RUMBLE

Launch Vehicle
Noise and Emissions
Simulation Model

Version 3.0
User Guide

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Abbreviations

AEDT	Aviation Environmental Design Tool
AEE	Office of Environment and Energy
AGL	Above Ground Level
ANSI	American National Standards Institute
ASIF	AEDT Standard Input File
AST	Office of Commercial Space Transportation
CNEL	Community Noise Equivalent Level
dB	Decibel
dBA	A-weighted Decibel
DI	Directivity Indices
DNL	Day-Night Average Sound Level
DSM-1	Distributed Source Method 1
EA	Environmental Assessment
EIS	Environmental Impact Statement
°F	Degrees Fahrenheit (temperature)
FAA	United States Federal Aviation Administration
ft	Feet (length)
g	Grams
GIS	Geographic Information System
GUI	Graphical User Interface
kg	Kilograms
LAMAX	Maximum A-weighted sound level with slow-scale exponential time weighting
LMAX	Maximum unweighted sound level with slow-scale exponential time weighting
lb	Pound (weight)
lbf	Pounds force
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NMGF	Noise Model Grid Format
nmi	International Nautical Miles (1,852 m)
OASPL	Overall Sound Pressure Level
OTO	One-Third Octave
Pa	Pascal (unit of pressure, one Newton per square meter)
PC	Project Consultant
PM	Project Manager
PS	Project Sponsor
s, sec	Second (time duration)
SEL	A-weighted sound exposure level
SPL	Sound Pressure Level
RSIF	RUMBLE Standard Input File
RSRM	Reusable Solid Rocket Motor
U.S.	United States
WGS84	World Geodetic System
µPa	Micropascal

Chemical Formulas and Abbreviations

Al_2O_3	Aluminum Oxide (Alumina)
BC	Black Carbon
Cl	Atomic Chlorine
Cl_2	Diatomic Chlorine
CO	Carbon Monoxide
CO_2	Carbon Dioxide
H	Atomic Hydrogen
H_2	Diatomic Hydrogen
H_2O	Water
HCl	Hydrogen Chloride
LOX	Liquid Oxygen
NO_x	Generic Term for Nitrogen Oxides
O_2	Diatomic Oxygen
O_3	Ozone
OH	Hydroxyl
PM	Particulate Matter
RP-1	Highly Refined Form of Kerosene Used as Rocket Fuel

1 Introduction

1.1 About Rumble

The launch vehicle noise and emissions simulation model, Rumble, is a software system that is designed to model commercial space launch, reentry, and static operations in space and time to compute far-field community noise and emissions exposures. A primary objective of Rumble is to help the analyst efficiently answer questions of interest about the environmental consequences of commercial space activities. The environmental consequences associated with noise and emissions from commercial space activities are evaluated through metrics, many of which are defined by regulatory standards. Rumble's inputs, outputs, workflow, and graphic user interface (GUI) are designed to complement the Federal Aviation Administration (FAA) Aviation Environmental Design Tool (AEDT) and simplify future integration efforts.

1.2 About this User Guide

This User Guide provides instruction on how to install, run, and interact with the Rumble application. The guide is organized into the following sections:

- Section 1 introduces Rumble.
- Section 2 provides detailed instructions on how to install and run Rumble.
- Section 3 provides instruction on how to interact with Rumble.
- Section 4 describes the metrics calculated by Rumble.
- Section 5 presents examples and exercises to learn how to create study elements.
- Section 6 defines the input files necessary to operate Rumble.
- Section 7 describes the output files generated by Rumble.
- Section 8 provides examples of the types of error and warning messages displayed in Rumble.
- Section 9 presents the technical details of the noise methodologies employed by Rumble.
- Section 10 presents the technical details of the emissions methodologies employed by Rumble.
- Section 11 describes the Rumble Standard Input File (RSIF) format and its usage.

> For the benefit and ease of users familiar with AEDT, this user guide adopts the language and style of the AEDT 3c User Guide, Installation Guide, Technical Manual, ASIF Reference Guide, and Instructional Resources, with changes applicable to the Rumble application.

The following symbols will appear throughout this document to highlight important information:

Warnings to avoid errors in execution and ensure that the intended execution occurs.

Notes containing helpful information and tips regarding the functionality of the tool.

The question mark icon provides answers to common questions.

This User Guide does not contain guidance or policy for regulatory analyses. Guidance documentation can be found on the FAA office of environment and energy (AEE) website:
(https://www.faa.gov/about/office_org/headquarters_offices/apl/environ_policy_guidance/).

2 System and Installation

This section provides detailed instructions for installing and running RUMBLE 3.0. Installation components must run locally.

2.1 System Requirements

System specifications for computers capable of hosting the RUMBLE application are displayed in Table 1. The preferred specifications are listed with suggested minimum requirements, where applicable.

Table 1. RUMBLE system specifications.

Specification	Minimum
Operating Systems	Microsoft Windows 7 x64-based Systems
Processor	Modern Dual Core Processor with 2 GHz or Higher Clock
RAM	4 GB Memory
Hard-disk Space	2 GB Storage
Software Requirements	Adobe Reader DC
Screen Resolution	1280 x 768

⚠ RUMBLE requires administrative privileges for both installation and execution of the software.

2.2 Installation Package Contents

2.2.1 RUMBLE Software

Install RUMBLE 3.0.exe – Installer for RUMBLE 3.0

2.2.2 Required Software

RUMBLE uses MATLAB Runtime v98.

MATLAB Runtime v98 will automatically be installed in conjunction with the installation of the RUMBLE software. If the target computer contains one or more previous versions of the MATLAB Runtime, complete one of the following steps to ensure reliable performance.

1. Uninstall previous versions of MATLAB Runtime, or
2. Edit the environment variables for MATLAB Runtime.

⚠ If a previous version of MATLAB Runtime is required to execute other applications on the target computer, use the second option to edit the environment variables to avoid uninstalling the necessary MATLAB Runtime(s).

To uninstall previous versions of MATLAB Runtime:

1. Navigate to *Start, Control Panel,* and select *Uninstall a Program.*
2. Select previous version(s) of MATLAB Runtime and click *Uninstall/Change*.
3. Follow the steps in the wizard to uninstall the runtime.

To edit environment variables for MATLAB Runtime:

1. Navigate to *Start, Control Panel, System and Security* and select *System.*
2. Select *Advanced System Settings*.
3. Under the advanced tab, select *Environment Variables…*
4. Select Path in the "System variables" box and click *Edit…*
5. Find and select the entry for MATLAB Runtime v98.
6. Click *Move Up* to move MATLAB Runtime v98 to the top.
7. Click *OK* to exit and save changes.

Windows limits the environment variable to 2047 characters. In the event that the entry for MATLAB Runtime v98 cannot be found and the environment variable has a character length greater than 2047, consider removing obsolete paths from the environment variable to make space for MATLAB Runtime v98.

2.3 Software Installation

2.3.1 Install RUMBLE

Follow the instructions below to install the RUMBLE 3.0 application.

1. To start the installer, double-click the *Install RUMBLE 3.0.exe* file.
2. If a User Account Control dialog opens, click 'Yes' to allow necessary files to be installed.
3. After performing a brief initial setup, the RUMBLE Installer wizard will open. If your internet connection requires a proxy server, click 'Connection Settings' and follow the instructions. Press 'Next' to continue to the next step.

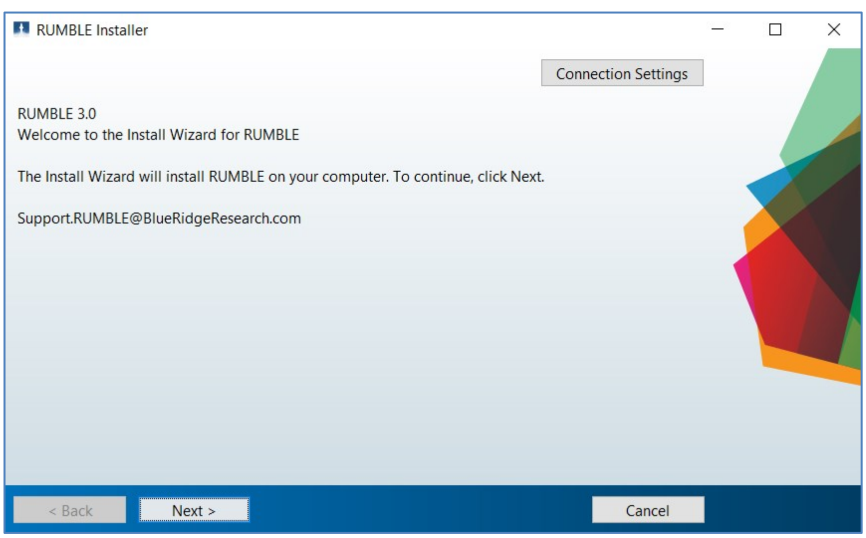


Figure 1. RUMBLE install wizard – welcome.

4. Click *Browse* and select the desired RUMBLE installation folder. Click *Add a shortcut to the desktop.* Click *Next.*

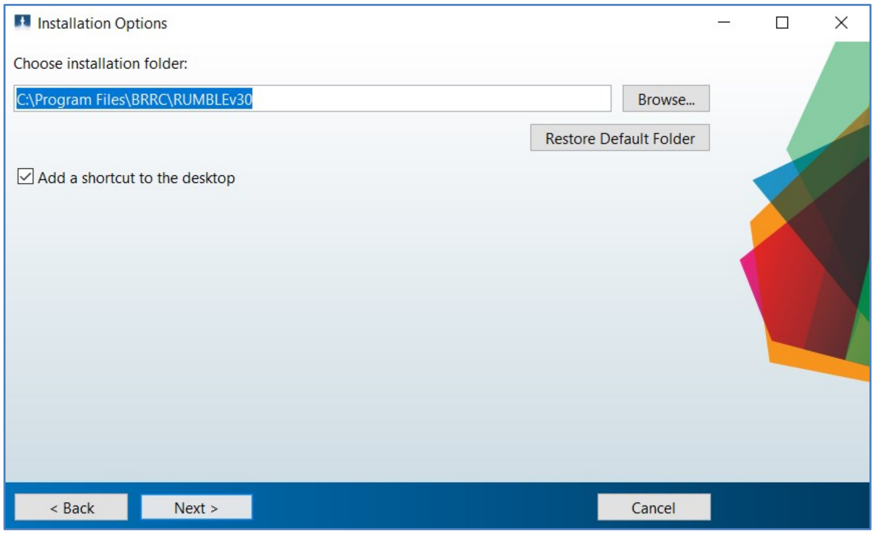


Figure 2. RUMBLE install wizard – installation options.

5. Click *Browse* and select the desired MATLAB Runtime installation folder. Click *Next.*

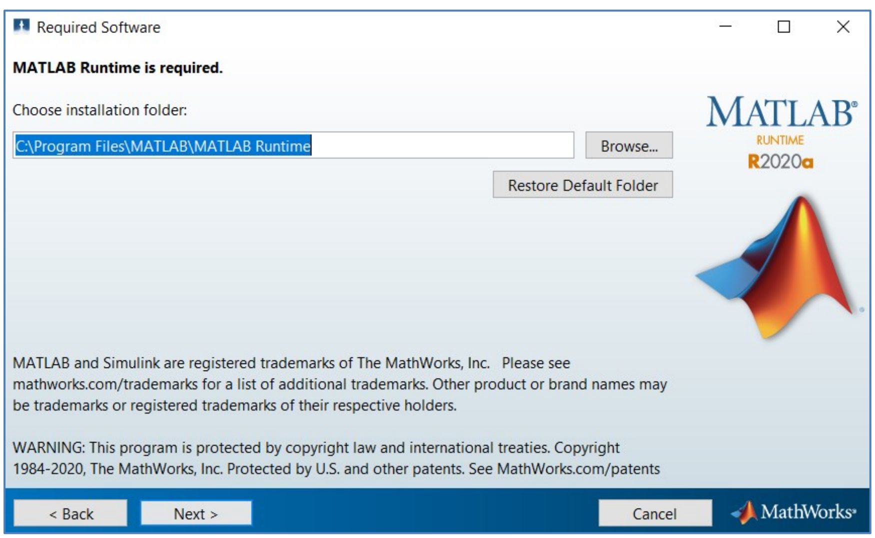


Figure 3. RUMBLE install wizard – required software.

6. Read the license terms and click *Yes* to accept the terms of the MATLAB Runtime license agreement. Click *Next.*

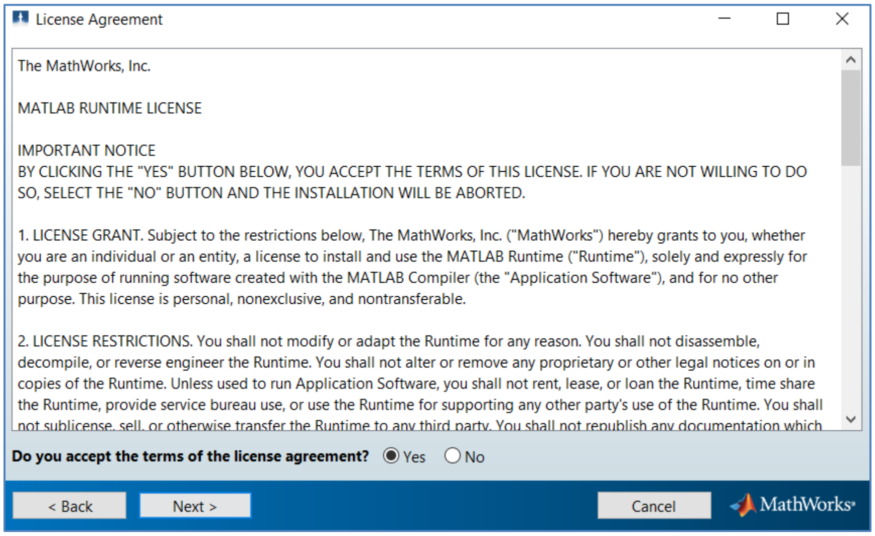


Figure 4. RUMBLE install wizard – license agreement.

7. Click *Install* to start the installation. The installation progress will be displayed.

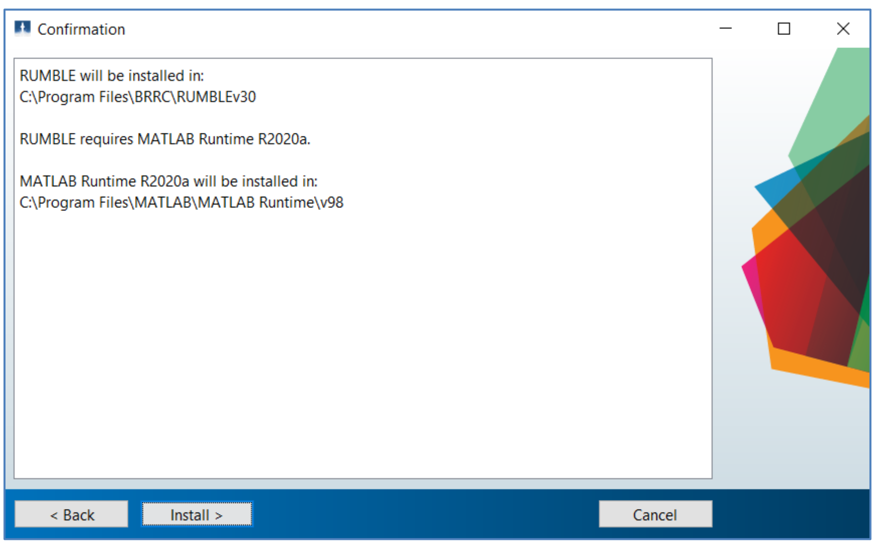


Figure 5. RUMBLE install wizard – ready to install.

8. Read the RUMBLE End User License Agreement and click *Finish* to accept when installation is complete.

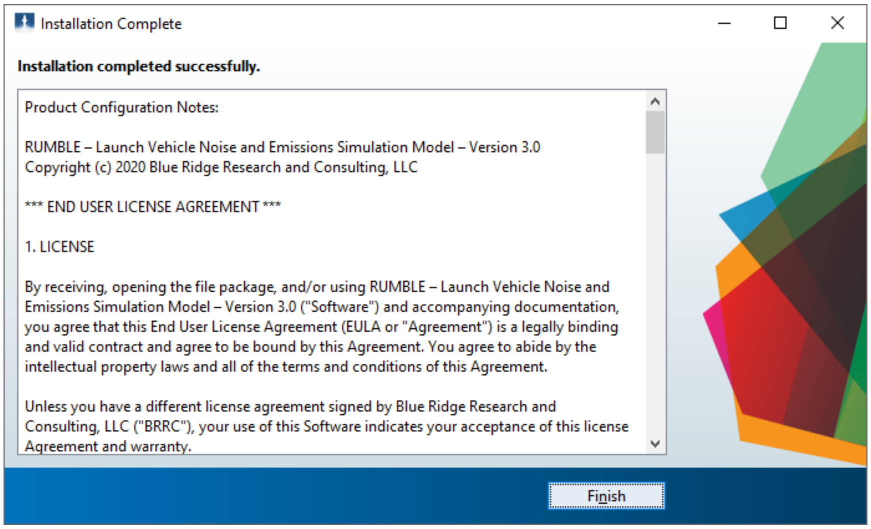


Figure 6. RUMBLE install wizard – installation complete.

The application will extract the required packages when it is opened for the first time. Thus, the startup time may be longer on first use than subsequent uses.

2.3.2 Steps to Uninstall RUMBLE

To uninstall RUMBLE:

1. Navigate to *Start, Control Panel,* and select *Uninstall a program.*
2. Select *RUMBLE* from the program list and click *Uninstall.*

3 Program Operation

This section provides instruction on how to interact with the RUMBLE 3.0 application. It is organized according to the order in which the tabs appear in the RUMBLE application, from left to right. High-level steps for creating a new study in RUMBLE are described in Section 3.1.2.

3.1 Getting Started

If RUMBLE is not already installed, follow the instructions provided in Section 0 to install the application software. RUMBLE requires administrative privileges for both 1) installation, and 2) execution of the software.

3.1.1 Start RUMBLE 3.0

To start the RUMBLE 3.0 application:

1. On the Desktop, right-click on the *RUMBLE* shortcut and click Run as Administrator.
   - RUMBLE 3.0 can also be accessed by navigating to *C:\Program Files\BRRC\RUMBLE\application* and right-clicking on the executable named *RUMBLE.exe* and selecting *Run as Administrator.*
   - Note, there may be a brief time lag between the splash screen and the active session during which the program is being initialized.
2. The *Study* tab opens upon application startup.
   - Click *Open* to select an existing study (see Section 3.3.1 for more information);
   - Click *New* to create a blank study (see Section 3.3.3 for more information); or
   - Click *Import* to import a study into RUMBLE (see Section 3.3.2).

3.1.2 High-level Workflow for Building a New Study

1. In the *Study* tab, create a new study (Section 3.3).
2. In the *Spaceport* tab, add a spaceport (Section 3.3.9).
3. In the *Receptors* tab, add receptors (Section 3.5).
4. In the *Operations* tab, create desired operations (Section 3.6).
5. In the *Scenarios* tab, create desired scenario(s) for the operations (Section 3.7).
6. In the *Metric Results* tab, define metric result(s) (Section 3.8).
7. In the *Metric Results* tab, run and view the metric result(s) (Section 3.8.3 and 3.8.6).

Study progress is saved upon exiting the application and no explicit “save” is required. However, saving the study periodically as changes are made is recommended.

3.2 User Interface Navigation

The RUMBLE 3.0 graphical interface consists of three main components:

1. Tabs
2. Ribbon
3. Workspace

The *Study* tab opens upon application startup (Figure 7).

The recommended screen resolution is 1920x1080 (or full HD resolution).

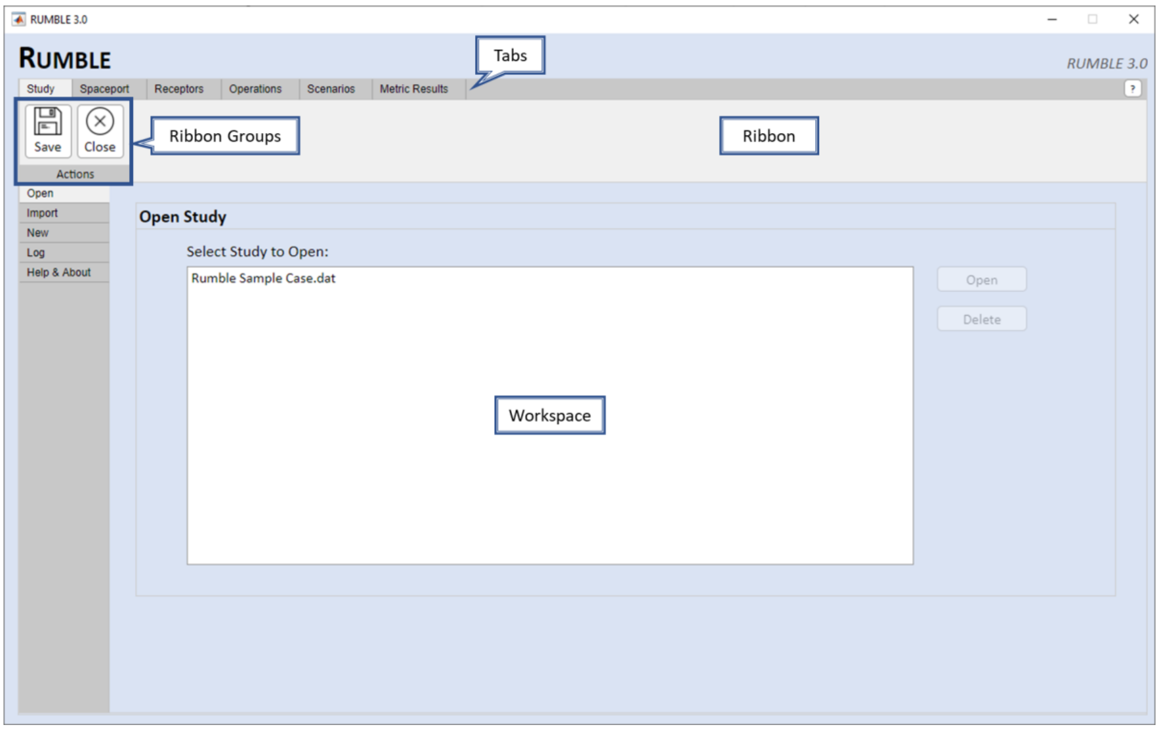


Figure 7. Study tab.

3.2.1 Tabs

RUMBLE 3.0 features are organized by tabs as follows:

Study Tab

The Study tab includes the following menu options:

- *Open*: displays the *Open Study* box.
- *Import*: displays the *Import Study* box.
- *New*: displays the *Create New Study* box.
- *Log:* displays RUMBLE log messages.
- *Help & About:* displays RUMBLE version and a link to the User Guide.

See Section 3.3 for more information on *Study* tab functionality.

Spaceports Tab

The *Spaceports* tab supports adding a spaceport. See Section 3.3.9 for more information.

Receptors Tab

The *Receptors* tab supports setting up receptors. See Section 3.5 for more information.

Operations Tab

The *Operations* tab supports managing spacecraft operations. See Section 3.6 for more information.

Scenarios Tab

The *Scenarios* tab supports setting up scenarios. See Section 3.7 for more information.

Metric Results Tab

The *Metric Results* tab supports construction and processing of metric result definitions, and generating and viewing result layers and reports. See Section 3.8 for more information.

3.2.2 Ribbon

The ribbon provides easy access to commands that are applicable in the current tab. The command buttons are grouped together by functional categories.

3.2.3 Workspace

The workspace in the RUMBLE interface is the area where users can complete actions they have initiated via the ribbon buttons. In the *Receptors*, *Operations*, *Scenarios*, and *Metric Results* tabs, the workspace is divided into two sections. While the divisions are consistent between these tabs, the content changes as specific to each tab.

Table Work Area: The table work area contains a list of data available for use in the currently selected tab. This work area is present in every tab except for the *Study* and *Spaceport* tabs.

Details Work Area: The details work area provides appropriate tools to manage the content in the table work area.

3.3 Study Tab

In RUMBLE 3.0, the *Study* tab provides access to studies. See the sections below for detailed information on the features of the study tab.

3.3.1 Open Study

To open a study:

1. Click the *Study* tab and click *Open* to display the *Open Study* work area (Figure 8).
2. *Click* on the name of the desired study.
3. Click *Open* to load the study.

