.2 Functions Interfacing With the Coefficient Generator

3.1.3.2.1 Interface to Truth Database

The Truth Database contains the training and verification sets. These are the inputs to the Coefficient Generator.

3.1.3.2.2 Interface to LAR Algorithm

The LAR Algorithm is a mathematical fitting algorithm to determine the footprint parameters. The CLARA process refers to the LAR Algorithm and does not specify a specific algorithm to allow for maximum flexibility on the part of the data modeler to choose the most appropriate mathematical fitting technique The Coefficient Generator uses the chosen LAR Algorithm to generate and verify the coefficients.

3.1.3.2.3 Interface to Reconstructor

The Reconstructor uses the coefficients from the Coefficient Generator to construct a footprint for a target point in the delivery envelope.

3.1.3.2.4 Interface to Data Space Generator

When the coefficients do not meet performance measures, the Coefficient Generator requests additional data within the input space.

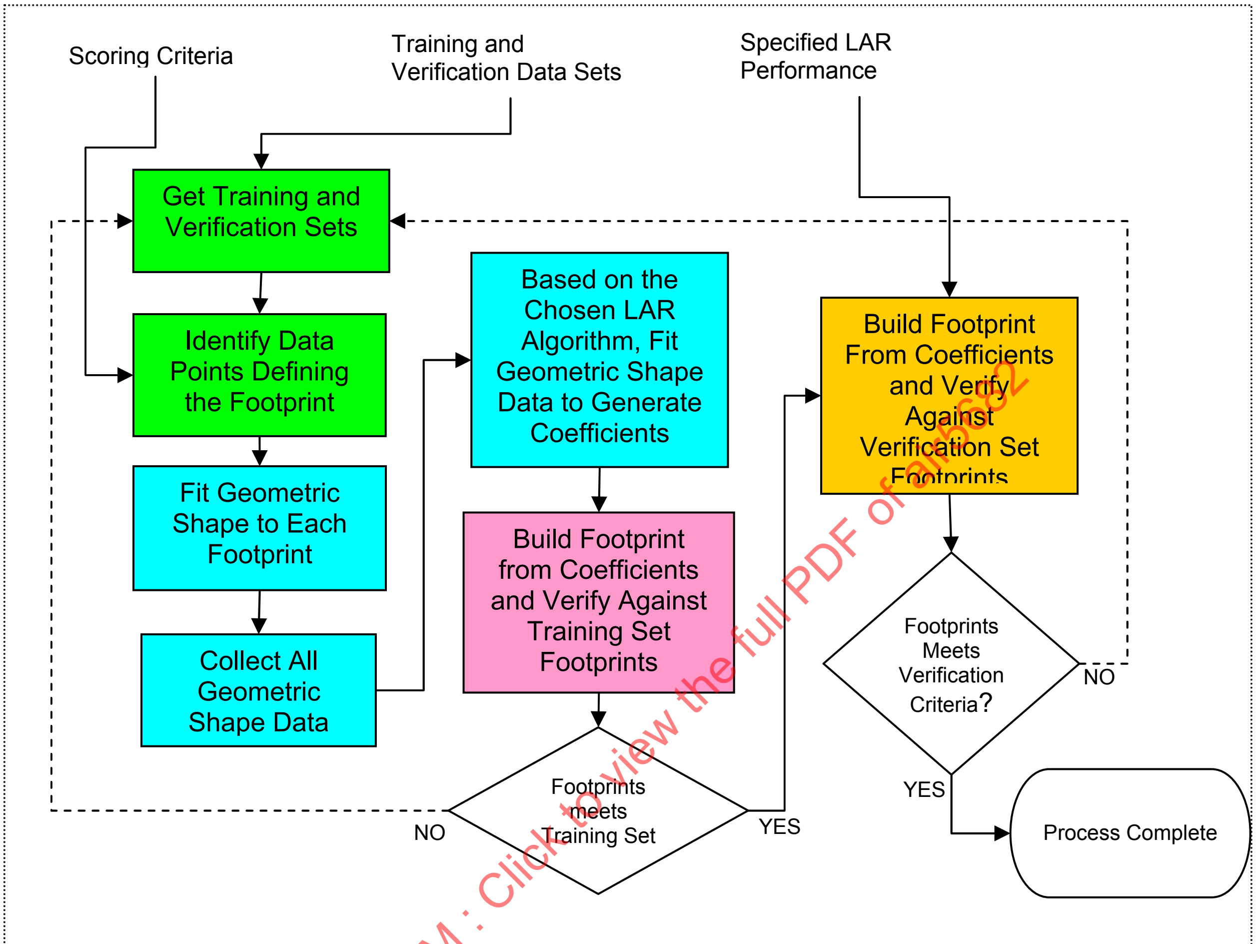

FIGURE 6 - NOTIONAL COEFFICIENT GENERATION PROCESS

3.1.3.3 Coefficient Generator Input and Output Files

The Coefficient file shall be delivered in an electronic file accompanied by a file specification document indicating the order and arrangement of the data.