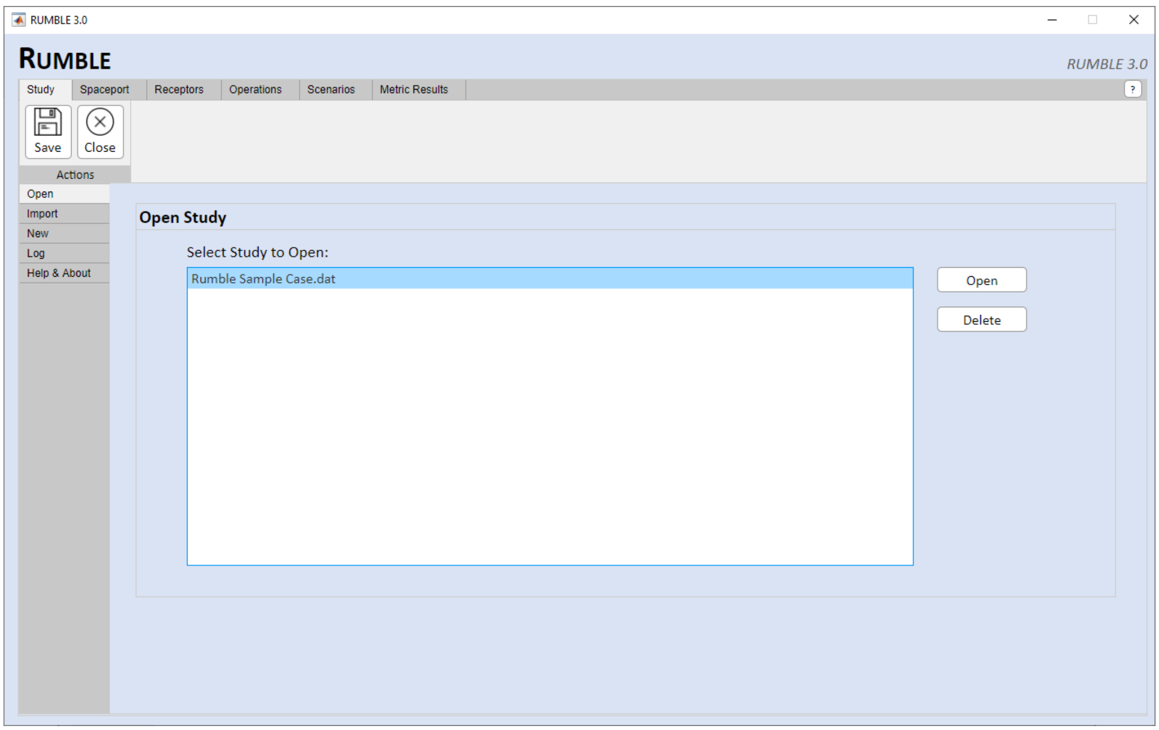


Figure 8. Study tab Open panel.

Sample Study

The following study file is included in RUMBLE 3.0:

- *Rumble Sample Case*: This study contains the vehicle and trajectory input data associated with notional horizontal and vertical launch operations.

The sample study contains different data sets and highlights different features of RUMBLE. Refer to Section 5.1 for a detailed description of the content included in the sample study.

Sample case study cannot be edited or deleted.

3.3.2 Import Study

To import a full-study from RSIF:

1. Click the *Study* tab and click *Import* to display the *Import Study* work area (Figure 9).
2. Click the *Browse* button, navigate to the RSIF study file and select *Import*.
3. In the study name field, enter a unique study name or accept the default name.
    - Enter a description in the study description field, if desired.
4. Click *Create* to import the study.

When the import is complete, the imported study is opened and the Spaceports tab is displayed.

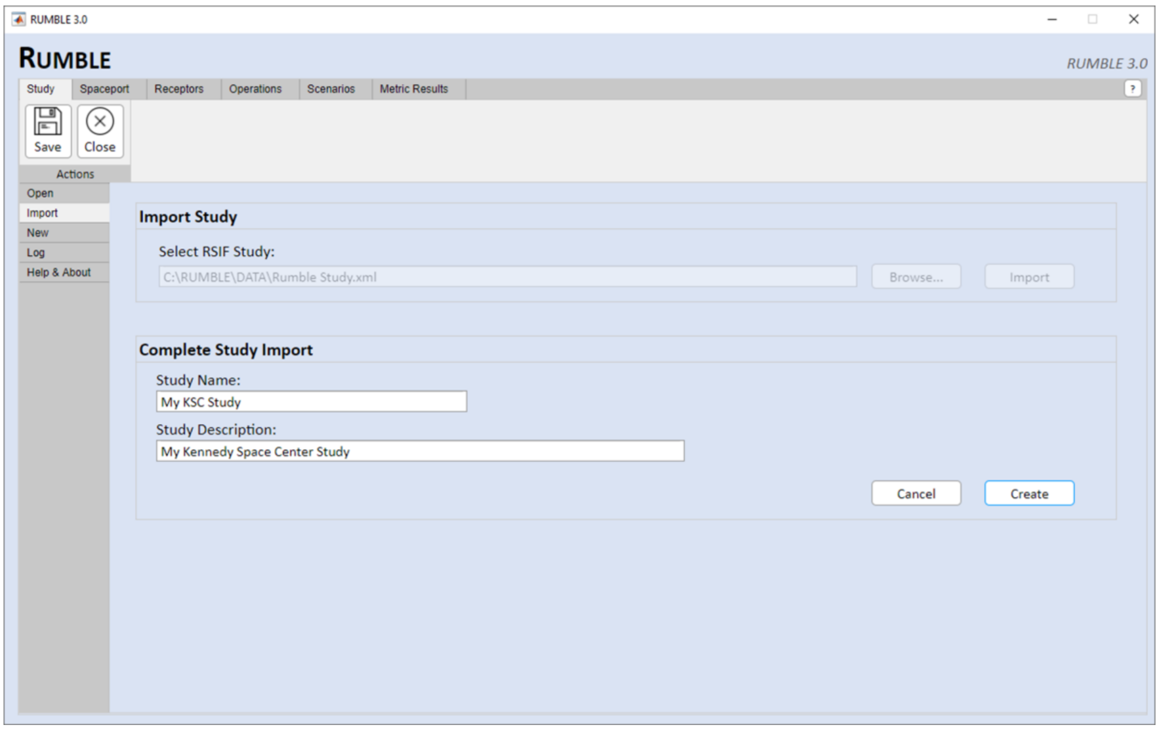


Figure 9. Study tab Import panel.

Partial RSIF input cannot be loaded via the Study tab’s Import panel.

3.3.3 Create New Study

To create a new study:

1. Click the *Study* tab, then click *New* to display the *Create New Study* work area (Figure 10).
2. Enter a study name (study description is optional).
3. Click *New* to create a new study.

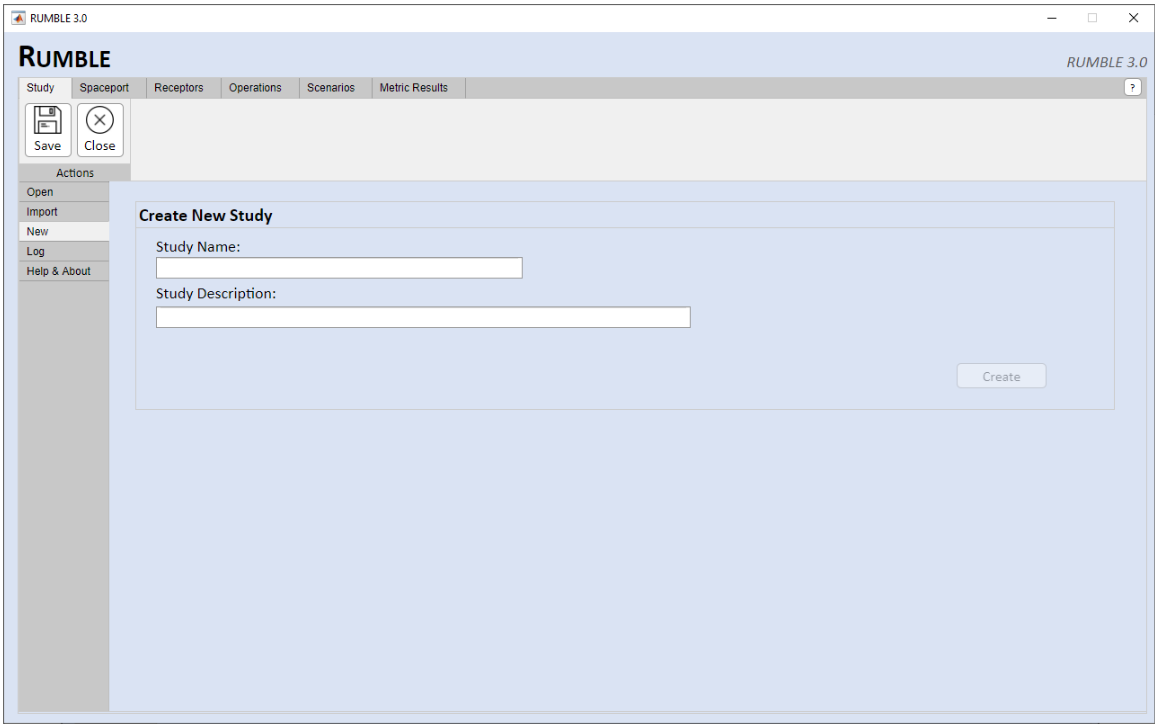


Figure 10. Study tab New panel.

3.3.4 Save Study

To close the currently open study, click the *Study* tab then click *Save* from the *Actions* ribbon group.

3.3.5 Close Study

To close the currently open study, click the *Study* tab then click *Close* from the *Actions* ribbon group.

An opened study must be closed before a new study can be opened, imported, or created.

3.3.6 View RUMBLE Log

To view system status and logged information, click on the *Study* tab and click *Log* (Figure 11). The information shown in the message pane is also written to the *RUMBLE.log* file in the *C:\RUMBLE\Logs* folder. The message pane displays the system status and messages, timestamp, and the originating RUMBLE module name. There are three different log levels:

- Information;
- Warning: minor (non-critical) issues/events;
- Error: a critical error or problem.

To clear all messages from the message pane, click *Clear Log.*

To open the RUMBLE log file, click *Open Log File.*

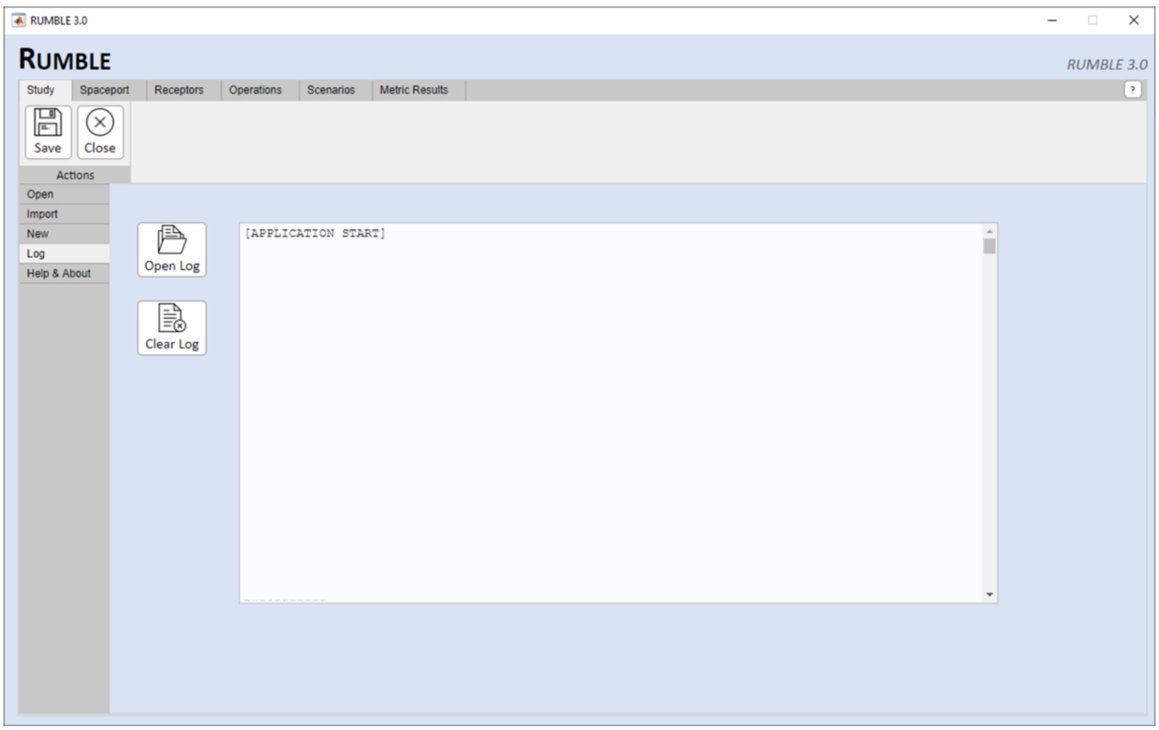


Figure 11. Study tab Log panel.

3.3.7 *Help & About*

To view version information, click on the *Study* tab then click *Help & About* (Figure 12). The following information is displayed:

- The version numbers for RUMBLE and MATLAB Runtime.
- An *Open user guide* button which opens a PDF of the RUMBLE 3.0 User Guide.

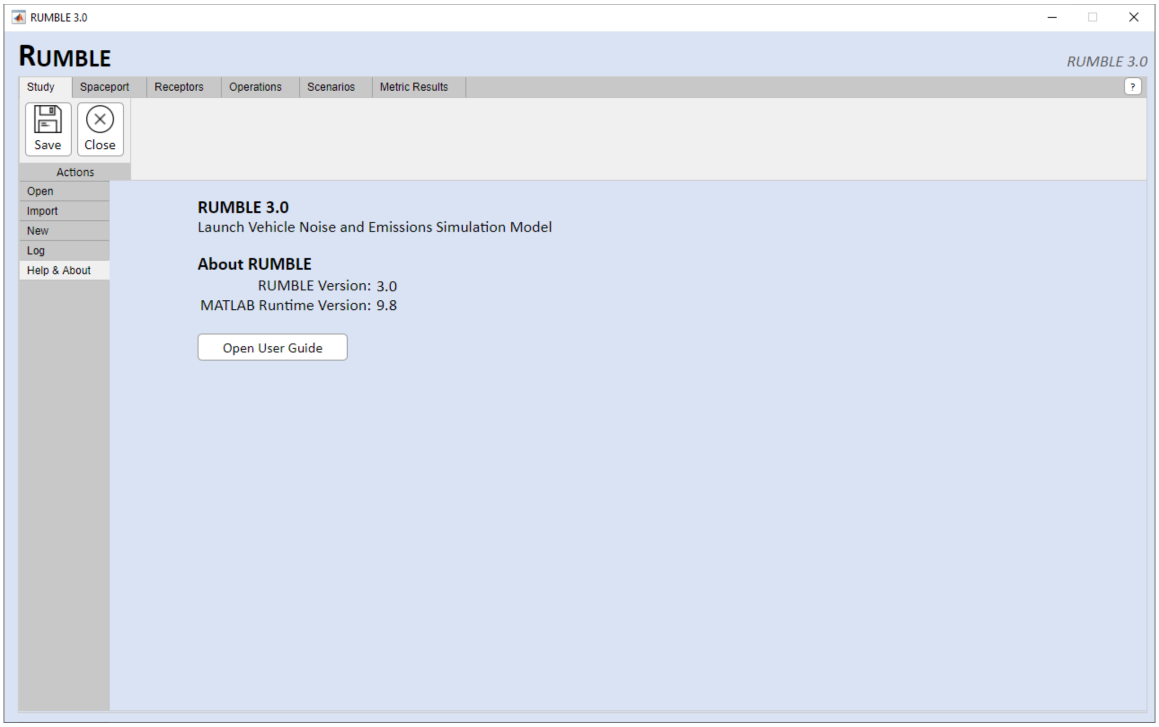


Figure 12. Study tab Help & About panel.

3.3.8 *Exit the RUMBLE Application*

To exit the RUMBLE 3.0 application, click the “X” at the top right corner of the application window.

Study progress is saved upon exiting the application and no explicit “save” is required. However, saving a study periodically as changes are made is recommended.

3.3.9 *Delete Existing Study*

To delete an existing study:

1. Click the *Study* tab and click *Open* to display the *Open Study* work area.
2. *Click* on the name of the desired study.
3. Click *Delete* to delete the study.

Alternatively,

1. Exit the RUMBLE application before deleting a RUMBLE study file.
2. Locate the study output directory *C:\RUMBLE\DATA*.
3. Select the study folder of interest and delete.

3.4 Spaceport Tab

The *Spaceports* tab supports adding a spaceport.

The spaceport elevation is used to convert the trajectory altitude from MSL to AGL.

3.4.1 Add Spaceport

To add a spaceport:

1. Click the *Spaceport* tab and click *New* to enable the *Spaceport* work area (Figure 13).
2. Enter the appropriate data in the required fields.
3. Click *Save* to save the spaceport in the study, or *Cancel* to discard changes.

To edit an existing spaceport:

1. Click the *Spaceport* tab and click *Edit* to enable the *Spaceport* work area.
2. Edit the desired fields.
3. Click *Save* to apply changes or *Cancel* to discard changes.

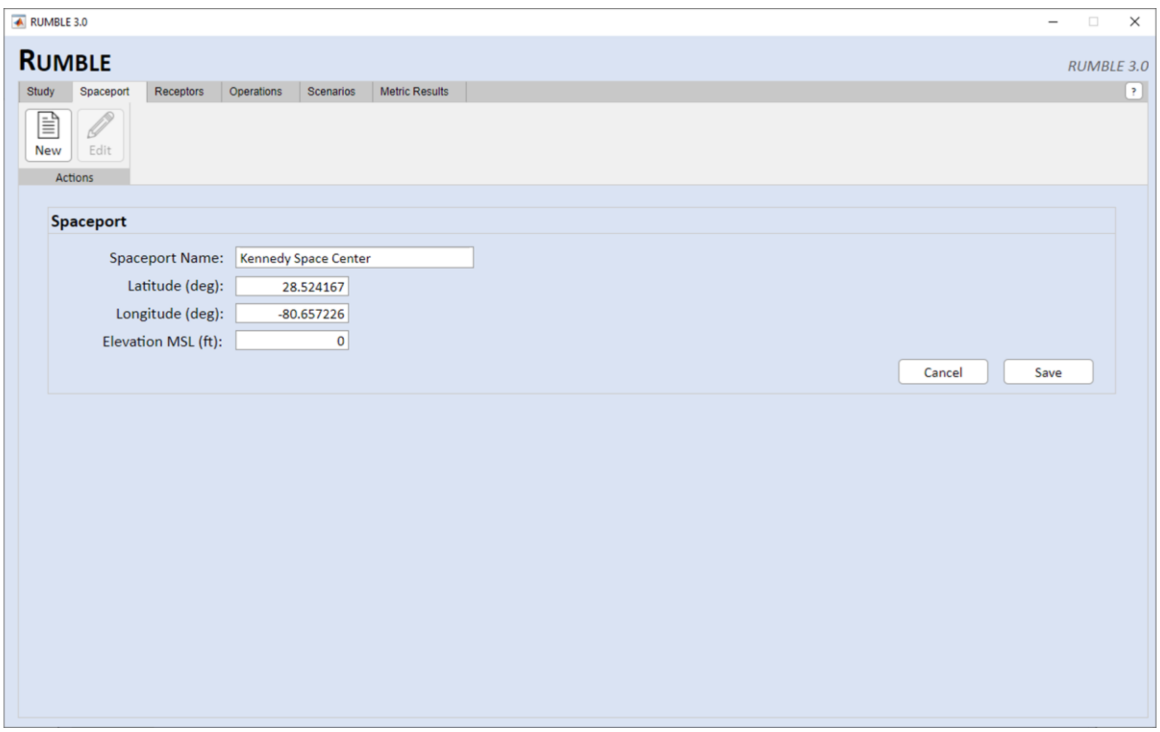


Figure 13. Spaceport tab.

3.5 Receptors Tab

To view receptors in the current study, click the *Receptors* tab. There are two receptor types: point and grid. Receptors can be created, copied, edited, and deleted; however, receptors that are assigned to a metric result cannot be deleted.

Receptors are only required to run noise metric results. Receptors are not required to run emissions reports.

3.5.1 Point-Type Receptor

To create a point-type receptor:

1. Click on the *Receptors* tab and click *New,* or select an existing receptor from the *Table of Receptors* and click *Copy* in the *Actions* ribbon group to create a new receptor from an existing receptor.
2. From the *Type* drop-down menu, select *Point* to display the point receptor details work area (Figure 14).

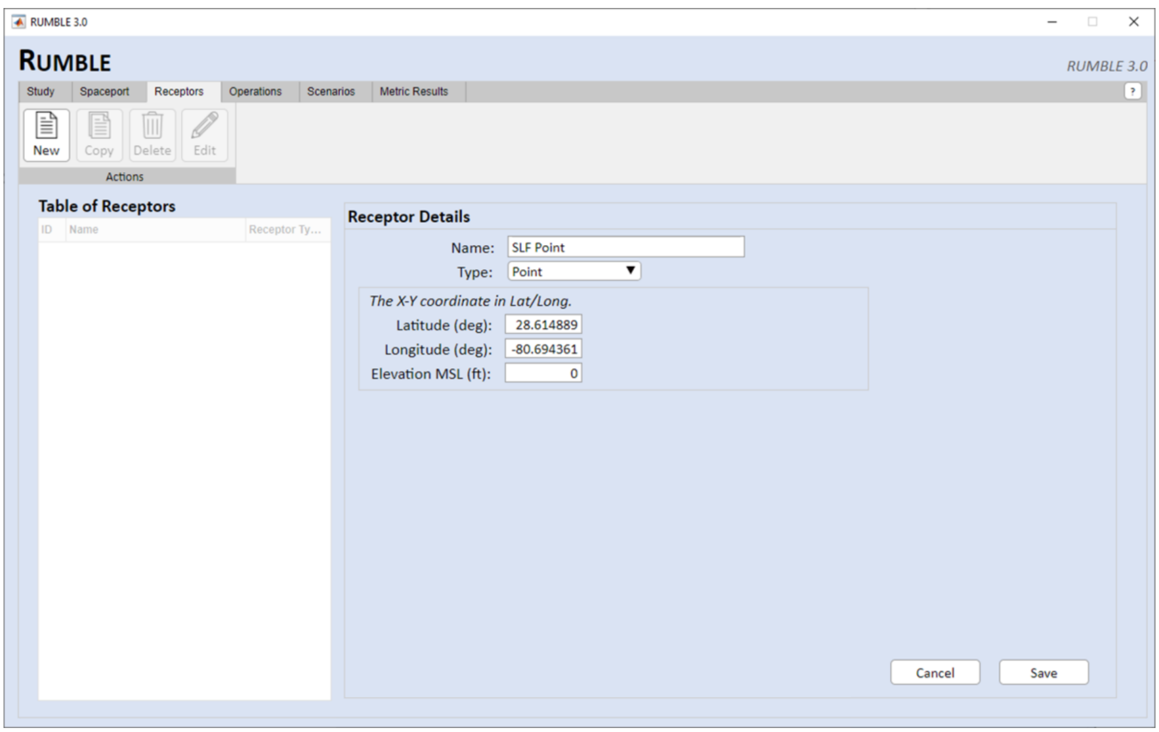


Figure 14. Receptors tab – point receptor details.

3. Enter the appropriate data in the required fields.
   - The *Latitude* and *Longitude* are set to the spaceport origin by default. Update the location information of the location of interest.
4. Click *Save* to apply changes or *Cancel* to discard changes.

To edit a point-type receptor:

1. Select the desired receptor from the *Table of Receptors* and click *Edit* in the *Actions* ribbon group.

2. Edit the desired fields.
3. Click *Save* to apply changes or *Cancel* to discard changes.

Elevation MSL (ft): This elevation corresponds to the elevation of the area; for example, the elevation of the spaceport. If the receptors are at a different elevation than the spaceport, the appropriate elevation should be used.

3.5.2 Grid-Type Receptor

To create a grid-type receptor:

1. Click on the *Receptors* tab and click *New,* or select an existing receptor from the *Table of Receptors* and click *Copy* in the *Actions* ribbon group to create a new receptor from an existing receptor.
2. From the *Type* drop-down menu, select *Grid* to display the grid receptor details work area (Figure 15).

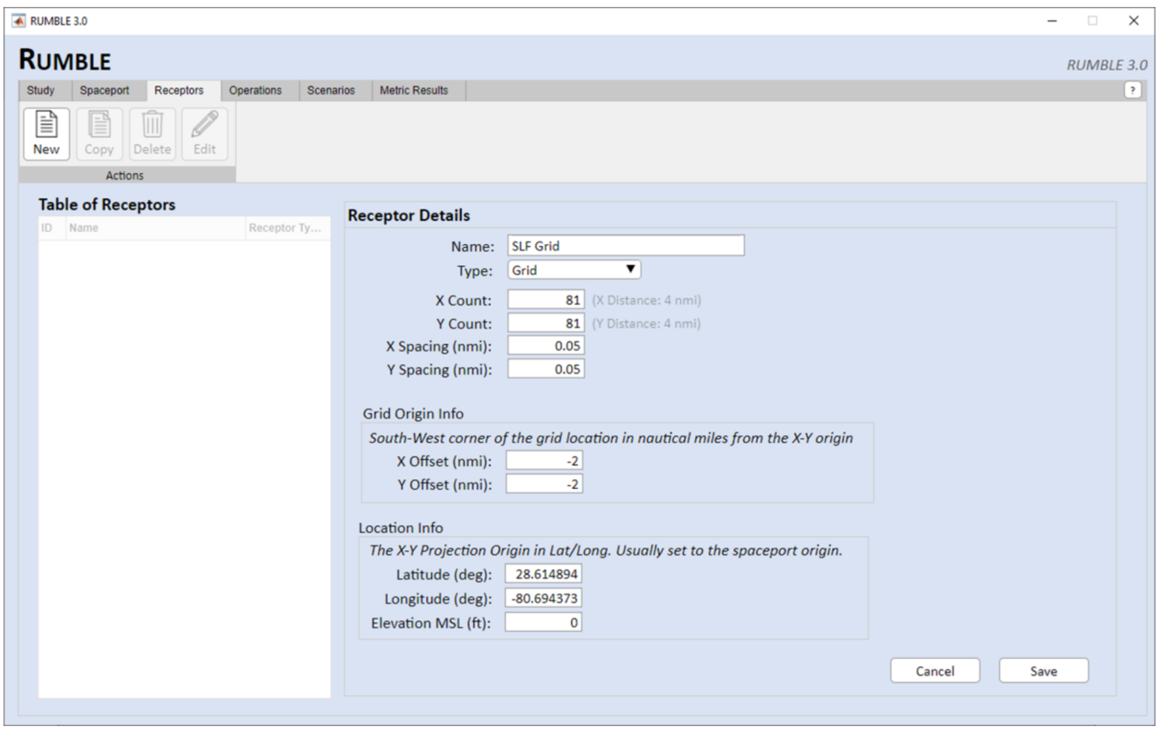


Figure 15. Receptors tab – grid receptor details.

3. Enter the appropriate data in the required fields.
   - The *X Distance* and *Y Distance* will automatically display non-zero distances based on the defined count and spacing.
   - The *Latitude* and *Longitude* are set to the spaceport origin by default. Use one of the following methods (depicted in Figure 16) to update the grid location:
     - Method 1:
       a. In the *Location Info* section, change the *Latitude* and *Longitude* to the location of the lower left corner of the grid.

   b. Leave the *Grid Origin Info* set to 0.
- Method 2:
   a. Confirm that the *Location Info* represents the desired spaceport location (i.e. spaceport origin).
   b. In the *Grid Origin Info* section, enter the location of the south-west corner of the grid as an offset from the spaceport origin by specifying the *X offset* and *Y offset* parameters.

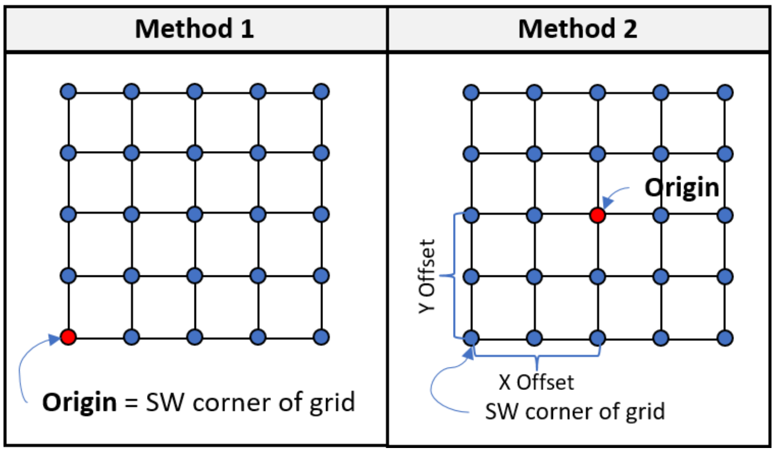


Figure 16. Depiction of methods to update the grid location.

4. Click *Save* to apply changes or *Cancel* to discard changes.

To edit a grid-type receptor:

1. Select the desired receptor from the *Table of Receptors* and click *Edit* in the *Actions* ribbon group.
2. Edit the desired fields.
3. Click *Save* to apply changes or *Cancel* to discard changes.

Elevation MSL (ft): This elevation corresponds to the elevation of the area; for example, the elevation of the spaceport. If the receptors are at a different elevation than the spaceport, the appropriate elevation should be used.

3.5.3 Delete Receptor

To delete an existing receptor:

1. Select the desired receptor from the *Table of Receptors.*
2. From the *Actions* ribbon group, click *Delete.*

Receptors that are assigned to a metric result cannot be deleted.

3.6 Operations Tab

The *Operations* tab supports managing spacecraft operations. To view operations in the current study, click the *Operations* tab. There are three operation types: launch, landing, and static. Operations can be created, copied, edited, and deleted; however, operations that are assigned to a scenario cannot be deleted.

Use the buttons in the *Actions* ribbon group to create, copy, edit, or delete spacecraft operations.

- Click *New* to enable the *Operation Details* work area (Figure 17).
- Click *Copy* or *Edit* to display the *Operation Details* work area for the currently selected operation. Each field will display the values from the original operation.
- Click *Delete* to delete the currently selected operation.

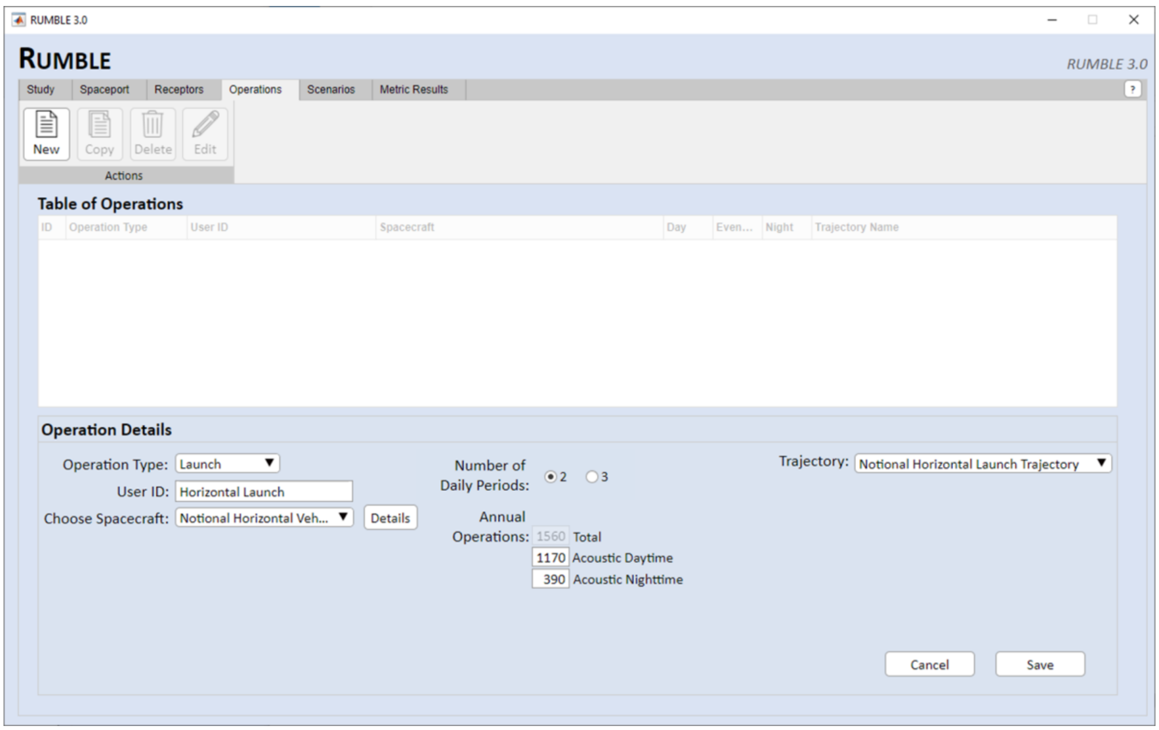


Figure 17. Operations tab – launch details.

3.6.1 Create Spacecraft Operation

To create a spacecraft operation:

1. Click on the *Operations* tab and click *New,* or select an existing operation from the *Table of Operations* and click *Copy* in the *Actions* ribbon group to create a new operation from an existing operation.
2. From the *Operation Type* drop-down menu, select an operation type.
3. Enter a *User ID*.
4. From the *Vehicle* drop-down menu, select the desired spacecraft.
   - The vehicle list includes spacecraft in the RUMBLE database and user-defined spacecraft.
     - Click *Details* to view the parameters of a specific vehicle. Data was obtained from the FAA AST STAR Database unless otherwise noted. An asterisk indicates the parameter is required for operating RUMBLE (see Section 0 for a description of the spacecraft database fields).
   - Select *Browse* to import a partial RSIF file that contains user-defined fleet data (see Section 0 for a description of the RSIF for user-defined fleet data).
     - The Imported user-defined spacecraft will be available within the list for future operations.
5. Enter the desired annual operation counts.
   - To enable the calculation of the DNL and CNEL metrics, the annual operation counts are defined according to two (day and night) or three (day, evening, and night) daily periods.
   - If CNEL is calculated for operations defined according to two daily periods, zero evening operations are assumed.
6. Choose flight trajectory for launch/landing operations or provide static details.
   - For launch/landing operation: Select *Browse* to import a partial RSIF file that contains user-defined trajectory data (see Section 11.5.27 for a description of the RSIF for user-defined trajectory data).
     - The Imported user-defined trajectory will be available within the list for future operations.
   - For static operation: Enter the orientation, latitude, longitude, height, heading, and duration.
     - The heading is disabled when the vertical orientation option is chosen.
7. Click *Save* to apply changes or *Cancel* to discard changes.

To edit a spacecraft operation:

1. Select the desired operation from the *Table of Operations* and click *Edit* in the *Actions* ribbon group.
2. Edit the desired fields.
3. Click *Save* to apply changes or *Cancel* to discard changes.

3.6.2 Delete Spacecraft Operation

Click *Delete* to delete the currently selected operation.

Operations that are assigned to a scenario cannot be deleted.

3.7 Scenarios Tab

What is a scenario?

In RUMBLE, a scenario is a hierarchical grouping of operations associated with the following parameters: time period to be analyzed, operations included in the time period, and weighted groupings of the included operations. Creating a scenario provides a convenient way to adjust contributions of individual operation groups by scaling operations up or down using weightings.

To view scenarios in the current study, click the *Scenarios* tab. Scenarios can be created, copied, and deleted; however, operations that are assigned to a metric result cannot be deleted.

Use the buttons in the *Actions* ribbon group to create, copy, or delete scenarios.

- Click *New* to enable the *Scenario Details* work area.
- Click *Copy* to display the *Scenario Details* work area for the currently selected scenario.
- Click *Delete* to delete the currently selected scenario.

Editing an existing scenario is supported only through the *Copy* feature to create a new scenario based on an existing one and to edit the parameters. Each step will display the selections of the existing scenario.

3.7.1 Create Scenario

To complete the *Create Scenario* workflow, the study must already contain spacecraft operations.

To access the *Scenario Details* work area: Click on the *Scenarios* tab and click *New*.

Step 1: Assign Existing Operation Groups

The first step of the *Create Scenario* workflow is organized into two areas

1. Select options at the top half of the details work area, and
2. Assign existing operation groups at the bottom of the details work area.

Select Option(s)

First, select at least one option from the list of checkboxes:

1. Assign existing operation group(s) – check this option to enable the bottom half of the details work area – *Existing Operation Groups* area, and
2. Add new spacecraft operation group(s).

Assign Existing Operation Group(s)

Existing operation groups are assigned in the current step (Figure 18).

A list of existing operation group(s) is displayed on the left, and a list of operation groups assigned to the annualization is displayed on the right.

To assign an existing operation group:

1. Select the desired operation group(s) from the *Available operation groups* list and click the *Add Arrow*.
2. To remove existing group(s) from the *Assigned operation groups* list, click the *Remove Arrow.*
3. When finished with this step, click *Next.*

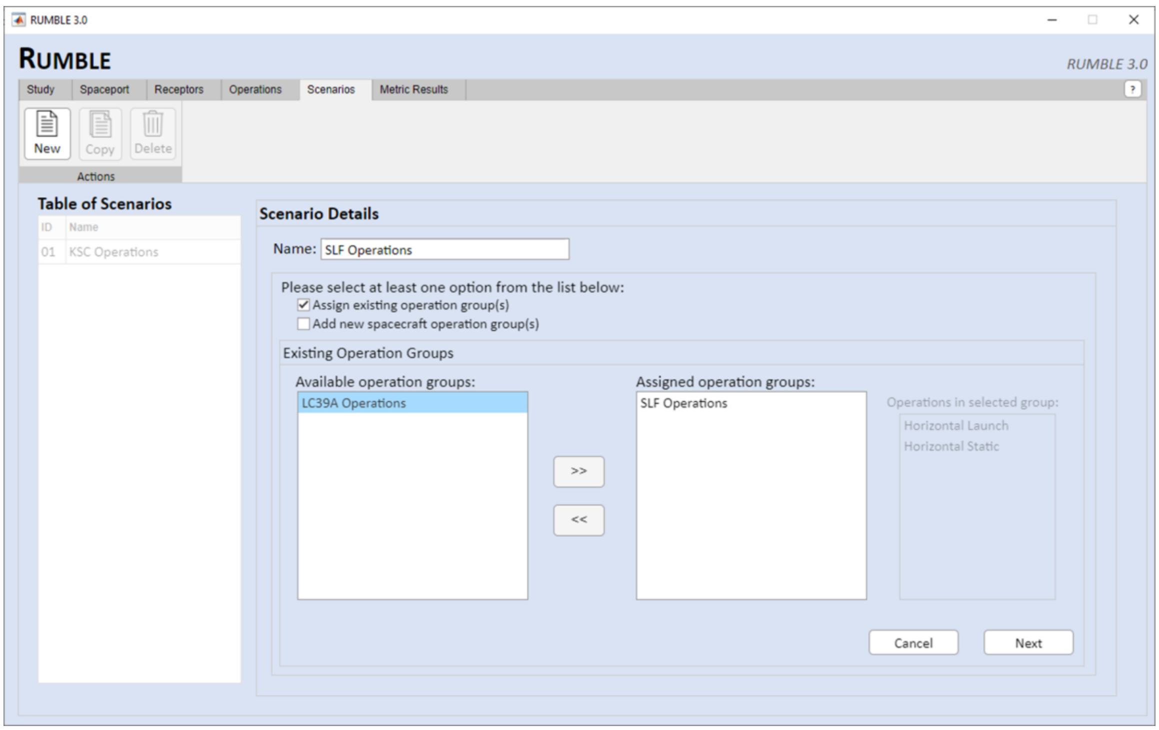


Figure 18. Scenarios tab – assign existing operation group(s).

Existing operation groups cannot be edited. Operations cannot be assigned or removed from these groups and they cannot be renamed.

Step 2: Create Spacecraft Operation Groups

In this step, spacecraft operations can be organized into groups and assigned to the scenario. A list of available spacecraft operations is displayed on the left, and a list of operation groups assigned to the scenario is displayed on the right (Figure 19).

To create a new spacecraft operation group:

1. Enter a name in the *Add New Group* field and click *Add.*
2. The new group is displayed in the *Assigned operation groups* list and automatically selected.
3. From the *Available operations* list on the left side of the details work area, select the desired operation(s). To select multiple rows, hold the control or shift key while clicking rows.
4. Click the *Add Arrow* to add the selected operation(s) to the selected operation group in the *Assigned operation groups* list and removed them from the *Available operations* list.
5. To remove operations from an operation group, select the desired operation(s) and click the *Remove Arrow* to add the selected operation(s) back to the *Available operations* list. Although operation groups cannot be deleted, groups with zero assigned operations will automatically be removed.

When finished grouping operations, click *Next.*

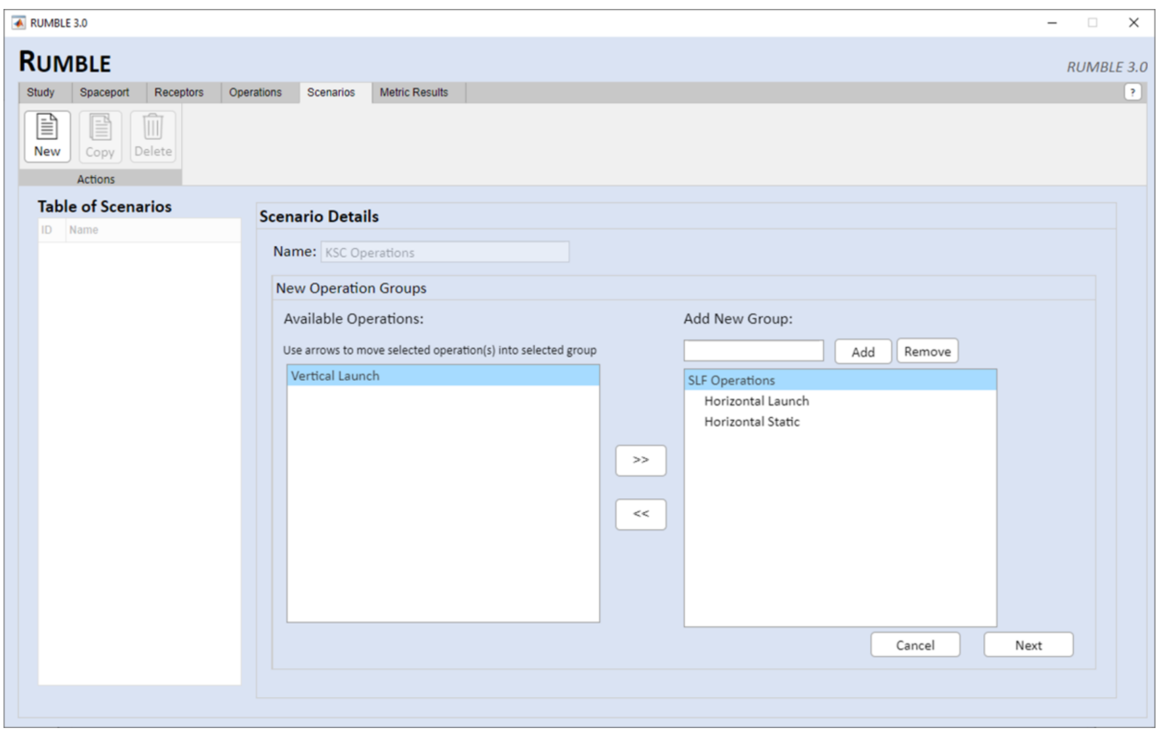


Figure 19. Scenarios tab – add new operation group(s).

Each operation group must have a unique name.

Operations can be assigned and removed from new operation groups.

Step 3: Build Scenario

The scenario tab allows for user-defined weighting of noise results. A scenario weighting hierarchy can be created in this step for the operation groups defined in the previous steps (Figure 20).

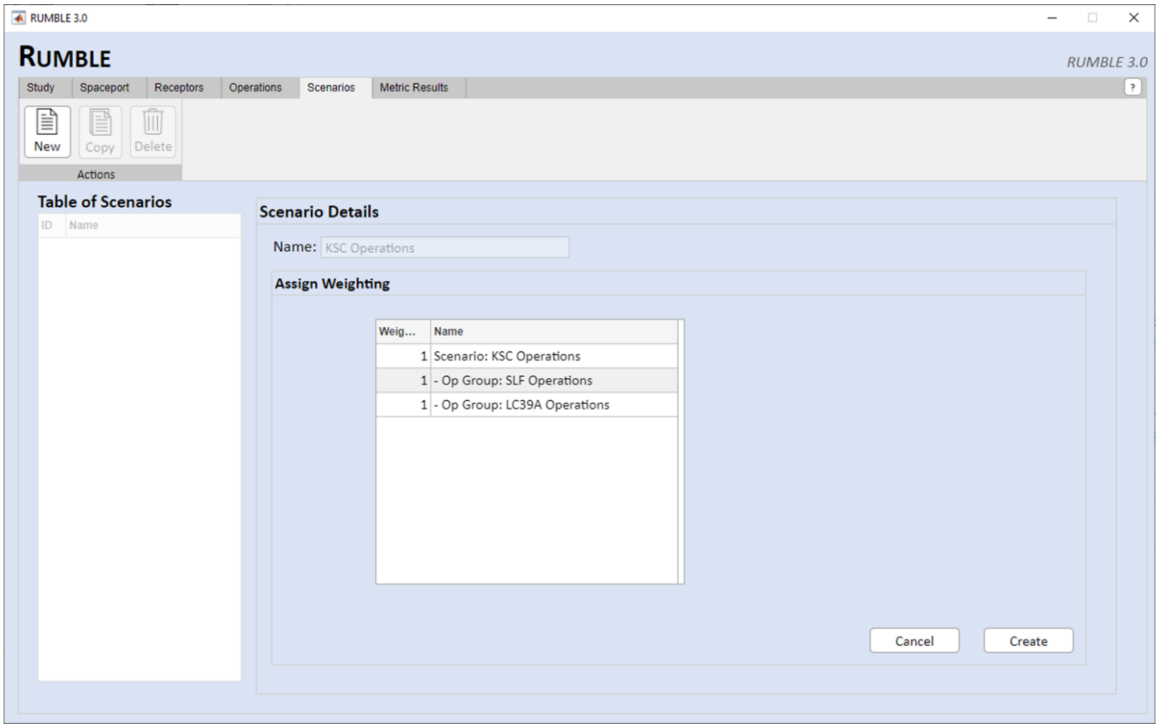


Figure 20. Scenarios tab – assign weighting.

By default, the scaling factor is 1, representing the unit weighting (no change).

3.7.2 Copy Scenario

The *Copy* option allows users to create a new scenario based on an existing scenario.

To copy a scenario:

1. Click on the *Scenarios* tab.
2. In the *Table of Scenarios*, select a desired scenario to copy.
3. Click *Copy* to enable the *Scenario Details* work area.
4. Each step will display the values from the original scenario.

3.7.3 Delete Scenario

Click *Delete* to delete the currently selected scenario. In order to delete a scenario, first delete any metric results that use the scenario.

Scenarios that are assigned to a metric result cannot be deleted.

Deleting a scenario does not delete its operation groups. Operation groups, once created, cannot be deleted.

3.8 Metric Results Tab

Each metric result is representative of a metric, scenario (which includes operations), receptor set, and atmospheric profile combination. Metric results are listed in the *Metric Results Table.* The metrics results tab (Figure 21) allows for running metric results (Section 3.8.3), deleting metric results (Section 3.8.4), exporting metric results (Section 3.8.5), viewing maps of contours and receptors (Section 3.8.6), and viewing emissions reports (Section 3.8.7).

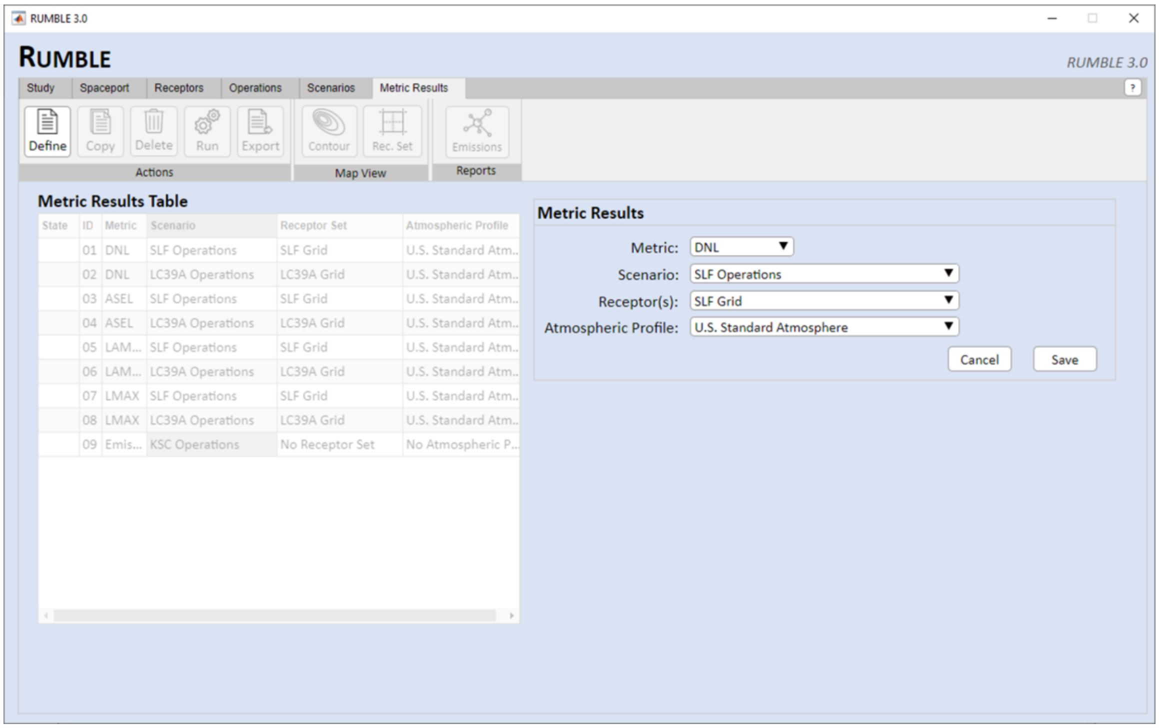


Figure 21. Metric results tab.