3.1.4 Reconstructor

3.1.4.1 Overview

The Reconstructor constructs the footprint using the coefficients generated by the Coefficient Generator, the Input conditions (Table 5), the chosen LAR Algorithm, and a conservatism method. The Reconstructor may use a conservatism method to increase the probability of successfully hitting the target. The output of the Reconstructor (Table 6) may then be used to generate display data as illustrated in Figure 7. The displayed data may be that of a footprint or a LAR. The displayed shape of the footprint or the LAR shall be an N-sided polygon.

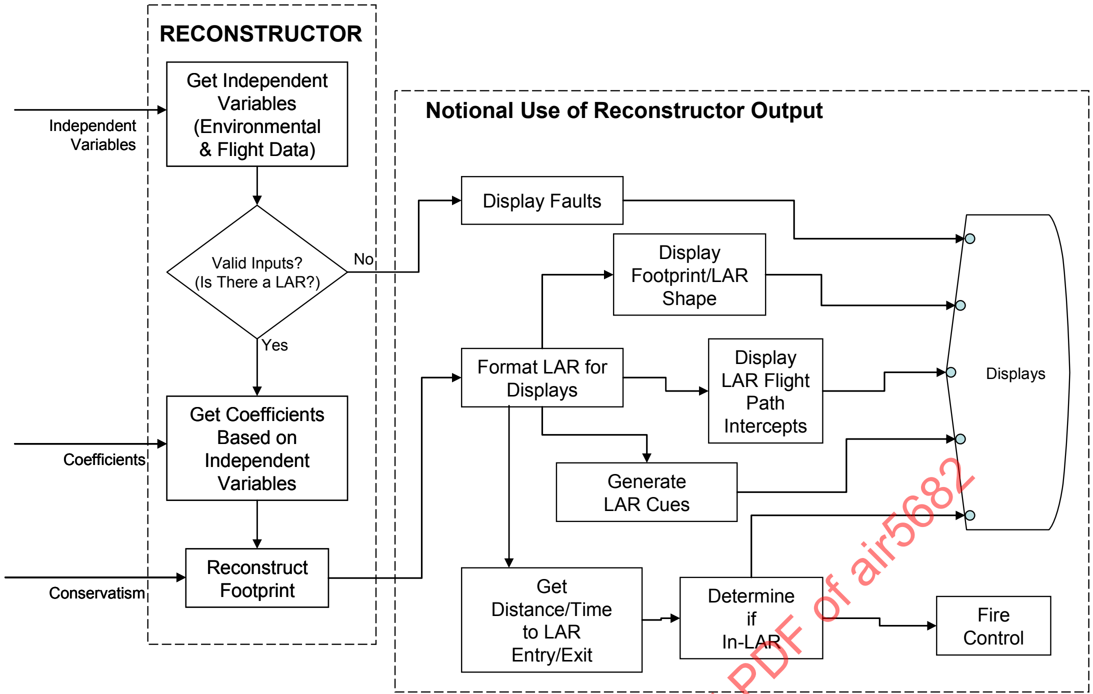

FIGURE 7 - NOTIONAL RECONSTRUCTOR BLOCK DIAGRAM

3.1.4.2 Functions Interfacing with the Reconstructor

3.1.4.2.1 Interface to Coefficient Generator

The Reconstructor produces the footprint using the coefficients generated by the Coefficient Generator.

3.1.4.2.2 Interface to LAR Algorithm

The Reconstructor uses the chosen LAR Algorithm (the same algorithm used by the Coefficient Generator) to construct the footprint.

3.2 Interface Requirements

Table 1 lists the interface tables for each of the CLAR functions.

TABLE 1 - INTERFACE TABLES

Function	Input	Output
Data Space Generator	Table 2	Table 3
Truth Data Generator	Table 3	Table 4
Coefficient Generator	Table 3 & Table 4	Note 1
Reconstructor	Table 5 Note 1	Table 6

NOTES:

1. The Coefficient Generator output file contains the coefficients used by the Reconstructor. Its contents and data description are LAR Algorithm-specific and defined in its file specification document.