If the 'Emissions' metric selected, the receptor set and atmospheric profile drop-down menus are hidden as these elements are not needed to compute emissions.

3.8.1 Define New Metric Result

To complete the *Define Metric Results* workflow, the study must already contain scenario(s) (which includes operations) and receptor(s).

To define a metric result:

1. Click on the *Metric Results* tab and click *Define,* or select an existing metric result from the *Metric Results Table* and click *Copy* in the *Actions* ribbon group to create a new metric result from an existing metric result.
2. From the *Metric* drop-down menu, select the desired metric.
    - Available metrics include: DNL, CDNL, CNEL, LMAX, LAMAX, LCMAX, SEL, ASEL, CSEL, Emissions
3. From the *Scenario* drop-down menu, select the desired scenario.
4. From the *Receptor(s)* drop-down menu, select the desired receptor(s) (point or grid).

5. From the *Atmospheric Profile* drop-down menu, select the desired atmospheric profile.
    - Available atmospheric profiles include: U.S. Standard Atmosphere.
        - Sources: 0 – 95,000 ft: U.S. Standard Atmosphere (1976), 100,000 – 295,000 ft: NASA Technical Memo, and 300,000 – 350,000 ft: Handbook of Astronautical Engineering (McGraw-Hill 1961).
    - Select *Browse* to import a partial RSIF file that contains user-defined atmospheric profile data (see Section 11.5.4 for a description of the RSIF for user-defined atmospheric profile data).
        - The imported user-defined atmospheric profile will be available within the list for future metric results.
6. Click *Save* to apply changes or *Cancel* to discard changes.

3.8.2 Copy Metric Results

The *Copy* option allows users to create a new metric result based on an existing metric result.

To copy a metric result:

1. Click on the *Metric Results* tab.
2. In the *Metric Results Table*, select a desired metric result to copy.
3. Click *Copy* to enable the *Metric Results Details* work area.
4. Each field will display the values from the original metric result.

3.8.3 Run Metric Results

Metric result definitions that have been defined can be processed to generate the specified results. Metric result definitions can be run individually or in groups from the *Metric Results* tab.

To process metric result definitions listed in the *Metric Results Table*:

1. Select desired metric result(s) and click *Run* from the *Actions* ribbon group.
    - Use the shift key to select multiple metric results.
2. Once the run is complete, the *State* column will display a check icon.

3.8.4 Delete Metric Results

Click *Delete* to delete the currently selected metric result.

3.8.5 Export Noise Metric Results

To enable the *Export* button, select a completed noise metric result. This button allows the user to export the selected noise metric result in a Noise Model ASCII Grid Format (NMAGF) file.

To export noise metric result:

1. In the *Metric Results Table*, select a completed noise metric result.
2. In the *Metric Results Actions* group in the ribbon, click the *Export* button.
3. Accept the default file name or enter a new file name and click *Save.*
4. A grid file is saved to the selected location.

The default export location is *C:\RUMBLE\DATA\[Study Folder]*. The default filename is based on the scenario name, receptor set name, and metric.

3.8.6 View Maps of Noise Contours and Receptors

Data can be visualized on a map by generating contour or receptor layers. The *Map View* ribbon group in the *Metric Results* tab supports generating two types of layers: contour and receptor(s).

View Noise Contour Layer

1. In the *Metric Results Table*, select a desired noise metric result (with a grid-type receptor).
2. From the *Map View* ribbon group, click the *Contour* button.
3. The *Viewing Options* work area is displayed.
4. Accept the default minimum, maximum, and increment values under *Contour Settings* or enter new values.
5. Select the desired basemap under *Basemap Layer*.
6. Click *View*.
7. The contour layer is displayed on a map (Figure 22).

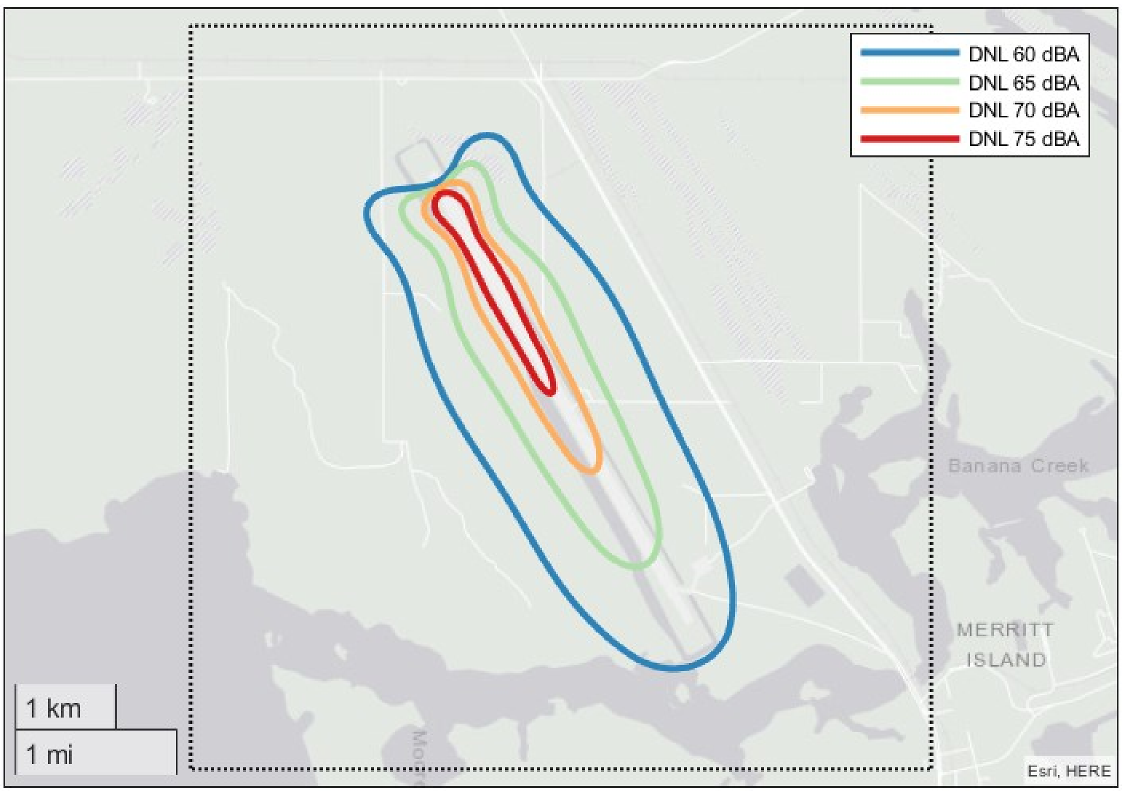


Figure 22. Metric results tab – view contours.

To improve the smoothness of the contours, increase the grid point density and/or the spatial resolution of the trajectory points.

View Receptor Layer

1. In the *Metric Results Table*, select a desired metric result.
2. From the *Map View* ribbon group, click the *Receptor* button.
3. The *Viewing Options* work area is displayed.
4. Select the desired basemap under *Basemap Layer*.
5. Click *View*.
6. The receptor layer is displayed on a map (Figure 23).

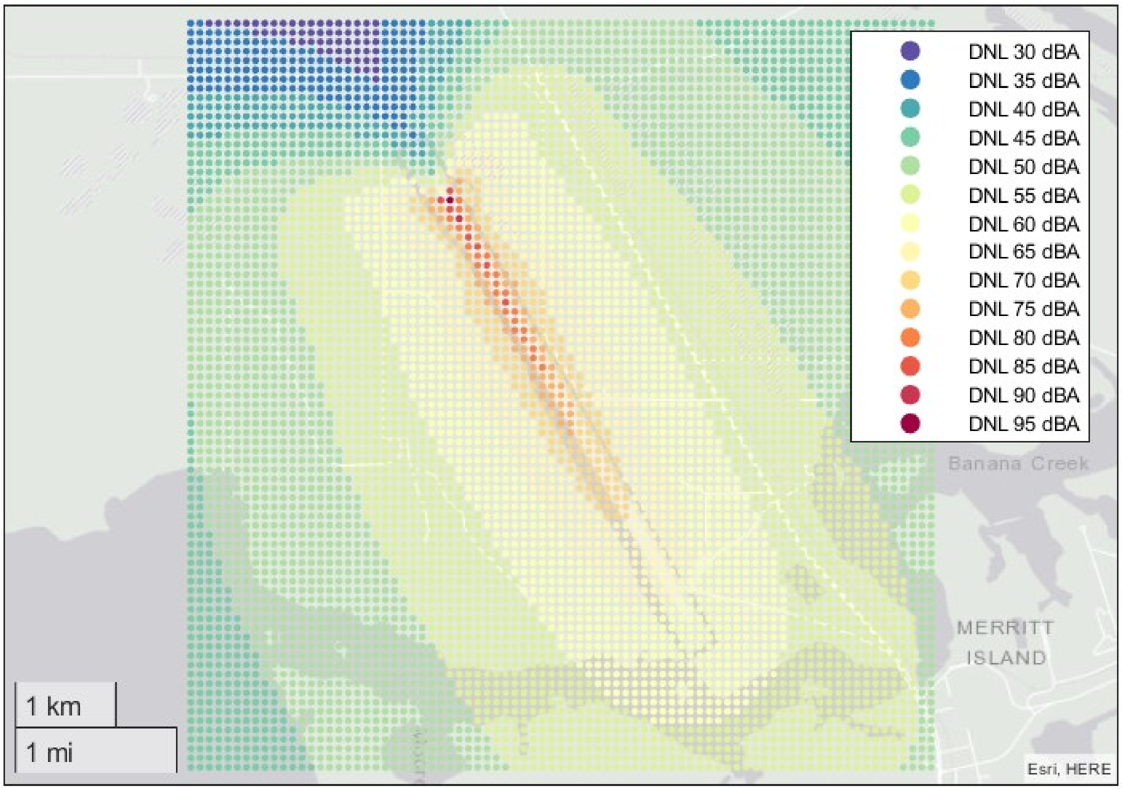


Figure 23. Metric results tab – view receptors.

3.8.7 View and Export Emissions Reports

Data can be visualized in a table by generating emissions reports.

View Emissions Reports

1. In the *Metric Results Table*, select a desired emissions metric result.
2. From the *Reports* ribbon group, click the *Emissions* to open the report (displayed in a separate window (Figure 24).
3. Select the *Operation Group*, *Group by*, and *Units* options from the drop-down menus.

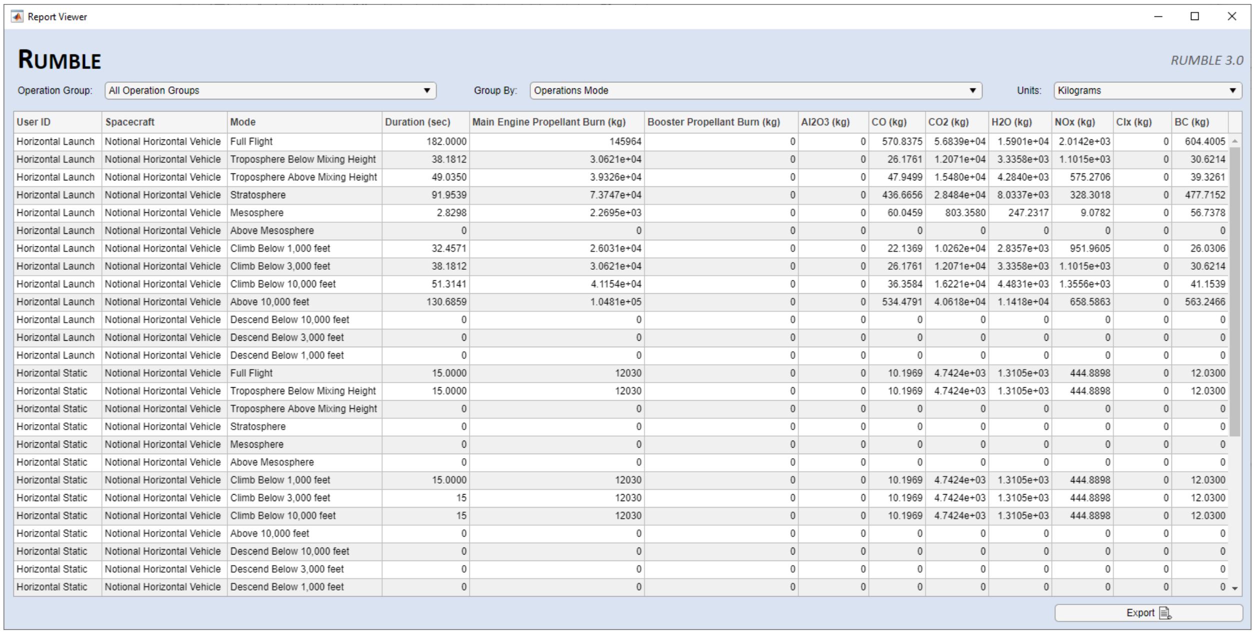
What are the *Group by* options in the emissions report?

- Operations Group Summary: Summarizes the results by operation group and mode; and displays results that reflect the operation count of each operations.

- Operations Summary: Summarizes results by events; displays results that assume an operation count of one.
- Operations Mode: Summarizes results by event and mode; displays results that assume an operation count of one.
- Operations Detail: Summarizes results by events at the segment level; displays results that assume an operation count of one.
- Annualized Operations Group Summary: Summarizes annualized results by operation group and mode; and displays results that reflect the operation count and the annualization weightings.
- Annualized Operations Summary: Summarizes annualized results by events; displays results that assume an operation count of one and the annualization weightings.
- Annualized Operations Mode: Summarizes annualized results by event and mode; displays results that assume an options count of one and the annualization weightings.
- Annualized Operations Detail: Summarizes annualized results by events at the segment level; displays results that assume an operation count of one and the annualization weightings.

? What are the *Mode* categories in the emissions report?

- Climb Below 1000: Summarizes emissions from takeoff flight segments below 1000 feet.
- Climb Below Mixing Height: Summarizes emissions from takeoff flight segments below the mixing height, which is typically approximately 3000 feet. (Includes summary of the Climb Below 1000).
- Climb Below 10000: Summarizes emissions from climb flight segments below 10000 feet. (Includes summary of the Climb Below Mixing Height).
- Above 10000: Summarizes emissions from flight segments above 10000 feet.
- Descend Below 10000, Descend Below Mixing Height, Descend Below 1000: The arrival modes which are reciprocal to the departure modes. For example, Descend Below 1000 summarizes emissions from landing flight segments below 1000 feet.
- Full Flight: Full flight emissions.
- Stationary Sources: Emissions from stationary sources.
- Troposphere Below Mixing Height: Summarizes emissions from flight segments below the mixing height (3000 feet).
- Troposphere Above Mixing Height: Summarizes emissions from flight segments between the mixing height (3000 feet) and 10 kilometers.
- Stratosphere: Summarizes emissions from flight segments between 10 and 50 kilometers.
- Mesosphere: Summarizes emissions from flight segments between 50 and 85 kilometers.
- Above Mesosphere: Summarizes emissions from flight segments above 85 kilometers.



User ID	Spacecraft	Mode	Duration (sec)	Main Engine Propellant Burn (kg)	Booster Propellant Burn (kg)	Al2O3 (kg)	CO (kg)	CO2 (kg)	H2O (kg)	NOx (kg)	Clx (kg)	BC (kg)
Horizontal Launch	Notional Horizontal Vehicle	Full Flight	182.0000	145964	0	0	570.8375	5.6839e+04	1.5901e+04	2.0142e+03	0	604.4005
Horizontal Launch	Notional Horizontal Vehicle	Troposphere Below Mixing Height	38.1812	3.0621e+04	0	0	26.1761	1.2071e+04	3.3358e+03	1.1015e+03	0	30.6214
Horizontal Launch	Notional Horizontal Vehicle	Troposphere Above Mixing Height	49.0350	3.9326e+04	0	0	47.9499	1.5480e+04	4.2840e+03	575.2706	0	39.3261
Horizontal Launch	Notional Horizontal Vehicle	Stratosphere	91.9539	7.3747e+04	0	0	436.6656	2.8484e+04	8.0337e+03	328.3018	0	477.7152
Horizontal Launch	Notional Horizontal Vehicle	Mesosphere	2.8298	2.2695e+03	0	0	60.0459	803.3580	247.2317	9.0782	0	56.7378
Horizontal Launch	Notional Horizontal Vehicle	Above Mesosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Launch	Notional Horizontal Vehicle	Climb Below 1,000 feet	32.4571	2.6031e+04	0	0	22.1369	1.0262e+04	2.8357e+03	951.9605	0	26.0306
Horizontal Launch	Notional Horizontal Vehicle	Climb Below 3,000 feet	38.1812	3.0621e+04	0	0	26.1761	1.2071e+04	3.3358e+03	1.1015e+03	0	30.6214
Horizontal Launch	Notional Horizontal Vehicle	Climb Below 10,000 feet	51.3141	4.1154e+04	0	0	36.3584	1.6221e+04	4.4831e+03	1.3556e+03	0	41.1539
Horizontal Launch	Notional Horizontal Vehicle	Above 10,000 feet	130.6859	1.0481e+05	0	0	534.4791	4.0618e+04	1.1418e+04	658.5863	0	563.2466
Horizontal Launch	Notional Horizontal Vehicle	Descend Below 10,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Launch	Notional Horizontal Vehicle	Descend Below 3,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Launch	Notional Horizontal Vehicle	Descend Below 1,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Full Flight	15.0000	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Troposphere Below Mixing Height	15.0000	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Troposphere Above Mixing Height	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Stratosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Mesosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Above Mesosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Climb Below 1,000 feet	15.0000	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Climb Below 3,000 feet	15	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Climb Below 10,000 feet	15	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Above 10,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Descend Below 10,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Descend Below 3,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Descend Below 1,000 feet	0	0	0	0	0	0	0	0	0	0

Figure 24. Metric results tab – view emissions tables.

Export Emissions Reports

1. In the *Reports Viewer* window, click the *Export* button in the lower right-hand corner.
1. Accept the default file name or enter a new file name and click *Save.*
2. A grid file is saved to the selected location.

The default export location is *C:\RUMBLE\DATA\[Study Folder]*. The default filename is based on the scenario name, receptor set name, and metric.

4 Metrics

This section provides descriptions of the noise and emissions metrics used in RUMBLE 3.0.

4.1 Noise Metrics

Noise metrics are used to describe the noise event and to identify any potential impacts to receptors within the environment. These metrics are based on the nature of the event and who or what is affected by the sound. Noise sources can be continuous (constant) or transient (short-duration) and contain a wide range of frequency (pitch) content. Determining the character and level of sound aids in predicting the way it is perceived. The unit of measure for defining a noise level or a noise exposure level is a decibel (dB). The number of decibels is calculated as $10\log_{10}$ of the ratio of mean-square pressure or noise exposure. The reference root-mean-square pressure is 20 µPa, the threshold of human hearing.

The noise-level metrics computed by RUMBLE are associated with two groups: A-weighted and unweighted. A-weighted noise metrics give less weighting to the low and high frequency portions of the spectrum, providing a good approximation of the response of the human ear, and correlates well with an average person's judgement of the relative loudness of a noise event. Unweighted noise metrics weight all frequencies equally. The noise metrics computed by RUMBLE are summarized in Table 2.

Table 2. Summary of RUMBLE noise metric abbreviations and definitions.

Abbreviation		MetricType	Weighting	Description/Full Name
Rumble	Standard			
LMAX	L_{Smx}	Maximum Level	Unweighted	Unweighted Maximum Sound Level
LAMAX	L_{ASmx}	Maximum Level	A-weighted	A-weighted Maximum Sound Level
LCMAX	L_{ASmx}	Maximum Level	C-weighted	C-weighted Maximum Sound Level
SEL	L_{AE}	Exposure	Unweighted	Unweighted Sound Exposure Level
ASEL	L_{AE}	Exposure	A-weighted	A-weighted Sound Exposure Level
CSEL	L_{AE}	Exposure	C-weighted	C-weighted Sound Exposure Level
DNL	L_{dn}	Exposure	A-weighted	Day Night Average Sound Level
CDNL	L_{dn}	Exposure	C-weighted	C-weighted Day Night Average Sound Level
CNEL	L_{den}	Exposure	A-weighted	Community Noise Equivalent Level

The metrics that can be computed in RUMBLE can be organized into two categories: exposure-based metrics and maximum noise level metrics. The exposure-based metrics (SEL, ASEL, CSEL, DNL, CDNL, and CNEL), represent the total sound exposure for a given time period. The maximum noise level metrics (LMAX, LAMAX, and LCMAX) represent the maximum noise level at a receptor location, taking into account a particular set of spacecraft operations.

The RUMBLE noise metrics are computed by applying metric-specific, time-averaging constants and/or day, evening, and night-time weighting factors to the base metrics. The time-averaging constant applies a metric-specific duration factor to the noise metric. For exposure metrics, the weighting factor applies time-period-specific weighting (or penalties) to events that occur during those periods. For the maximum-level metrics, the weighting factors equal one. The weighting and averaging factors used to compute the noise metrics in RUMBLE are summarized in Table 3. The metric-specific time-averaging constants and weighting factors are used to accumulate the noise metrics from all the spacecraft operations at all the receptors in a RUMBLE analysis.

Table 3. RUMBLE noise metric-specific weighting and averaging factors.

Metric Type	Noise Metric	Abbr.	Weighting Factor			Averaging Time	Averaging Constant
			Day	Evening	Night		
Maximum Level	Maximum Sound Level						
	Unweighted	LMAX	1	1	1	--	--
	A-weighted	LAMAX	1	1	1	--	--
	C-weighted	LCMAX	1	1	1	--	--
Exposure Based	Sound Exposure Level						
	Unweighted	SEL	1	1	1	--	1
	A-weighted	ASEL	1	1	1	--	1
	C-weighted	CSEL	1	1	1	--	1
	Day-Night Average Sound Level						
	A-weighted	DNL	1	1	10	24hr	86,400
	C-weighted	CDNL	1	1	10	24hr	86,400
	Community Noise Equivalent Level						
	A-weighted	CNEL	1	3	10	24hr	86,400

The noise metrics computed by RUMBLE are described in more detail in the following sections.

4.1.1 Maximum Sound Level

The highest time-weighted sound level measured during a single event is called the Maximum Sound Level. The Maximum Sound Level is abbreviated L_{max} for unweighted sound levels, $L_{A,max}$ for A-weighted sound levels, and $L_{C,max}$ for C-weighted sound levels. Although the maximum sound level provides some measure of the event, it does not fully describe the noise, because it does not account for how long the sound is heard. Note, for multiple operations, the maximum sound level is the maximum over all of the operations.

4.1.2 Sound Exposure Level

Sound Exposure Level combines both the intensity of a sound and its duration. It is abbreviated SEL for unweighted sound levels, ASEL for A-weighted sound levels, and CSEL for C-weighted sound levels. SEL represents the total sound energy of the event as if all the sound energy were contained in one second. Because commercial space events last more than a few seconds, the SEL value is larger than L_{max}. It does not directly represent the sound level heard at any given time, but rather, it provides a representation of the total sound energy over the entire event. SEL provides a better measure of commercial space launch vehicle noise exposure than L_{max} alone. Note, for multiple operations, the Sound Exposure Level is the cumulative energy over all of the operations.

4.1.3 Day-Night Average Sound Level and Community Noise Equivalent Level

Day-Night Average Sound Level (DNL) is a cumulative metric that accounts for all noise events in a 24-hour period. To account for people's increased sensitivity to noise at night, DNL applies a 10 dB penalty to events during the nighttime period, which is defined as 10:00 p.m. to 7:00 a.m. The notations DNL and L_{dn} are both used for Day-Night Average Sound Level and are equivalent. DNL does not represent a level heard at any given time but represent long term exposure.

CNEL is a variation of DNL specified by law in California (21 CCR § 5006). CNEL has the 10 dB nighttime penalty for events between 10:00 p.m. and 7:00 a.m. but also includes a 4.8 dB penalty for events during the evening period of 7:00 p.m. to 10:00 p.m. The evening penalty in CNEL accounts for the added intrusiveness of sounds during that period.

The abbreviations of DNL and CNEL typically refer to A-weighted levels. C-weighted DNL is abbreviated as CDNL.

4.2 Emissions

The emissions inventory enumerates the masses of the various pollutants emitted as a result of commercial space operations.

5 Instructional Resources

5.1 Sample Cases

Two sample study files are included in RUMBLE 3.0: the *Horizontal Launch Sample Case* and the *Vertical Launch Sample Case*. The study files can be accessed via the list of existing studies displayed within the open panel in the RUMBLE GUI's study tab (Figure 25). Associated sample case data files are described in Section 5.1.1 and the step-by-step workflow to create the sample case is described via the Create New Study Exercise in Section 5.2.

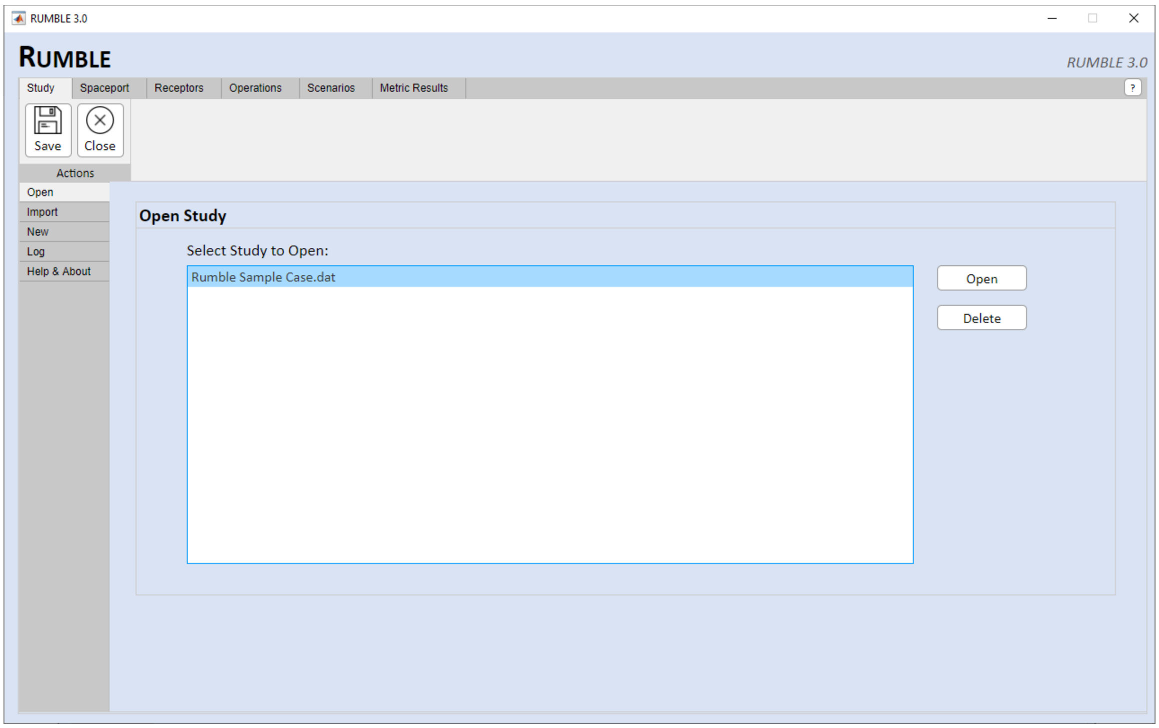


Figure 25. Sample cases displayed in the list of existing studies.

5.1.1 Sample RSIF

A set of sample partial RSIF is located in *C:\Program Files\BRRC\RUMBLE\Examples* directory. These files include:

- *PartialRSIF_SampleHorizontalVehicle.xml* – contains *Notional Horizontal Spacecraft* data for a sample horizontally launched spacecraft.
- *PartialRSIF_SampleHorizontalLaunch.xml* – contains *Notional Horizontal Launch Trajectory* data for a sample horizontal launch.
- *PartialRSIF_SampleVerticalLaunch.xml* – contains *Notional Vertical Launch Trajectory* data for a sample vertical launch.
- *PartialRSIF_USStandardAtmosphere*.xml – contains *U.S. Standard Atmosphere* data.

Although these sample cases are provided in their entirety, the step-by-step workflow to create the horizontal launch sample case is provided in Section 5.2. These examples should be used as an aid for understanding the RSIF format, and not as a data reference.

5.1.2 RUMBLE Sample Case

The RUMBLE Sample Case is an example noise and emissions study that is based on horizontal and vertical launch operations from the NASA Kennedy Space Center, but the operations do not represent real operations. The study content of this sample case is described in Table 4.

Table 4. RUMBLE sample case content.

Content	Name	Description
Spaceport	Kennedy Space Center	Origin: 28.524167°N, 80.657226°W, 0 ft MSL
Receptors	SLF Grid	Origin: 28.614894°N, 80.694373°W (X/Y) Distance: 4 nmi • Count: 81 • Spacing: 0.05 • SW Corner Offset: -2 nmi
	LC39A Grid	Origin: 28.608389°N, 80.604333°W (X/Y) Distance: 10 nmi • Count: 101 • Spacing: 0.1 • SW Corner Offset: -5 nmi
Operations	Horizontal Launch	Notional Horizontal Spacecraft† • Notional Horizontal Launch Trajectory† Annual Operations: 1,560 (30 per week) • 75% Daytime, 25% Nighttime
	Horizontal Static	Notional Horizontal Spacecraft† • Coordinates: 28.632758°N, 80.706064°W Nozzle Exit Height: 7 ft • Heading: 150° • Elevation: 0° • Duration: 15 sec Annual Operations: 12 (1 per month) • 100% Daytime, 0% Nighttime
	Vertical Launch	Saturn V • Notional Vertical Launch Trajectory† Annual Operations: 12 (1 per month) • 66.7% Daytime, 33.3% Nighttime
Groups	SLF Operations	Contains two operations: *Horizontal Launch* and *Horizontal Static*
	LC39A Operations	Contains one operation: *Vertical Launch*
Scenarios	KSC Operations	Contains two groups: *SLF Operations* and *LC39A Operations*
	SLF Operations	Contains one group: *SLF Operations*
	LC39A Operations	Contains one group: *LC39A Operations*
Metric Results	DNL	SLF Operations • SLF 81x81 Grid • U.S. Standard Atmosphere† LC39A Operations • LC39A Grid • U.S. Standard Atmosphere†
	ASEL	SLF Operations • SLF 81x81 Grid • U.S. Standard Atmosphere† LC39A Operations • LC39A Grid • U.S. Standard Atmosphere†
	LAMAX	SLF Operations • SLF 81x81 Grid • U.S. Standard Atmosphere† LC39A Operations • LC39A Grid • U.S. Standard Atmosphere†
	LMAX	SLF Operations • SLF 81x81 Grid • U.S. Standard Atmosphere† LC39A Operations • LC39A Grid • U.S. Standard Atmosphere†
	Emissions	KSC Operations

† See sample RSIF in Section 5.1.1

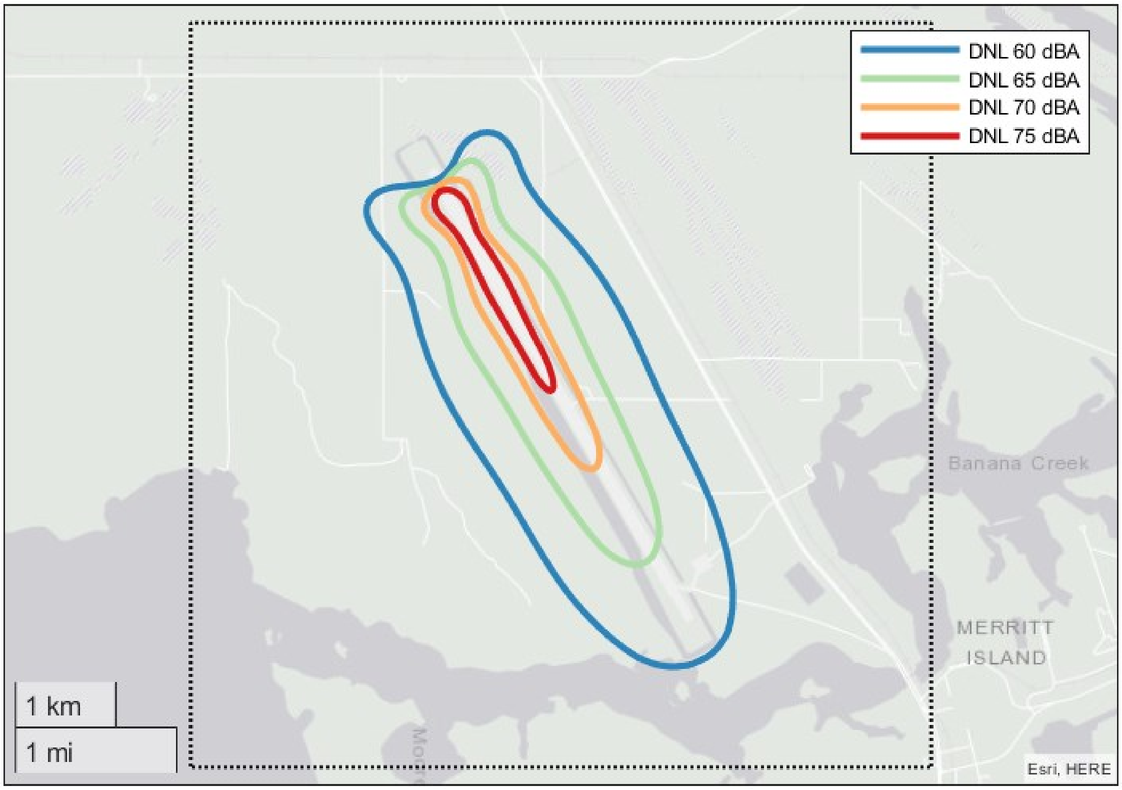
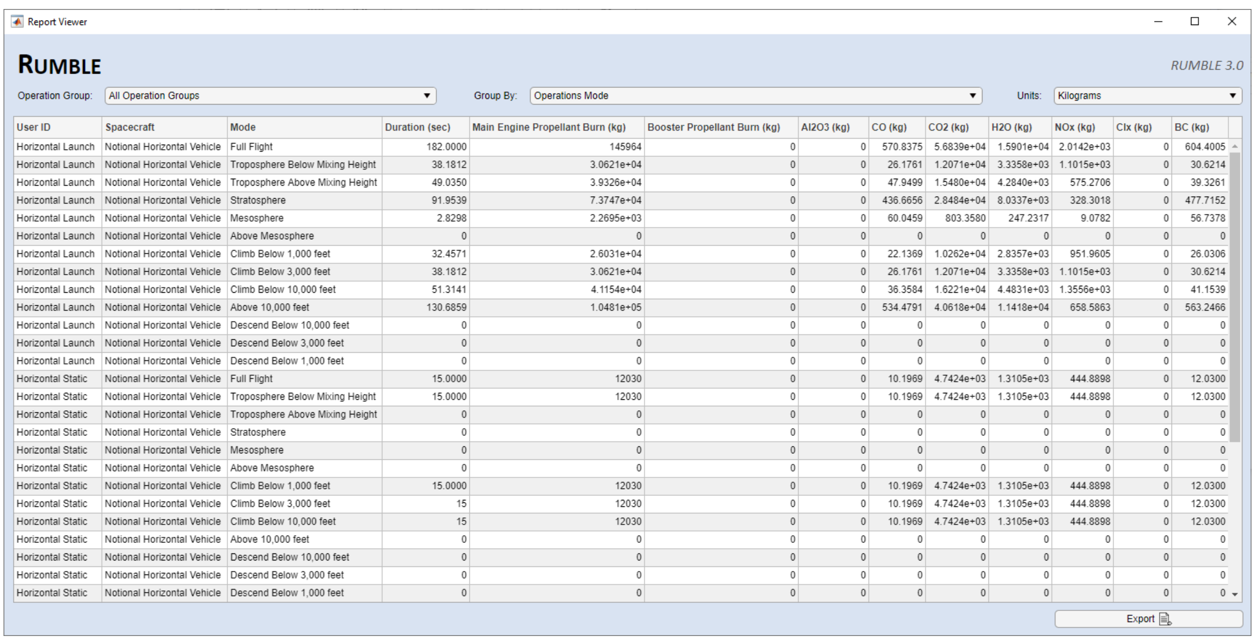


Figure 26. Example DNL metric result contours of the sample case.



User ID	Spacecraft	Mode	Duration (sec)	Main Engine Propellant Burn (kg)	Booster Propellant Burn (kg)	Al2O3 (kg)	CO (kg)	CO2 (kg)	H2O (kg)	NOx (kg)	Clx (kg)	BC (kg)
Horizontal Launch	Notional Horizontal Vehicle	Full Flight	182.0000	145964	0	0	570.8375	5.6839e+04	1.5901e+04	2.0142e+03	0	604.4005
Horizontal Launch	Notional Horizontal Vehicle	Troposphere Below Mixing Height	38.1812	3.0621e+04	0	0	26.1761	1.2071e+04	3.3358e+03	1.1015e+03	0	30.6214
Horizontal Launch	Notional Horizontal Vehicle	Troposphere Above Mixing Height	49.0350	3.9326e+04	0	0	47.9499	1.5480e+04	4.2840e+03	575.2706	0	39.3261
Horizontal Launch	Notional Horizontal Vehicle	Stratosphere	91.9539	7.3747e+04	0	0	436.6656	2.8484e+04	8.0337e+03	328.3018	0	477.7152
Horizontal Launch	Notional Horizontal Vehicle	Mesosphere	2.8298	2.2695e+03	0	0	60.0459	803.3580	247.2317	9.0782	0	56.7378
Horizontal Launch	Notional Horizontal Vehicle	Above Mesosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Launch	Notional Horizontal Vehicle	Climb Below 1,000 feet	32.4571	2.6031e+04	0	0	22.1369	1.0262e+04	2.8357e+03	951.9605	0	26.0306
Horizontal Launch	Notional Horizontal Vehicle	Climb Below 3,000 feet	38.1812	3.0621e+04	0	0	26.1761	1.2071e+04	3.3358e+03	1.1015e+03	0	30.6214
Horizontal Launch	Notional Horizontal Vehicle	Climb Below 10,000 feet	51.3141	4.1154e+04	0	0	36.3584	1.6221e+04	4.4831e+03	1.3556e+03	0	41.1539
Horizontal Launch	Notional Horizontal Vehicle	Above 10,000 feet	130.6859	1.0481e+05	0	0	534.4791	4.0618e+04	1.1418e+04	658.5863	0	563.2466
Horizontal Launch	Notional Horizontal Vehicle	Descend Below 10,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Launch	Notional Horizontal Vehicle	Descend Below 3,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Launch	Notional Horizontal Vehicle	Descend Below 1,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Full Flight	15.0000	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Troposphere Below Mixing Height	15.0000	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Troposphere Above Mixing Height	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Stratosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Mesosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Above Mesosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Climb Below 1,000 feet	15.0000	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Climb Below 3,000 feet	15	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Climb Below 10,000 feet	15	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Above 10,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Descend Below 10,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Descend Below 3,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Descend Below 1,000 feet	0	0	0	0	0	0	0	0	0	0

Figure 27. Example emissions metric result of the sample case.

5.2 Create New Study Exercise

The goal of the Create New Study Exercise is to learn how to create basic study elements in a new study, use those elements to define metric results, and explore the results. The study elements created in this exercise are intended to demonstrate the mechanics of creating a study structure in RUMBLE 3.0 and do not represent a real analysis.

Prerequisites

This exercise assumes no prior usage of RUMBLE and is designed to provide the user with basic knowledge of creating a new study and defining a metric result in RUMBLE 3.0.

What is a Metric Result?

In RUMBLE 3.0, a metric result represents the highest-level organization of data needed to answer questions of interest about the environmental consequences of commercial space activities. Each metric result consists of a metric, receptor set, atmospheric profile, operations, and scenario combination.

Major Steps

The major steps in this exercise are as follows:

- Create a new study,
- Add a spaceport,
- Create a grid receptor,
- Create spacecraft operations,
- Create a scenario,
- Define metric results,
- Run metric results,
- View noise metric results,
- Export noise metric results,
- View emissions metric results,
- Export emissions metric results.

5.2.1 Create a New Study

Follow the steps below to create a new study:

1. Open the RUMBLE application.
2. Click on the *Study* tab then click *New* to display the *Create New Study* work area.
3. In the *Study Name* field, enter “My KSC Study.”
4. In the *Study Description*, enter “My Kennedy Space Center Study.”
5. Click *Create*.

The *Spaceport* tab will open when the new study has been created, and the study name will appear in the top-right corner of the application.

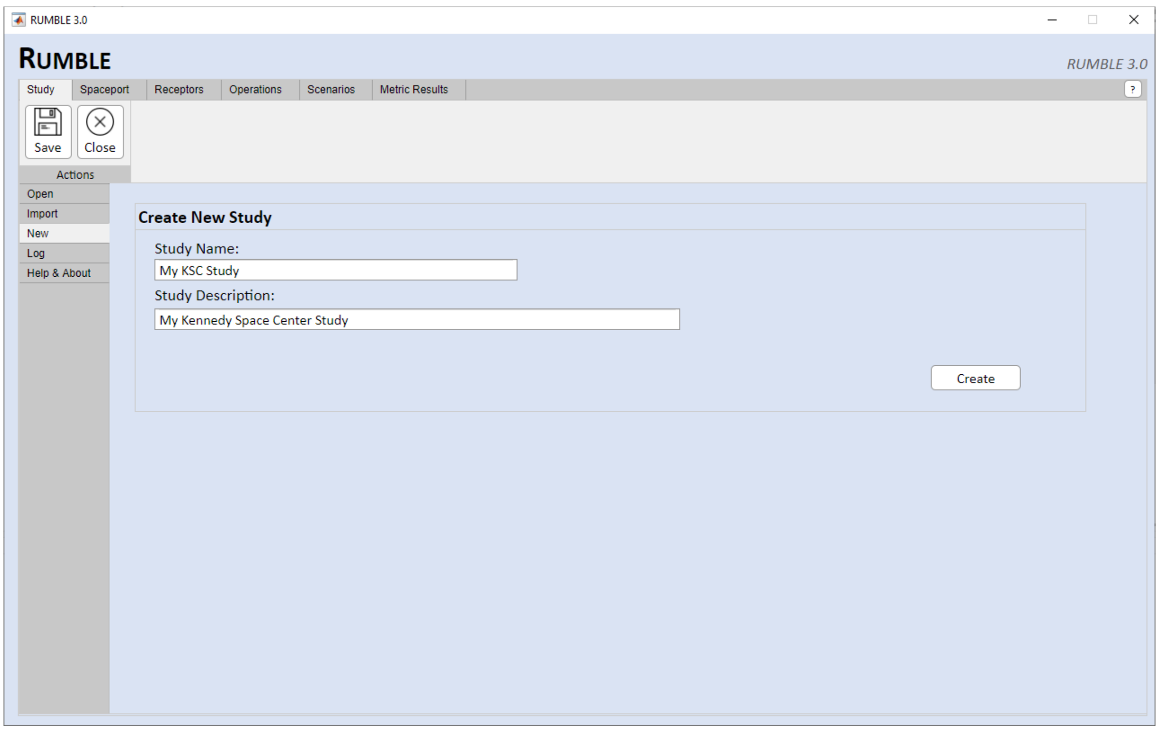


Figure 28. Create new study work area.

5.2.2 Add a Spaceport

Follow the steps below to add a spaceport to the study:

1. Click on the *Spaceport* tab.
2. In the *Actions* ribbon group, click *New* and enter the following data:
   a. In the *Name* field, enter "Kennedy Space Center".
   b. In the *Latitude* field, enter 28.524167.
   c. In the *Longitude* field, enter -80.657226.
   d. In the *Elevation* field, enter 0.
3. Click *Save* to save the new spaceport.

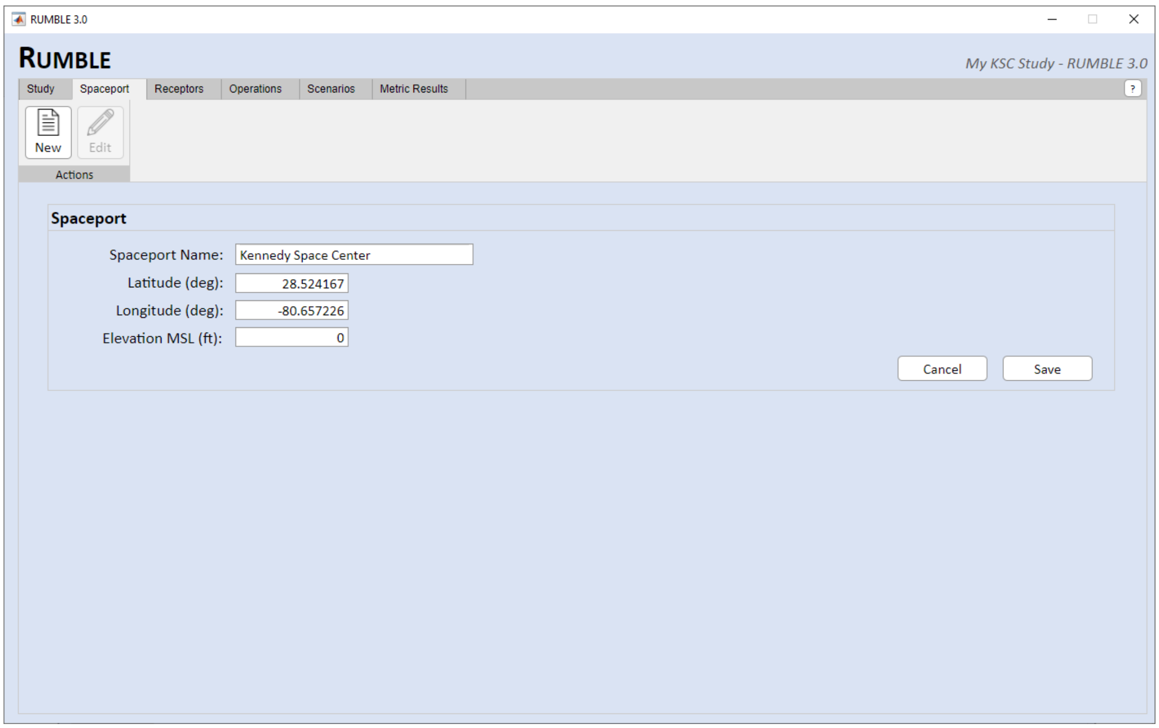


Figure 29. Spaceport work area.

5.2.3 Create a Grid Receptor

Receptors define the locations where noise is calculated.

Follow the steps below to define a grid receptor:

1. Click on the *Receptors* tab.
2. In the *Actions* ribbon group, click *New* and enter the following data:
   a. In the *Name* field, enter "SLF Grid."
   b. From the *Type* drop-down menu, select *Grid*.
   c. In the *X Count* field, enter 81.
   d. In the *Y Count* field, enter 81.
   e. In the *X Spacing* and *Y Spacing* fields, enter 0.05.
   f. In the *Grid Origin Info* section, enter the location of the south-west corner of the grid as an offset from the spaceport origin by specifying the *X offset* to be -2.0 and the *Y offset* to be -2.0.
   g. In the *Location Info* section, enter the grid origin by specifying the *Latitude* to be 28.614894 and the *Longitude* to be -80.694373.
3. Click *Save* to create the new receptor.

The receptor is created and listed in the *Table of Receptors*.

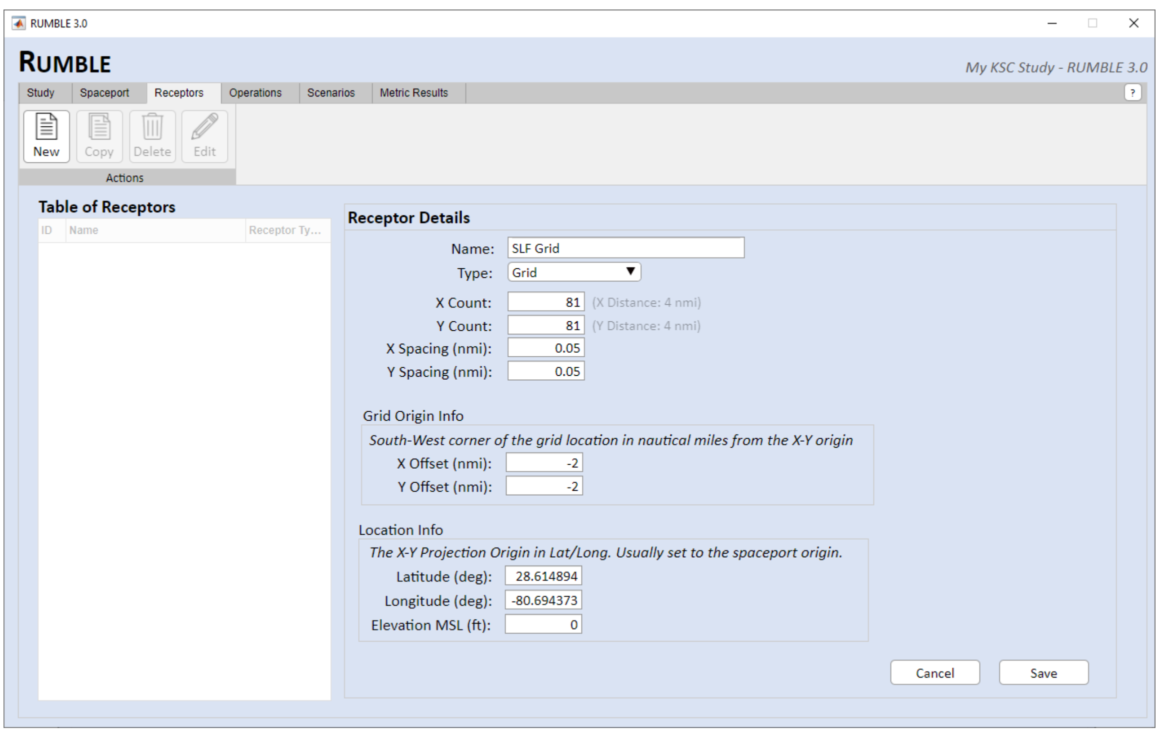


Figure 30. Create grid receptor work area.

5.2.4 Create Spacecraft Operations

Follow the steps below to create a launch operation and static fire operation:

Launch Operation

1. Click on the *Operations* tab.
2. In the *Actions* ribbon group, click *New* to open the *Operation Details* work area.
3. From the *Operation Type* drop-down menu, select *Launch*.
4. In the *User ID* field, enter "Horizontal Launch."
5. Choose Vehicle:
    a. From the *Choose Spacecraft* drop-down menu, select *Browse* to import the *PartialRSIF_SampleHorizontalVehicle.xml* file.
6. Define operations:
    a. Select the "two daily periods" radio button.
    b. In the *Daytime* field, enter 1170.
    c. In the *Nighttime* field, enter 390.
7. Choose trajectory:
    a. From the *Choose Trajectory* drop-down menu, select *Browse* to import the *PartialRSIF_SampleHorizontalLaunch.xml* file.
8. Click *Save* to create the new operation.

The launch operation is created and listed in the *Table of Operations*.

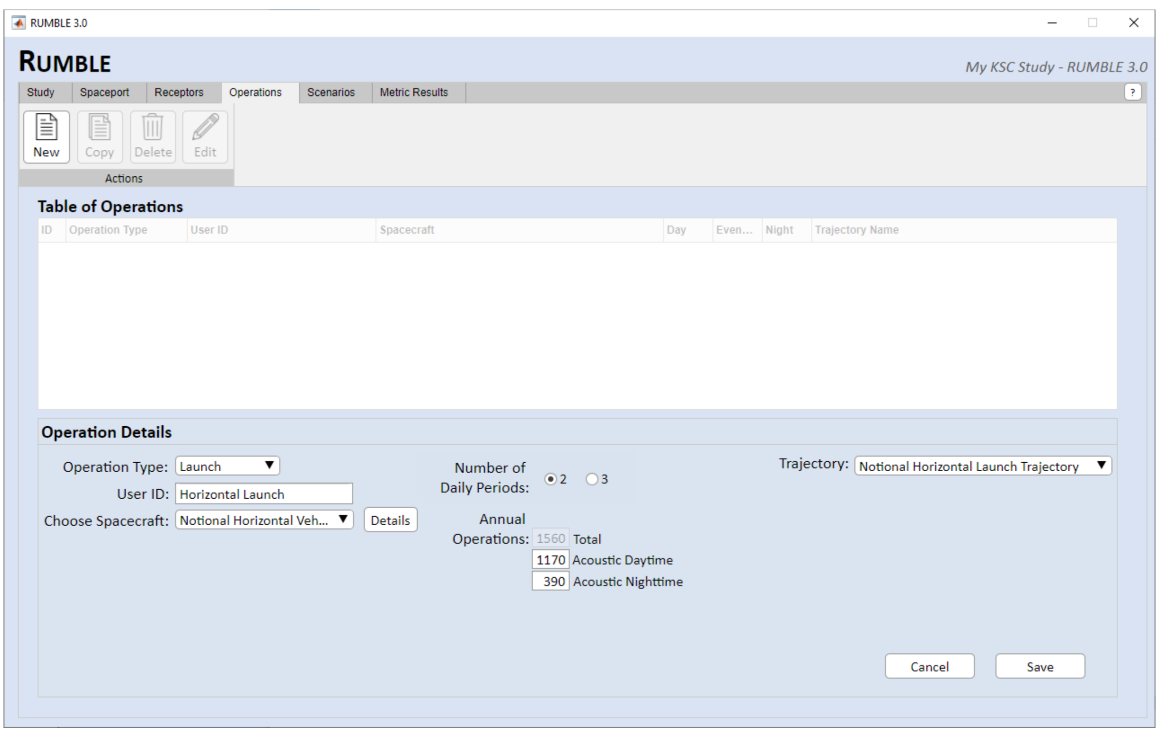


Figure 31. Launch operation details work area.

Static Fire Operation

1. In the *Actions* ribbon group, click *New* to open the *Operation Details* work area.
2. From the *Operation Type* drop-down menu, select *Static Fire*.
3. In the User ID field, enter "Horizontal Static."
4. Choose Vehicle:
    a. From the *Choose Spacecraft* drop-down menu, select the *Notional Horizontal Vehicle*.
5. Define operations:
    a. Check the *Two Daily Periods*.
    b. In the *Daytime* field, enter 12.
    c. In the *Nighttime* field, enter 0.
6. Enter static fire data:
    a. From the *Orientation* drop-down menu, select *Horizontal*.
    b. In the *Latitude* field, enter 28.632758.
    c. In the *Longitude* field, enter -80.706064.
    d. In the *Height* field, enter 7.
    e. In the *Heading* field, enter 150.
    f. In the *Elevation Angle* field, enter 0.
    g. In the *Duration* field, enter 15.
7. Click *Save* to create the new operation.

The static fire operation is created and listed in the *Table of Operations*.

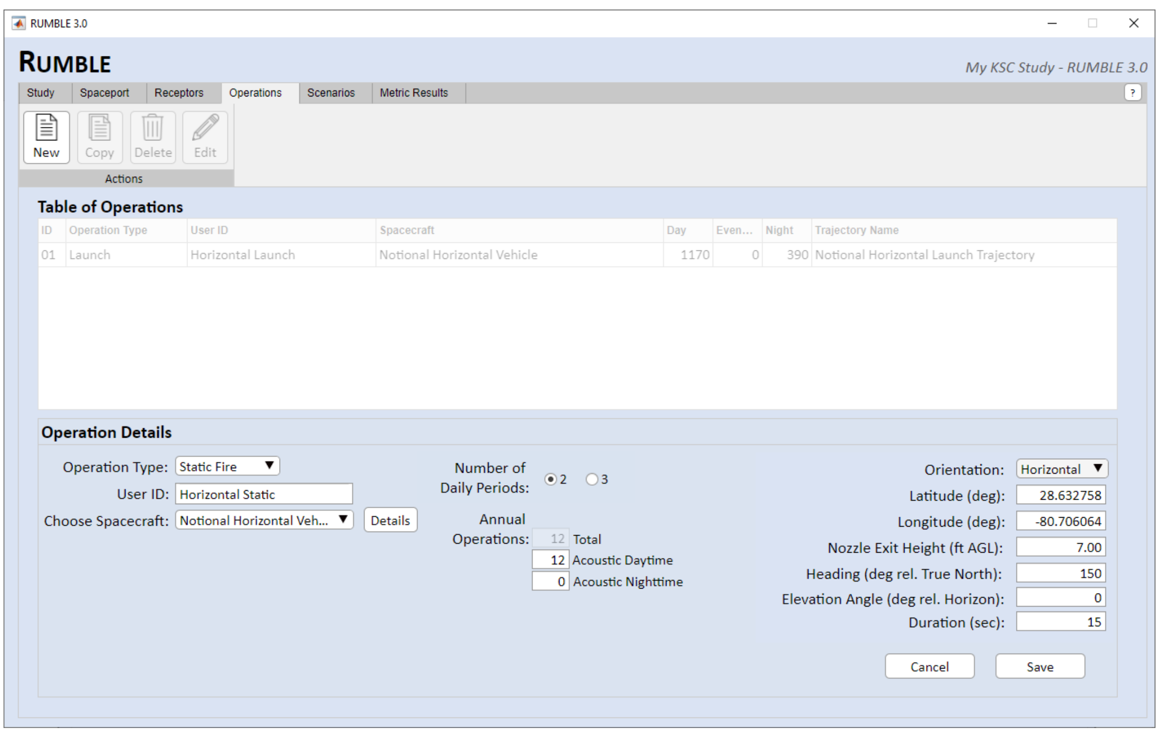


Figure 32. Static fire operation details work area.

5.2.5 Create a Scenario

In RUMBLE, a scenario is a weighted grouping of operations. Scenarios provide a convenient way to evaluate the noise with different weightings of individual operation groups. In this example, the operations will be weighted equally, and operation groups will be created for demonstration purposes.

Follow the steps below to build a scenario consisting of the operations created in previous steps:

1. Click on the *Scenarios* tab.
2. In the *Actions* ribbon group, click *New* to open the *Scenario Details* work area.
3. Assign Existing Operation Groups:
   a. In the *Name* field, enter "SLF Operations".
   b. Check the *Add new spacecraft operation group(s)*.
   c. Click *Next*.

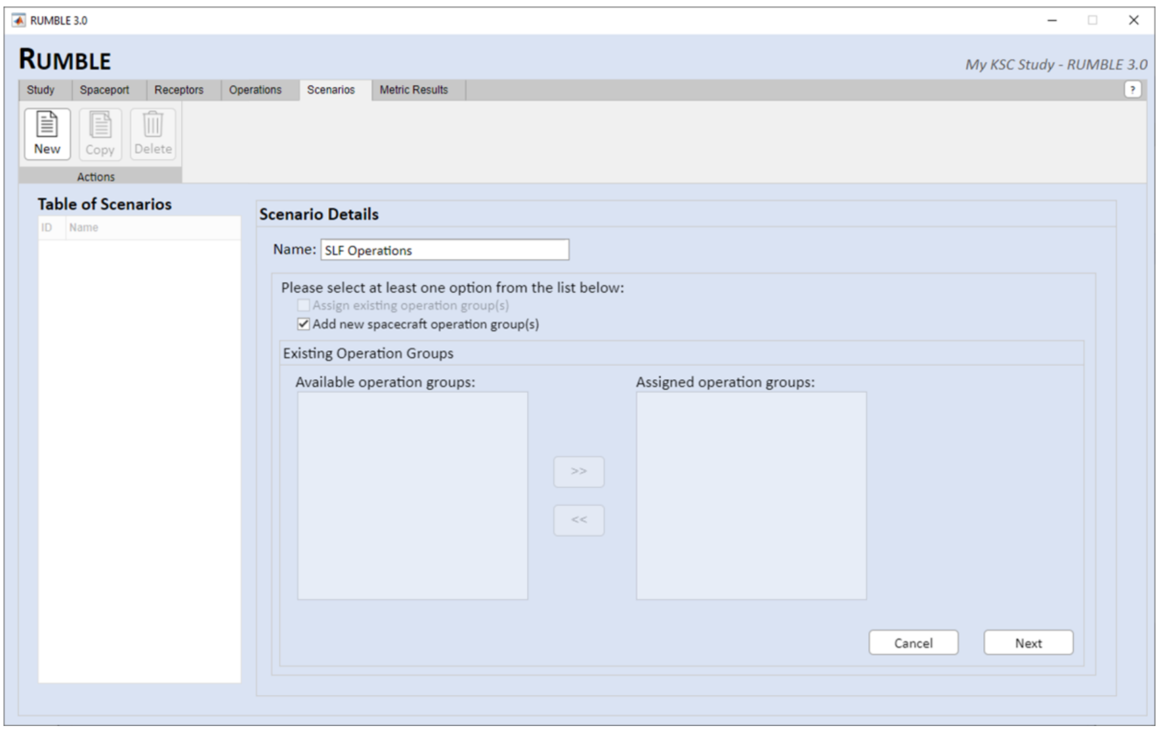


Figure 33. Scenario details work area – existing operation groups step.

4. Create Spacecraft Operation Groups:
   a. In the *Add New Group* field, enter "SLF Operations" and click *Add.*
   b. Select *SLF Operations* from the *Operation Groups* list and select *Horizontal Launch* and *Horizontal Static* from the *Available Operations* list, and click the forward arrows (>>) button to add the selected operation to the selected group.
   c. Click Next.

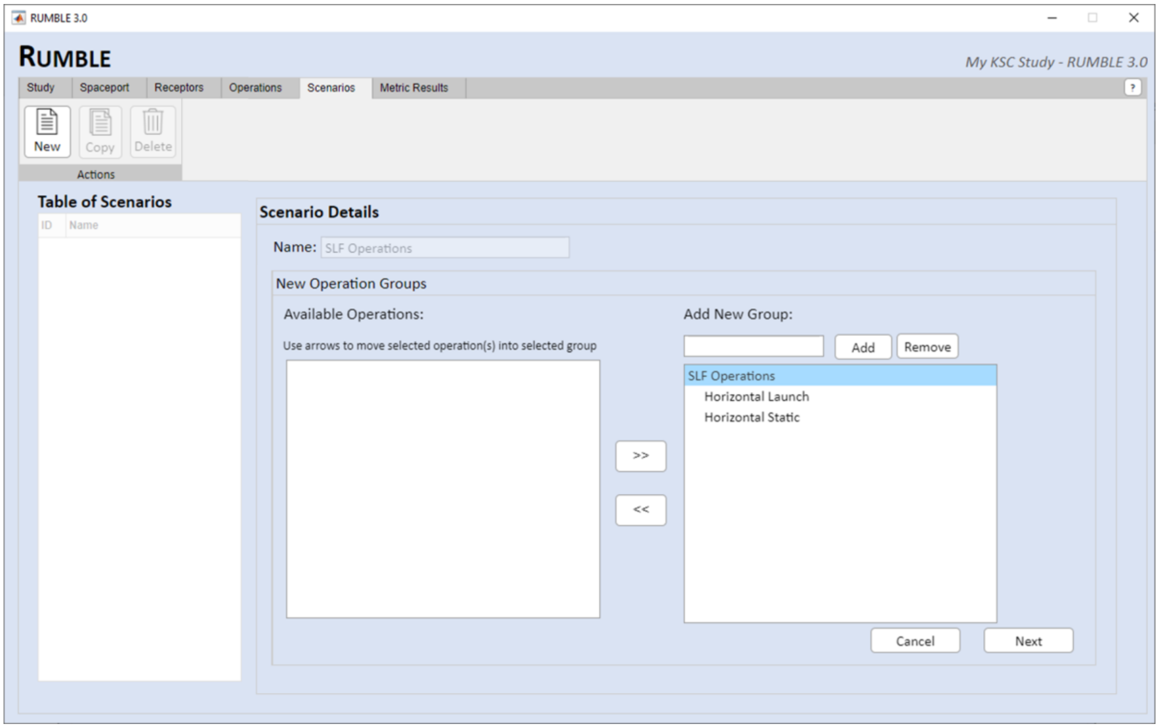


Figure 34. Scenario details work area – new operation groups step.

5. Assign weightings:
   a. Weightings can be applied to the scenario and/or its operation groups. For this example, leave the weighting as “1” for the scenario and both groups.
   b. Click Create.

The new scenario is listed in the *Table of Scenarios*.

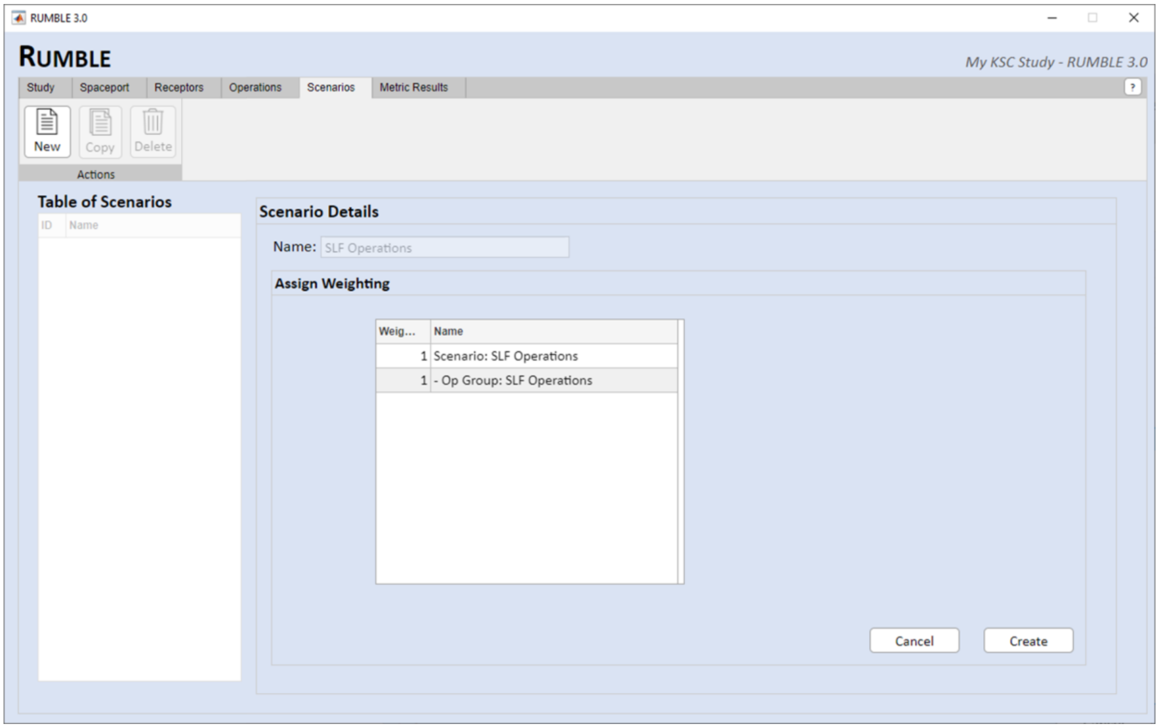


Figure 35. Scenario details work area – assign weighting step.

5.2.6 Define Noise Metric Result

Follow the instructions below to define noise (DNL) metric results:

1. Click on the *Metric Results* tab.
2. In the *Metric Results Actions* ribbon group, click *Define* and select the following options:
   a. From the Metric drop-down menu, select *DNL,*
   b. From the Scenario drop-down menu, select *SLF Operations,*
   c. From the Receptor(s) drop-down menu, select *SLF Grid,*
   d. From the Atmospheric Profile drop-down menu, select *U.S. Standard Atmosphere.*
3. Click Save.

The new metric result is listed in the *Table of Metric Results*.

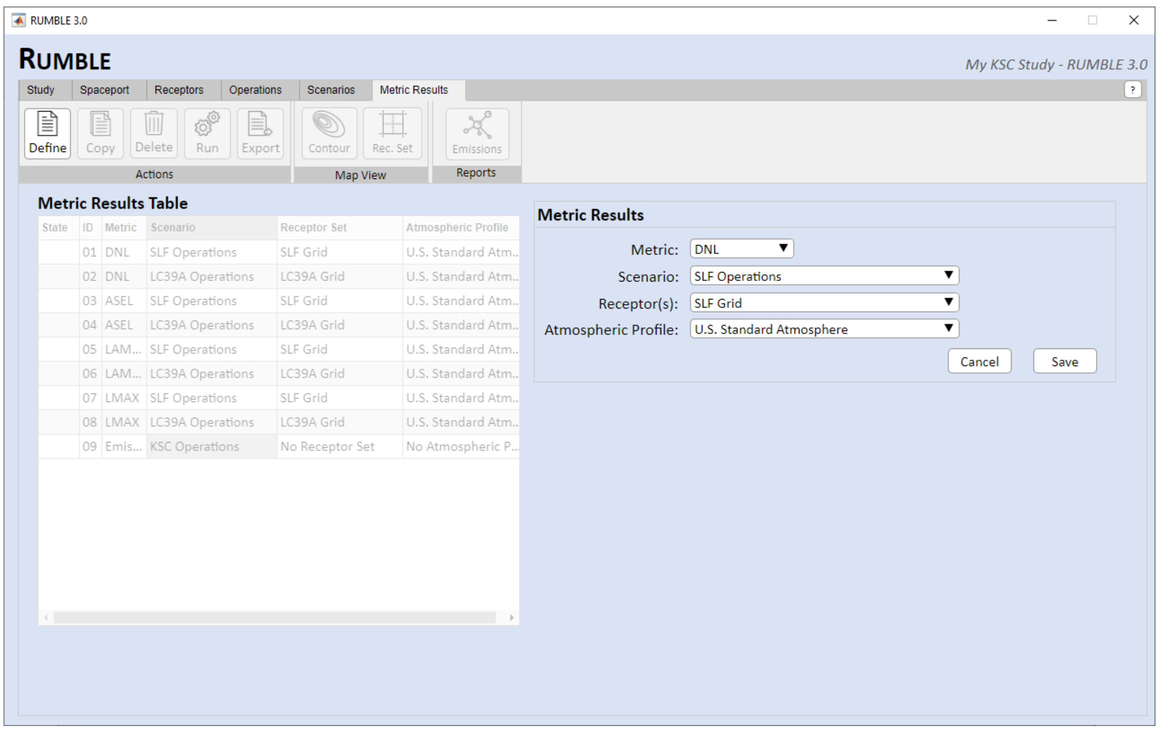


Figure 36. Metric result work area.

5.2.7 Define Emissions Metric Result

Follow the instructions below to define emissions metric results:

4. Click on the *Metric Results* tab.
5. In the *Metric Results Actions* ribbon group, click *Define* and select the following options:
   a. From the Metric drop-down menu, select *Emissions,*
   b. From the Scenario drop-down menu, select *SLF Operations,*
6. Click Save.

The new metric result is listed in the *Table of Metric Results*.

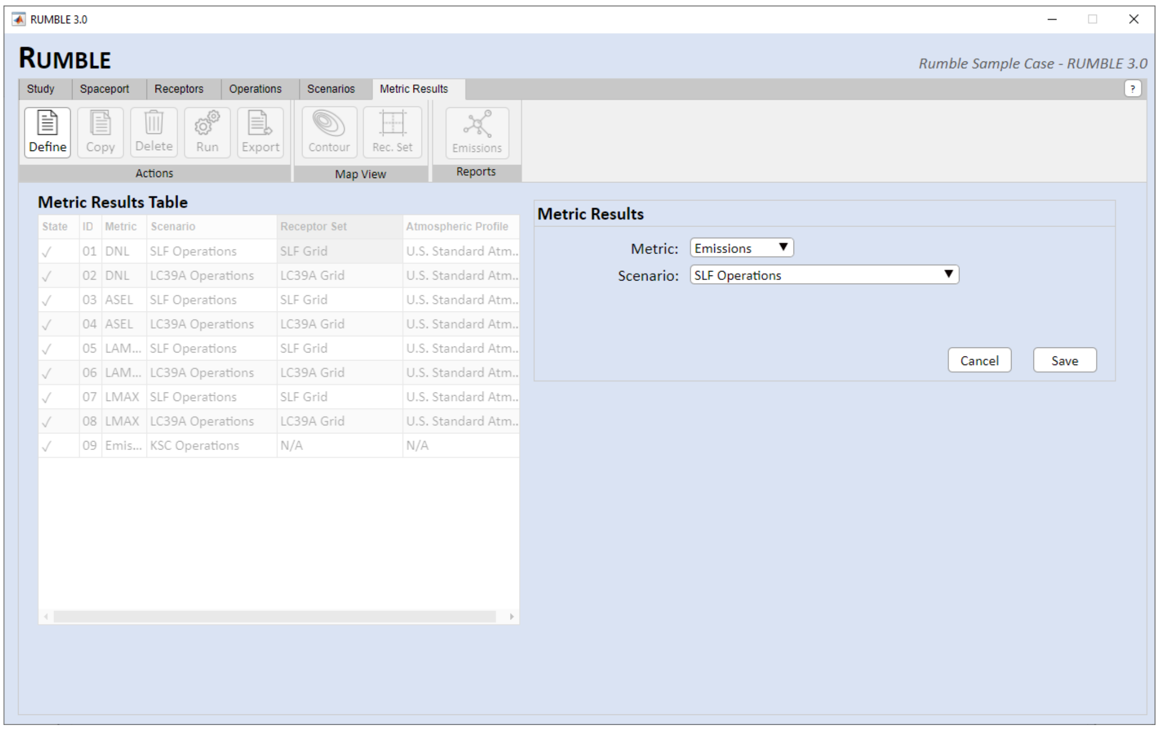


Figure 37. Metric result work area.

5.2.8 Run Metric Results

Follow the instructions below to run the metric result definitions:

1. In the table of metric results, select all metric results.
2. From the *Metric Result Actions* ribbon group, click *Run* to run the selected metric result definition.

When the metric results have finished running, the *State* column in the *Metric Results* pane will display a check icon.

5.2.9 View Noise Metric Results

Follow the instructions below to view the noise metric result definitions:

1. In the table of metric results, select the DNL metric result.
2. From the *Map View* ribbon group, click *Contour.*
3. In the *Viewing Options* work area, click *View* to accept the default *Contour Settings* and *Basemap Layer*.
4. The noise contour layer will then be displayed on the associated map.

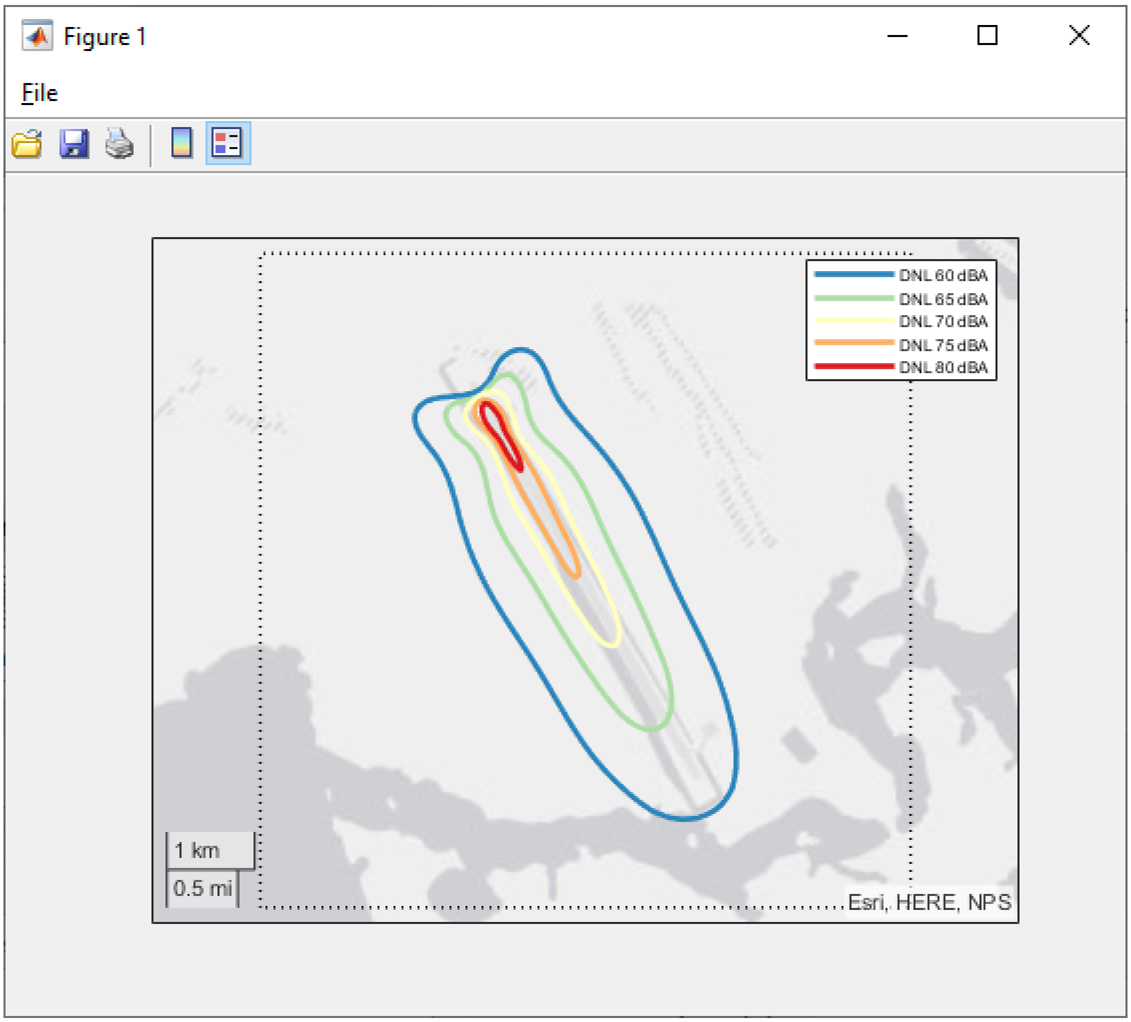


Figure 38. View contours figure window.

5.2.10 Export Noise Metric Results

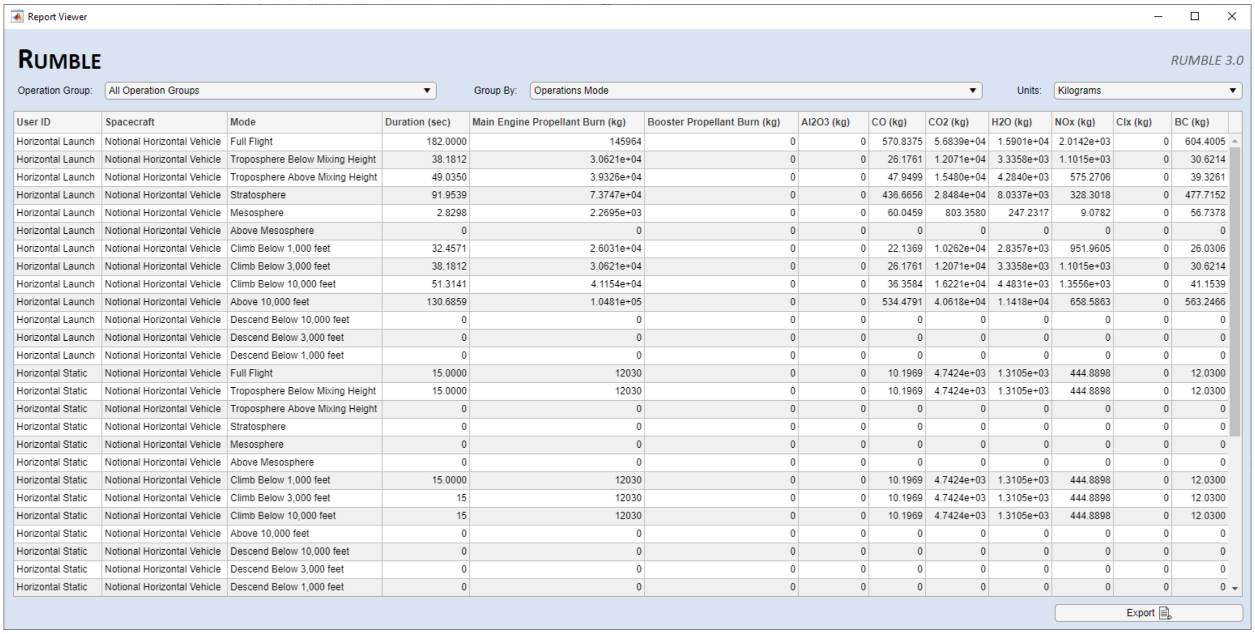
Follow the instructions below to export the metric result definitions:

1. In the table of metric results, select the DNL metric result.
2. From the *Actions* ribbon group, click *Export* and click *Save* to accept the default file path and name.

5.2.11 View Emissions Reports

Follow the instructions below to view the emissions metric result definitions:

1. In the table of metric results, select the Emissions metric result.
2. From the *Reports* ribbon group, click *Emissions.*
3. The emissions reports tables will then be displayed in a separate window.
4. Keep the default settings for *Operation Group* and *Group by*.
5. Change the Units as desired.



User ID	Spacecraft	Mode	Duration (sec)	Main Engine Propellant Burn (kg)	Booster Propellant Burn (kg)	Al2O3 (kg)	CO (kg)	CO2 (kg)	H2O (kg)	NOx (kg)	Clx (kg)	BC (kg)
Horizontal Launch	Notional Horizontal Vehicle	Full Flight	182.0000	145964	0	0	570.8375	5.6839e+04	1.5901e+04	2.0142e+03	0	604.4005
Horizontal Launch	Notional Horizontal Vehicle	Troposphere Below Mixing Height	38.1812	3.0621e+04	0	0	26.1761	1.2071e+04	3.3358e+03	1.1015e+03	0	30.6214
Horizontal Launch	Notional Horizontal Vehicle	Troposphere Above Mixing Height	49.0350	3.9326e+04	0	0	47.9499	1.5480e+04	4.2840e+03	575.2706	0	39.3261
Horizontal Launch	Notional Horizontal Vehicle	Stratosphere	91.9539	7.3747e+04	0	0	436.6656	2.8484e+04	8.0337e+03	328.3018	0	477.7152
Horizontal Launch	Notional Horizontal Vehicle	Mesosphere	2.8298	2.2695e+03	0	0	60.0459	803.3580	247.2317	9.0782	0	56.7378
Horizontal Launch	Notional Horizontal Vehicle	Above Mesosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Launch	Notional Horizontal Vehicle	Climb Below 1,000 feet	32.4571	2.6031e+04	0	0	22.1369	1.0262e+04	2.8357e+03	951.9605	0	26.0306
Horizontal Launch	Notional Horizontal Vehicle	Climb Below 3,000 feet	38.1812	3.0621e+04	0	0	26.1761	1.2071e+04	3.3358e+03	1.1015e+03	0	30.6214
Horizontal Launch	Notional Horizontal Vehicle	Climb Below 10,000 feet	51.3141	4.1154e+04	0	0	36.3584	1.6221e+04	4.4831e+03	1.3556e+03	0	41.1539
Horizontal Launch	Notional Horizontal Vehicle	Above 10,000 feet	130.6859	1.0481e+05	0	0	534.4791	4.0618e+04	1.1418e+04	658.5863	0	563.2466
Horizontal Launch	Notional Horizontal Vehicle	Descend Below 10,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Launch	Notional Horizontal Vehicle	Descend Below 3,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Launch	Notional Horizontal Vehicle	Descend Below 1,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Full Flight	15.0000	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Troposphere Below Mixing Height	15.0000	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Troposphere Above Mixing Height	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Stratosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Mesosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Above Mesosphere	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Climb Below 1,000 feet	15.0000	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Climb Below 3,000 feet	15	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Climb Below 10,000 feet	15	12030	0	0	10.1969	4.7424e+03	1.3105e+03	444.8898	0	12.0300
Horizontal Static	Notional Horizontal Vehicle	Above 10,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Descend Below 10,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Descend Below 3,000 feet	0	0	0	0	0	0	0	0	0	0
Horizontal Static	Notional Horizontal Vehicle	Descend Below 1,000 feet	0	0	0	0	0	0	0	0	0	0

Figure 39. View emissions reports tables figure window.

5.2.12 Export Emissions Reports

Follow the instructions below to export the metric result definitions:

1. In the *Reports Viewer* window, click *Export* and click *Save* to accept the default file path and name.

6 Input File Descriptions

The RUMBLE Standard Input File (RSIF) provides a standard file format to allow for the import of data into a RUMBLE study. A detailed description of the RSIF format for the RSIF schema is provided in Section 9. The following sections describe the partial RSIF files required to import user-defined fleet data (airframe, engine, and spacecraft), trajectory data, and atmospheric profile data.

At a minimum, a RSIF consists of the standard XML declaration, a content section (fleet, trajectorySet, or atmosphericProfile), and content metadata. In the examples below, the RSIF tags appear between < > or < /> braces. The sample content information (which can be set by the user) appears between these tags. The examples should be used as an aid for understanding the RSIF format, and not as a data reference.

6.1 Fleet Input Format

The fleet input data describes the user-defined spacecraft fleet participating in the study. Refer to Section 11.7.8 for a detailed description of the required and optional parameters associated with the fleet input data. Fleet data may be imported into an existing study from the *Operations* tab by selecting *Browse* from the *Choose Spacecraft* drop-down menu.

```
<RsifXml xmlns:RsifXml="RSIF.xsd" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" content="fleet" version="1">
 <fleet>
  <engine>
   <model>Notional Horizontal Vehicle Engine</model>
   <propellantDescription>LOX/Kerosene(RP-1)</propellantDescription>
   <massFlowRate>802</massFlowRate>
   <burnTime>183</burnTime>
   <thrust>13340</thrust>
   <nozzleExitDiameter>13</nozzleExitDiameter>
   <nozzleExitVelocity>9514</nozzleExitVelocity>
   <nozzleCount>1</nozzleCount>
   <emissionsIndices>
        <Al2O3>0</Al2O3>
          <CO>99</CO>
          <CO2>240</CO2>
          <H2O>100</H2O>
          <H>0</H>
          <H2>1</H2>
          <OH>0</OH>
          <HCl>0</HCl>
          <Cl>0</Cl>
          <Cl2>0</Cl2>
          <NOx>4</NOx>
          <BC>25</BC>
   </emissionsIndices >
  </engine>
  <spacecraft>
   <identifier>Notional Horizontal Vehicle</identifier>
   <stage>
    <number>1</number>
    <mainEngineModel>Notional Horizontal Vehicle Engine</mainEngineModel>
    <numMainEnginesPerCore>1</numMainEnginesPerCore>
    <numCores>1</numCores>
   </stage>
  </spacecraft>
 </fleet>
</RsifXml>
```

6.2 Trajectory Input Format

The trajectory input data describes the user-defined trajectories associated with the study. Refer to Section 11.5.27 for a detailed description of the required and optional parameters associated with the trajectory input data. Trajectory data may be imported into an existing study from the *Operations* tab by

selecting *Browse* from the *Trajectory* drop-down menu. Trajectory data input is the only external user-defined input required to operate RUMBLE.

```
<RsifXml xmlns:RsifXml="RSIF.xsd" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" content="trajectorySet">
 <trajectorySet>
  <trajectory>
   <name>Notional Suborbital Trajectory 1</name>
   <opType>Launch</opType>
   <trajectoryNodes>
    <trajectoryNode>
     <id>NaN</id>
     <description>NaN</description>
     <time>0</time>
     <latitude>28.632758</latitude>
     <longitude>-80.706064</longitude>
     <altitude>7</altitude>
     <speed>7</speed>
     <flightPathHeading>150</flightPathHeading>
     <flightPathAngle>0</flightPathAngle>
     <vehicleHeading>150</vehicleHeading>
     <vehiclePitch>0</vehiclePitch>
    </trajectoryNode>
    <trajectoryNode>
     <id>NaN</id>
     <description>NaN</description>
     <time>1</time>
     <latitude>28.632751</latitude>
     <longitude>-80.706059</longitude>
     <altitude>7</altitude>
     <speed>7</speed>
     <flightPathHeading>150</flightPathHeading>
     <flightPathAngle>0.1</flightPathAngle>
     <vehicleHeading>150 </vehicleHeading>
     <vehiclePitch>0.1</vehiclePitch>
    </trajectoryNode>
   </trajectoryNodes>
  </trajectory>
 </trajectorySet>
</RsifXml>
```

6.3 Atmospheric Profile Input Format

The atmospheric profile input data describes the user-defined atmospheric profile(s) associated with the study. Refer to Section 11.5.4 for a detailed description of the required and optional parameters associated with the atmospheric profile input data. Atmospheric profile data may be imported into an existing study from the *Metric Results* tab by selecting *Browse* from the *Atmospheric Profile* drop-down menu.

```
<RsifXml xmlns:RsifXml="RSIF.xsd" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" content="atmosphericProfile">
 <atmosphericProfile>
  <name>U.S. Standard Atmosphere</name>
  <atmosphericProfileNodes>
   <atmosphericProfileNode>
    <altitude>0</altitude>
    <temperature>58.91</temperature>
    <pressure>29.92</pressure>
    <humidity>76.03</humidity>
    <soundSpeed>1116.47</soundSpeed>
   </atmosphericProfileNode>
   <atmosphericProfileNode>
    <altitude>1640</altitude>
    <temperature>53.15</temperature>
    <pressure>28.19</pressure>
    <humidity>76.03</humidity>
    <soundSpeed>1110.24</soundSpeed>
   </atmosphericProfileNode>
  </atmosphericProfileNodes>
 </atmosphericProfile>
</RsifXml>
```

7 Output File Descriptions

7.1 RUMBLE Noise Grid File

Noise metric results are exported from RUMBLE in the form of Noise Model Grid Format (NMGF) files. NMGF is a standard data file format that contains predicted noise levels at a set of locations surrounding an installation. A number of standard noise models use NMGF to export results, including the FAA's AEDT and the U.S. Air Force's Noisemap.

Beginning of NMGF	`{TITL Grid Vers 2 3}`
Metric and units	`{MTRC "DNL" "dBA"}`
Data points	`{DPAL 6561`
	`(-80.732235,28.581468) 44.942453`
SW corner	`(-80.731288,28.581468) 45.114848`
	⋮
	`(-80.657434,28.648310) 43.847322`
NE corner	`(-80.656487,28.648309) 43.729018`
	`}`
Data points	`{ENDF}`

Figure 40. Sample RUMBLE NMGF file.

7.2 RUMBLE Emissions Report File

Emissions metric results are exported from RUMBLE in the form of comma-separated values (csv) delimited text files.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	User ID	Spacecraft	Mode	Duration (sec)	Main Engine Propellant Burn (kg)	Booster Propellant Burn (kg)	Al2O3 (kg)	CO (kg)	CO2 (kg)	H2O (kg)	NOx (kg)	Clx (kg)	BC (kg)
2	Horizontal Launch	Notional Horizontal Vehicle	Full Flight	182	145964	0	0	571	56839	15901	2014	0	604
3	Horizontal Launch	Notional Horizontal Vehicle	Troposphere Below Mixing Height	38	30621	0	0	26	12071	3336	1102	0	31
4	Horizontal Launch	Notional Horizontal Vehicle	Troposphere Above Mixing Height	49	39326	0	0	48	15480	4284	575	0	39
5	Horizontal Launch	Notional Horizontal Vehicle	Stratosphere	92	73747	0	0	437	28484	8034	328	0	478
6	Horizontal Launch	Notional Horizontal Vehicle	Mesosphere	3	2270	0	0	60	803	247	9	0	57
7	Horizontal Launch	Notional Horizontal Vehicle	Above Mesosphere	0	0	0	0	0	0	0	0	0	0
8	Horizontal Launch	Notional Horizontal Vehicle	Climb Below 1,000 feet	32	26031	0	0	22	10262	2836	952	0	26
9	Horizontal Launch	Notional Horizontal Vehicle	Climb Below 3,000 feet	38	30621	0	0	26	12071	3336	1102	0	31
10	Horizontal Launch	Notional Horizontal Vehicle	Climb Below 10,000 feet	51	41154	0	0	36	16221	4483	1356	0	41
11	Horizontal Launch	Notional Horizontal Vehicle	Above 10,000 feet	131	104810	0	0	534	40618	11418	659	0	563
12	Horizontal Launch	Notional Horizontal Vehicle	Descend Below 10,000 feet	0	0	0	0	0	0	0	0	0	0
13	Horizontal Launch	Notional Horizontal Vehicle	Descend Below 3,000 feet	0	0	0	0	0	0	0	0	0	0
14	Horizontal Launch	Notional Horizontal Vehicle	Descend Below 1,000 feet	0	0	0	0	0	0	0	0	0	0

Figure 41. Sample RUMBLE CSV file.

7.3 RUMBLE Log File

System status and information is written to the *RUMBLE.log* file in the *C:\RUMBLE\Logs* folder. Logged messages are timestamped and contain information, warnings, and errors. In the event of a fatal error that causes the application to stall or shut down, the *RUMBLE.log* file may be consulted to understand the case.

Beginning of log	`[APPLICATION START]`
Messages	`%-- 01/01/2020 01:00 PM --%`
	`2020-01-25 21:27:03,966 INFORMATION RUMBLE.RunMetricResults - initialized`
	`2020-01-25 21:27:04,333 INFORMATION RUMBLE.InputPreProcessor - initialized`
	`2020-01-25 21:27:04,357 INFORMATION RUMBLE.InputPreProcessor - completed, 0.3 seconds`
	`2020-01-25 21:27:05,833 INFORMATION RUMBLE.RunMetricResults - completed, 1.8 seconds`
	`%-- 01/01/2020 01:30 PM --%`
End of log	`[APPLICATION STOP]`

Figure 42. Sample RUMBLE log file.

8 Error and Warning Messages

RUMBLE provides error messages and warnings to inform users of the use of non-standard input or actions which may affect the integrity of the program. RUMBLE provides warning messages to help ensure input data values and formats conform to the model's requirements. If an invalid input is performed in the GUI, then the entry is outlined in red and a context sensitive message is displayed to aid the user in submitting a valid entry. The context sensitive messages may indicate the input data is outside the range of expected values (Figure 43) or that the format of the input data is incorrect (Figure 44).

Additionally, RUMBLE will display an error message if a user attempts to overwrite default fleet database values. For example, as shown in Figure 45, if the user attempts to input a user-defined spacecraft name which matches an existing spacecraft name defined in the RUMBLE fleet database, then an error will display. To resolve this error, the user should update the spacecraft name (identifier) to one that is unique to those used in the RUMBLE fleet database.

Fatal situations are accompanied by a chime sound and require cessation of program execution. Run-time error messages are also created and saved in the output log file (see Section 7.2) if fatal situations are encountered that require cessation of program execution. These error messages document the specific subroutine(s) that generated the error.

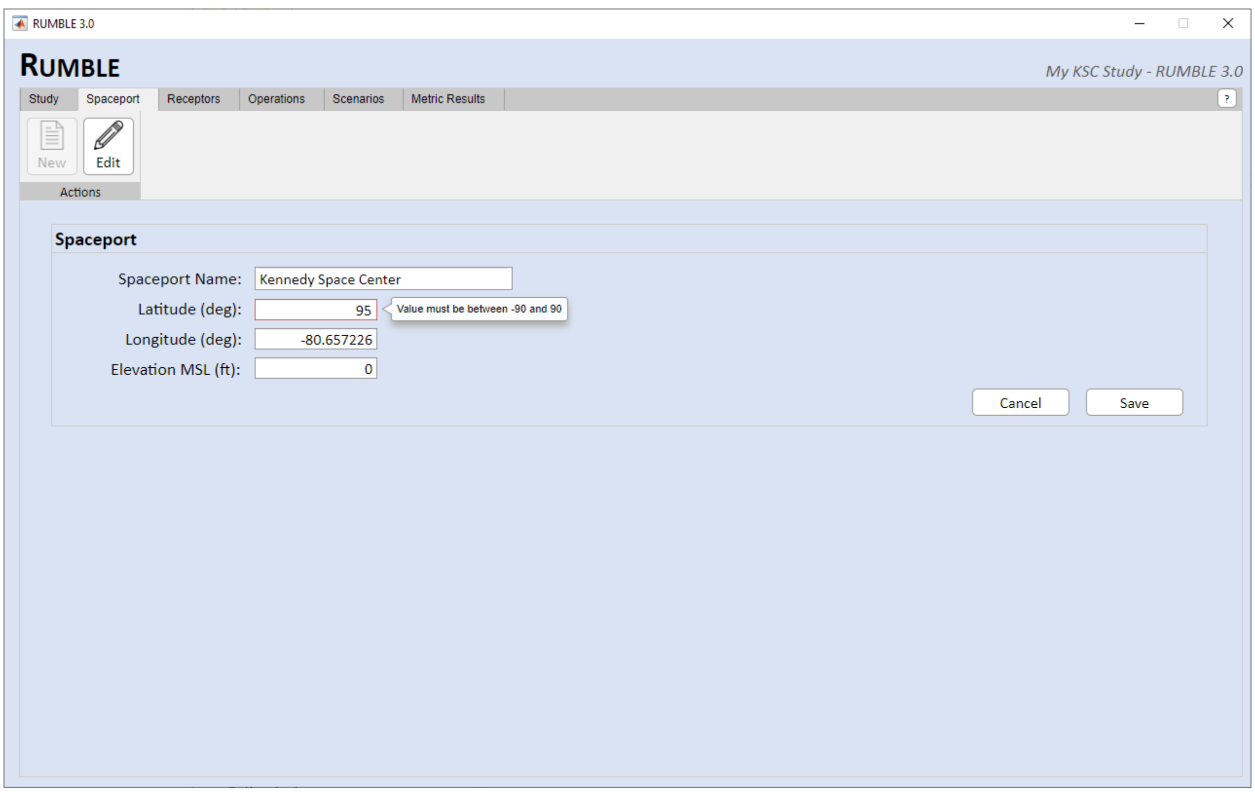


Figure 43. Sample warning message – invalid value.

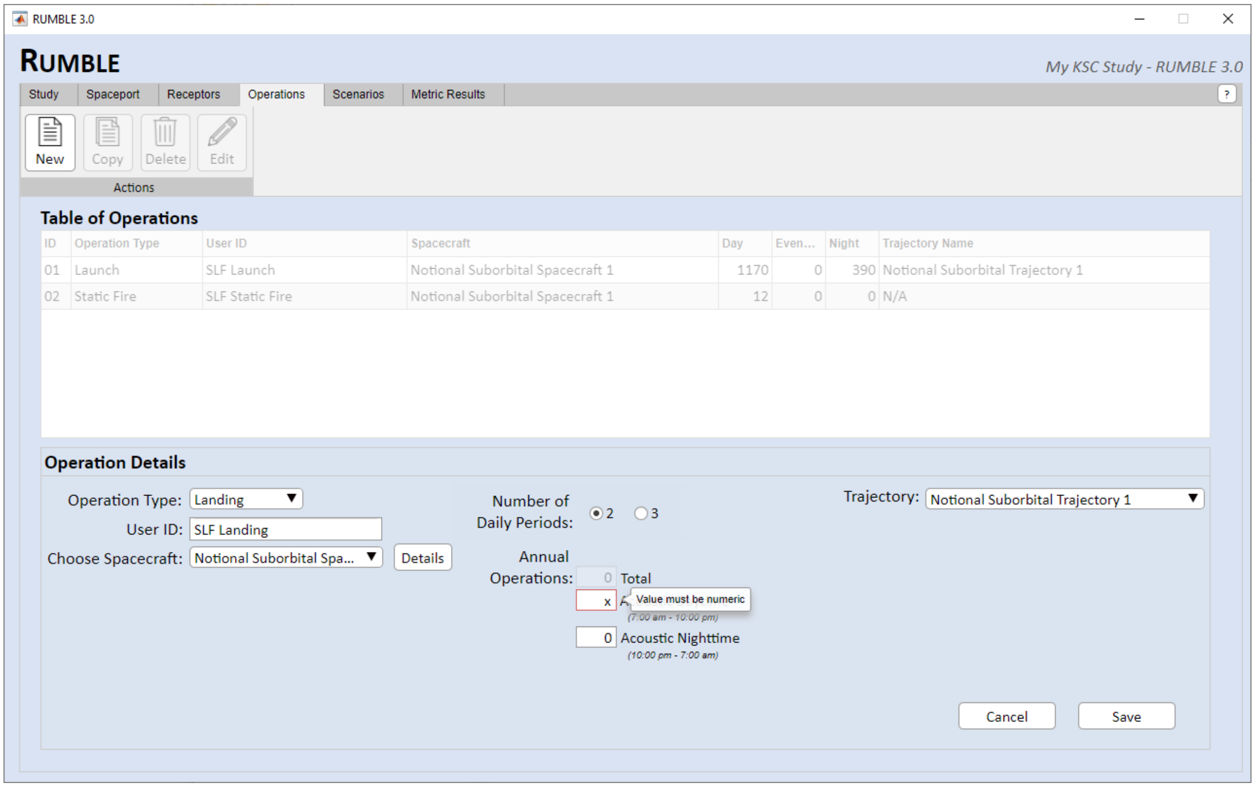


Figure 44. Sample warning message – invalid format.

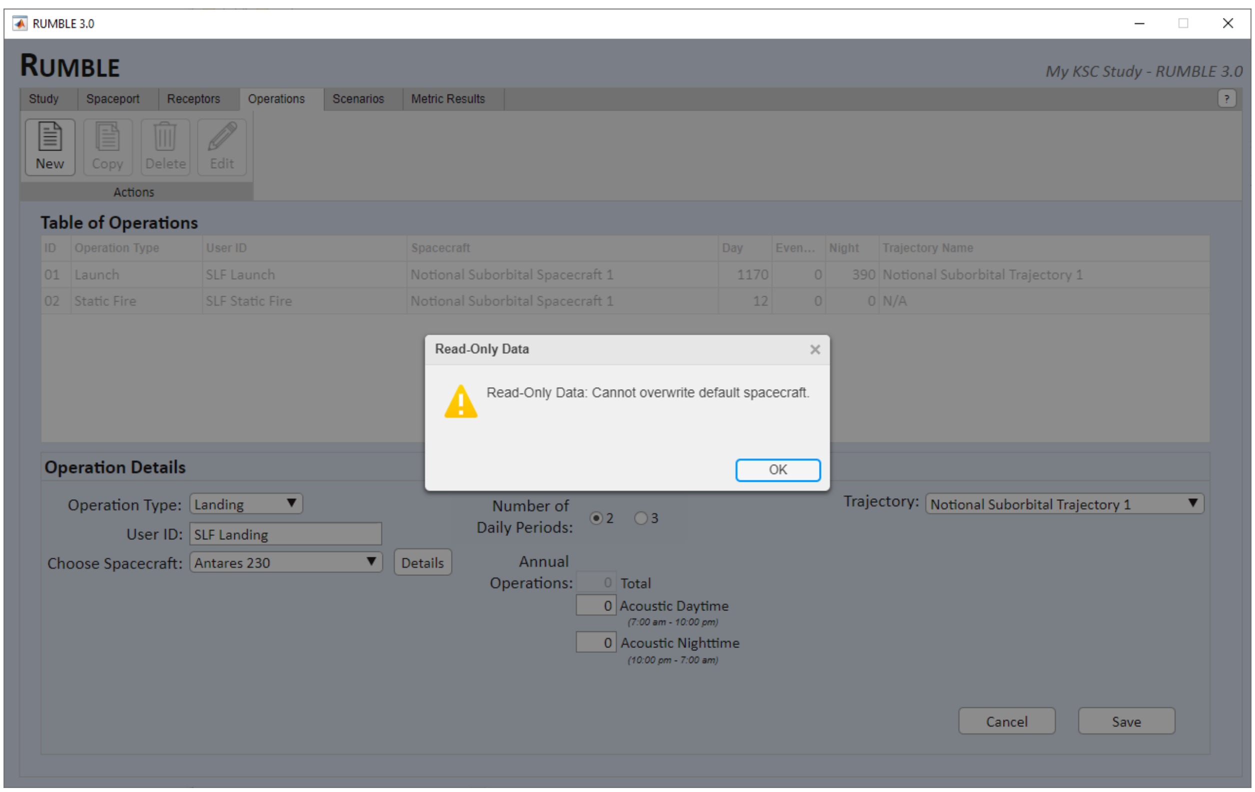


Figure 45. Sample error message – cannot overwrite default spacecraft.

9 Noise Modeling Methodology Technical Reference

The RUMBLE noise modeling methodology was developed to produce accurate acoustic estimates relevant to environmental analysis of commercial space operations. The model is applicable to inflight and static operations of vertical and horizontal launch vehicles. Launch vehicle propulsion systems, such as liquid-propellant rocket engines and solid rocket motors, generate high amplitude, broadband noise. The majority of the noise is created by the rocket plume, or jet exhaust, interacting with the atmosphere, and combustion noise of the propellants. This results in noise that radiates in all directions. However, it is highly directive, meaning that a significant portion of the source's acoustic power is concentrated in specific directions.

The emitted sound is modified in several ways as it propagates outward. These effects include the source directivity, forward flight effects, Doppler effect, geometric spreading, atmospheric absorption, and ground interference to a receiver location. The received one-third octave (OTO) band sound levels from a source can be expressed as the sum of source components and propagation effects:

$$SPL = \underbrace{L_w + A_{ffe} + A_{dir} + A_{dop}}_{\text{Source}} + \underbrace{A_{spread} + A_{atm} + A_{gnd}}_{\text{Propagation}}$$

where:

$L_w =$ Source sound power level;

$A_{ffe} =$ Forward flight effects;

$A_{dir} =$ Source directivity, azimuthal symmetry is assumed;

$A_{dop} =$ Doppler effect;

$A_{spread} =$ Geometrical spherical spreading loss (point source);

$A_{atm} =$ Atmospheric absorption; and

$A_{gnd} =$ Ground interference (interaction between direct and reflected acoustic rays).

Rocket propulsion noise is calculated based on a specific source (vehicle trajectory point) to a receiver geometry (grid point). The position of the rocket and the receiver grid are provided in latitude and longitude, defined relative to a reference system (WGS84). Implementation of this geo-referenced coordinate system ensures that large-distance geometric calculations are completed with greater accuracy than traditional flat earth models. The core components of the proposed model are described in the following subsections. A conceptual overview of the rocket noise prediction model methodology is presented in Figure 46.

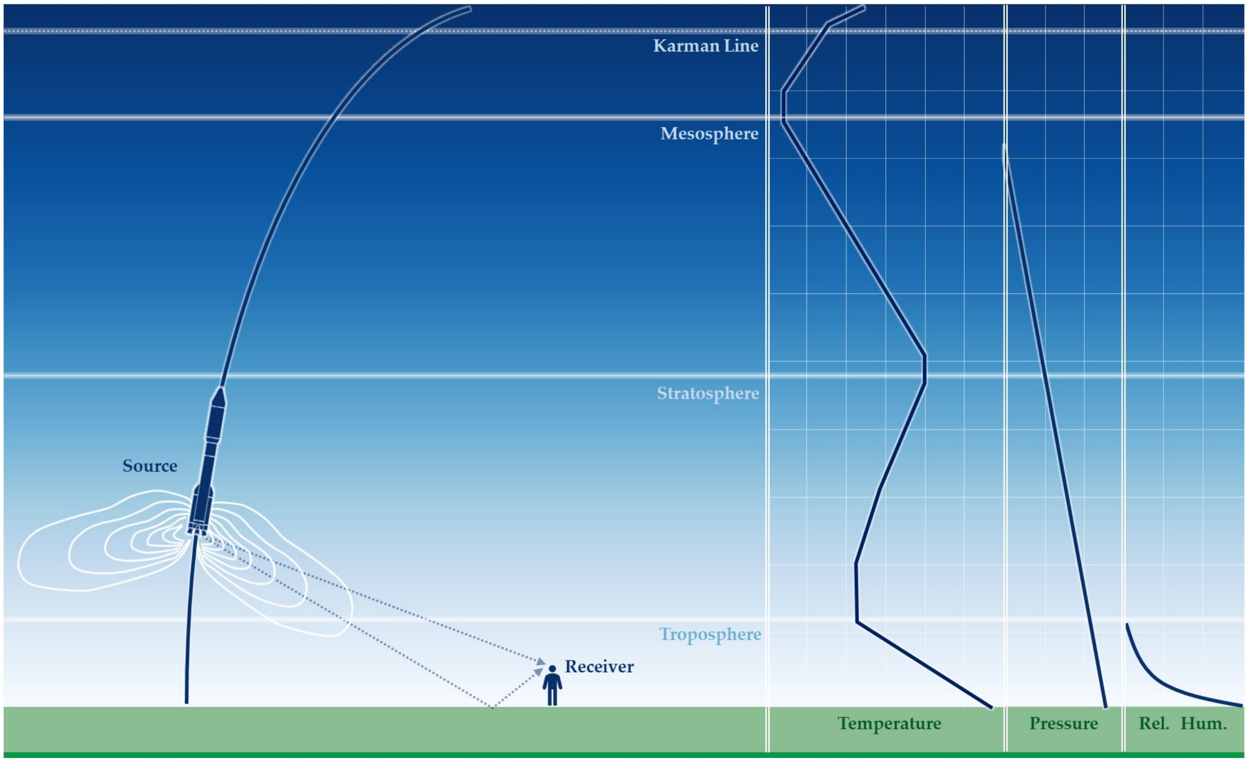


Figure 46. Conceptual overview of RUMBLE model methodology.

9.1 Source

The definition of a rocket noise source's strength and characteristics involves the acoustic power of the rocket, forward flight effects, directivity, and Doppler effect.

9.1.1 Acoustic Power

Eldred's Distributed Source Method 1 (DSM-1) [1] is utilized for the source characterization. The DSM-1 model determines the launch vehicle's sound power based on its total thrust, exhaust-velocity, and the engine/motor's acoustic efficiency. Recent validation by Blue Ridge Research and Consulting (BRRC) of the DSM-1 model demonstrated very good agreement between four separate full-scale rocket noise measurements and the empirical source curves [2]. The results of this validation are presented in Figure 47.

The acoustic efficiency of the rocket engine/motor specifies the percentage of the mechanical power that is converted into acoustic power. The acoustic efficiency of the rocket engine/motor will be modeled using Guest's variable acoustic efficiency [3]. In the far-field, distributed sound sources are modeled as a single compact source located at the nozzle exit with an equivalent total sound power. Therefore, launch vehicle propulsion systems with multiple tightly clustered equivalent engines can be modeled as a single engine with an effective exit diameter and total thrust [1]. Additional boosters or cores (that are not considered to be tightly clustered) are handled by summing the noise contribution from each booster/core.

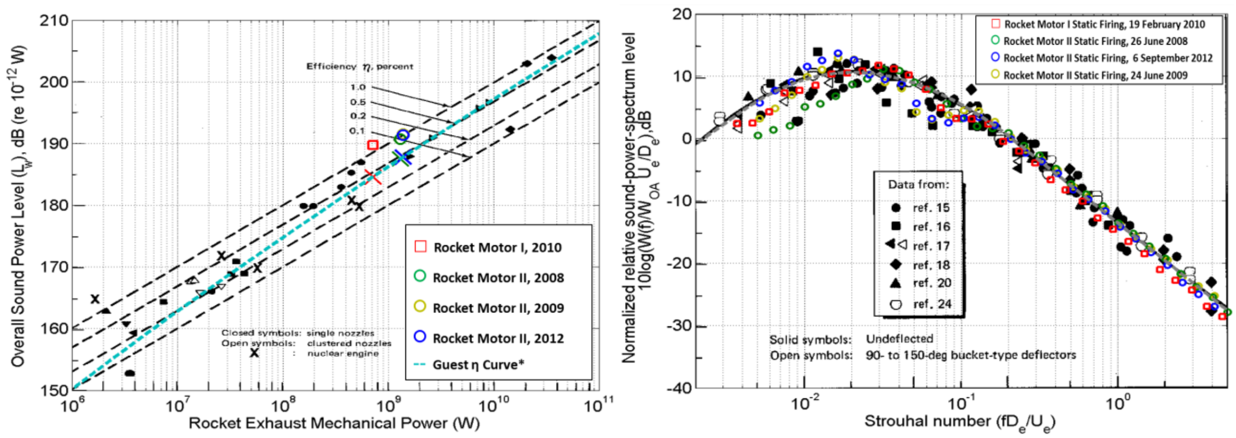


Figure 47. Validation of NASA SP-8072's DSM-1 empirical curves - (Left) overall sound power level for various rockets - (Right) normalized relative power spectrum.

9.1.2 Forward Flight Effect

A rocket in forward flight radiates less noise than the same rocket in a static environment. A standard method to quantify this effect reduces overall sound levels as a function of the relative velocity between the jet and the outside airflow [4, 5, 6, 7]. This outside airflow travels in the same direction as the rocket exhaust. At the onset of a launch, the rocket exhaust travels at far greater speeds than the ambient airflow. Conversely, for a vertical landing of a reusable launch vehicle, the ambient airflow around the descending rocket body and the jet exhaust are in opposing directions, yielding an increased relative velocity differential from the static condition, and creating increased jet mixing and resultant noise. As the differential between the forward flight velocity and exhaust velocity decreases, jet mixing is reduced, which reduces the corresponding noise emission. Notably, the maximum overall sound pressure levels are typically generated while the vehicle is at subsonic speeds. Thus, the modeled noise reduction is capped at a forward flight velocity of Mach 1.

9.1.3 Directivity

Rocket noise is highly directive, meaning the acoustic power is concentrated in specific directions and the sound pressure observed will depend on the angle from the source to the receiver. The National Aeronautics and Space Administration (NASA) Project Constellation Program has made significant improvements in determining launch vehicle directivity of the reusable solid rocket motor (RSRM) [8]. The RSRM directivity indices (DI) incorporate a larger range of frequencies and angles than any previously available data. Recently, BRRC and NASA have improved the formulation of the RSRM DI by accounting for the spatial extent and downstream origin of the rocket noise source [9]. This improved formulation substantially changes the directionality of the Overall Sound Pressure Level (OASPL) radiation by approximately 14°, from 51° to 65° and more closely matches measurements made in the far-field during launches. An example sound level map using these modified DI is shown in Figure 48, where the nozzle exhaust flows in the direction of 0°. These updated DI are included in the model. As future measurements make additional DI sets available, RUMBLE has the capability to implement updated DI sets specific to a spacecraft's engine(s).

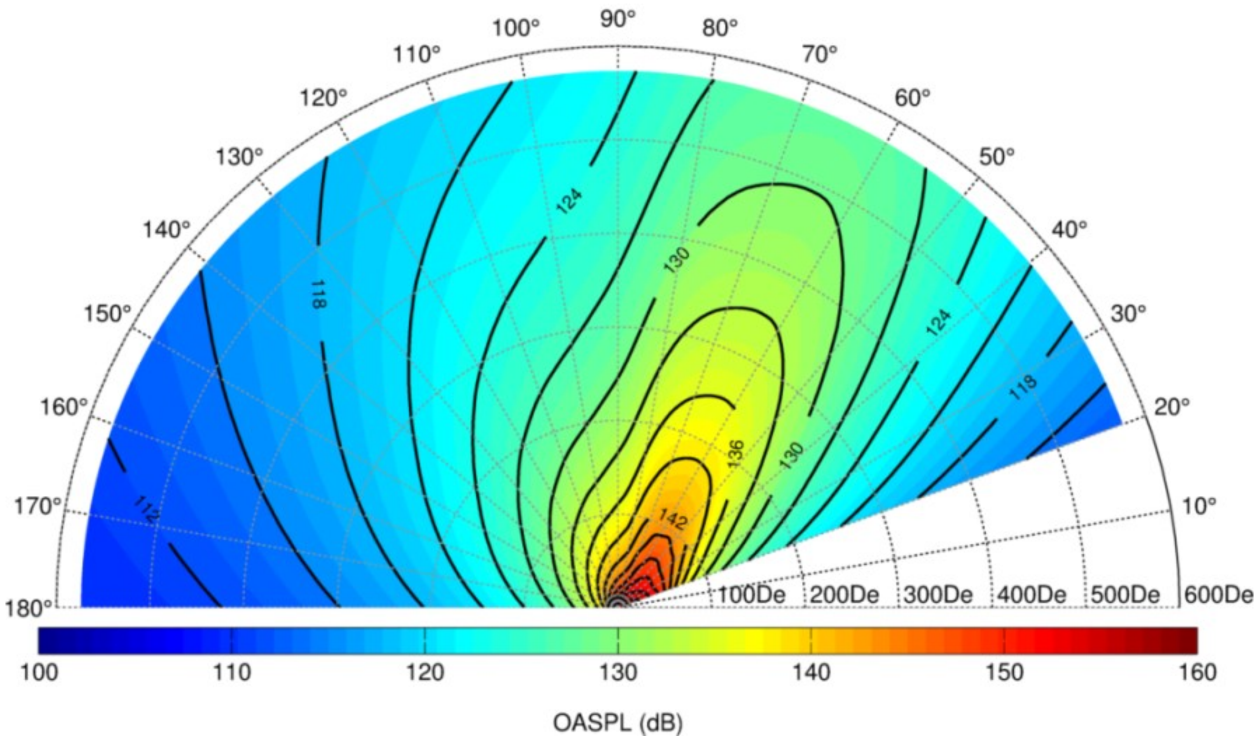


Figure 48. Predicted OASPL with modified DI - the downstream direction of the rocket is 0° and distance is indicated in nozzle diameters (De).

9.1.4 Doppler Effect

The Doppler effect is defined as the change in frequency of a wave for an observer moving relative to its source. The frequency at the receiver is related to the frequency generated by the moving sound source and by the speed of the source relative to the receiver. The received frequency is higher (compared to the emitted frequency) if the source is moving towards the receiver, it is identical at the instant of passing by, and it is lower if the source is moving away from the receiver. During a rocket launch, an observer on the ground will hear a downward shift in the frequency of the sound as the distance from the source to receiver increases. The relative changes in frequency can be explained as follows: when the source of the waves is moving toward the observer, each successive wave crest is emitted from a position closer to the observer than the previous wave. Therefore, each wave takes slightly less time to reach the observer than the previous wave, and the time between the arrivals of successive wave crests at the observer is reduced, causing an increase in the frequency. Conversely, if the source of waves is moving away from the observer, then each wave is emitted from a position farther from the observer than the previous wave; the arrival time between successive waves is increased, reducing the frequency.

Figure 49 illustrates this spreading effect for an observer in a series of images, where a) the source is stationary, b) the source is moving less than the speed of sound, c) the source is moving at the speed of sound, and d) the source is moving faster than the speed of sound. As the frequency is shifted lower, the A-weighting filtering on the spectrum results in a decreased A-weighted sound level. For unweighted overall sound levels, the Doppler effect does not change the levels since all frequencies are accounted for equally.

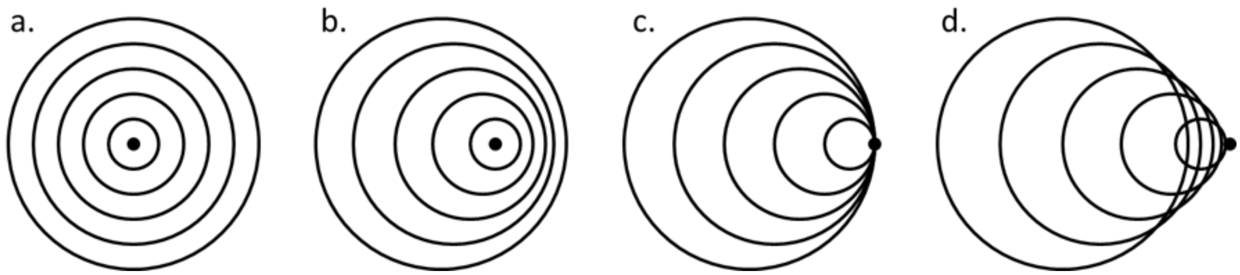


Figure 49. Effect of expanding wavefronts (decrease in frequency) that an observer would notice for higher relative speeds of the rocket relative to the observer for: (a) stationary source, (b) source velocity < speed of sound, (c) source velocity = speed of sound, (d) source velocity > speed of sound.

9.2 Propagation

The modeled sound propagation from the source to a receiver includes geometric spreading, atmospheric absorption, and ground interference.

9.2.1 Geometric Spreading

When sound leaves a source, it travels out in all directions, expanding outward as it travels. This expansion reduces the sound level the farther the sound travels. For every doubling of the slant range distance between the source and a receiver, the received sound level is reduced by 6 decibels (dB).

9.2.2 Atmospheric Absorption

Atmospheric absorption arises from the excitation of vibration modes of air molecules. Atmospheric absorption is a function of temperature, pressure, and relative humidity of the air. Atmospheric absorption is calculated using formulas found in the American National Standards Institute (ANSI) standard S1.26-1995 (R2004), which provides a sound-attenuation coefficient per unit distance that is a function of frequency and atmospheric conditions. Since a rocket travels to high altitudes, it will experience a wide range of atmospheric conditions. The amount of absorption depends on the parameters of the atmosphere in each layer and the distance that the sound travels through those layers. The total sound attenuation is the sum of the absorption experienced from each atmospheric layer. The ANSI sound attenuation algorithms are calculated for pure-tone sounds. As the rocket noise analysis is performed on an OTO-band basis, the SAE Method [10] is used as a simplified procedure to calculate the OTO-band attenuations utilizing the pure-tone sound attenuation of the ANSI standard.

9.2.3 Ground Interference

The calculated results of the sound propagation using DSM-1 provide a free-field sound level at the receiver. However, sound propagation near the ground is most accurately modeled as the combination of a direct wave (source to receiver) and a reflected wave (source to ground to receiver) as shown in Figure 50. The ground will reflect sound energy back toward the receiver and will interfere both constructively and destructively with the direct wave. Additionally, the ground may attenuate the sound energy causing the reflected wave to propagate a smaller portion of energy to the receiver. The model accounts for the attenuation of sound by the ground [11, 12] when estimating the received noise. To account for the random fluctuations of wind and temperature on the direct and reflected wave, the effect of atmospheric turbulence is also included in the ground interference [11, 13]. RUMBLE assumes a homogeneous soft ground when calculating ground interference.

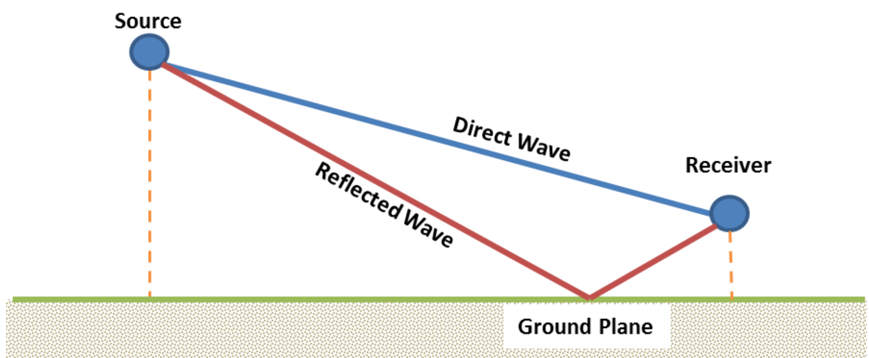


Figure 50. Sound propagation near the ground is modeled as the combination of a direct wave (blue) and a reflected wave (red) from the source to the receiver.

9.3 Receiver

The received noise is estimated by combining the source components and propagation effects. RUMBLE calculates and prepares the modeled received noise for six noise metrics relevant to environmental noise analysis: A-weighted and unweighted Sound Level (LAMAX, LMAX), Sound Exposure Level (SEL), Day-Night Average Sound Level (DNL), and Community Noise Equivalent Level (CNEL).

10 Emissions Modeling Methodology Technical Reference

The RUMBLE emissions modeling methodology was developed to produce accurate emissions estimates relevant to environmental analysis of commercial space operations. The model is applicable to inflight and static operations of vertical and horizontal launch vehicles. Launch vehicle propulsion systems, such as liquid-propellant rocket engines and solid rocket motors, produce emissions through a series of chemical reactions, as shown in Figure 51. First, combustion occurs between the fuel and oxidizer inside the rocket engine. Next, the combustion products expand and accelerate through the nozzle, where additional chemical reactions may occur. Finally, the chemical species in the high-temperature exhaust plume may continue to react with each other and the surrounding air in a process called afterburning.

The combustion products present at the nozzle exit plane are called the *primary emissions* of the rocket engine. The products formed by afterburning and other reactions in the high-temperature exhaust plume are referred to as *secondary emissions*. The chemical species emitted into the atmosphere after the rocket has passed by and the exhaust plume has cooled to the ambient temperature include contributions from both the primary and secondary emissions. RUMBLE is designed to estimate these *final emissions* since they are the chemical species that the vehicle ultimately emits into the atmosphere.

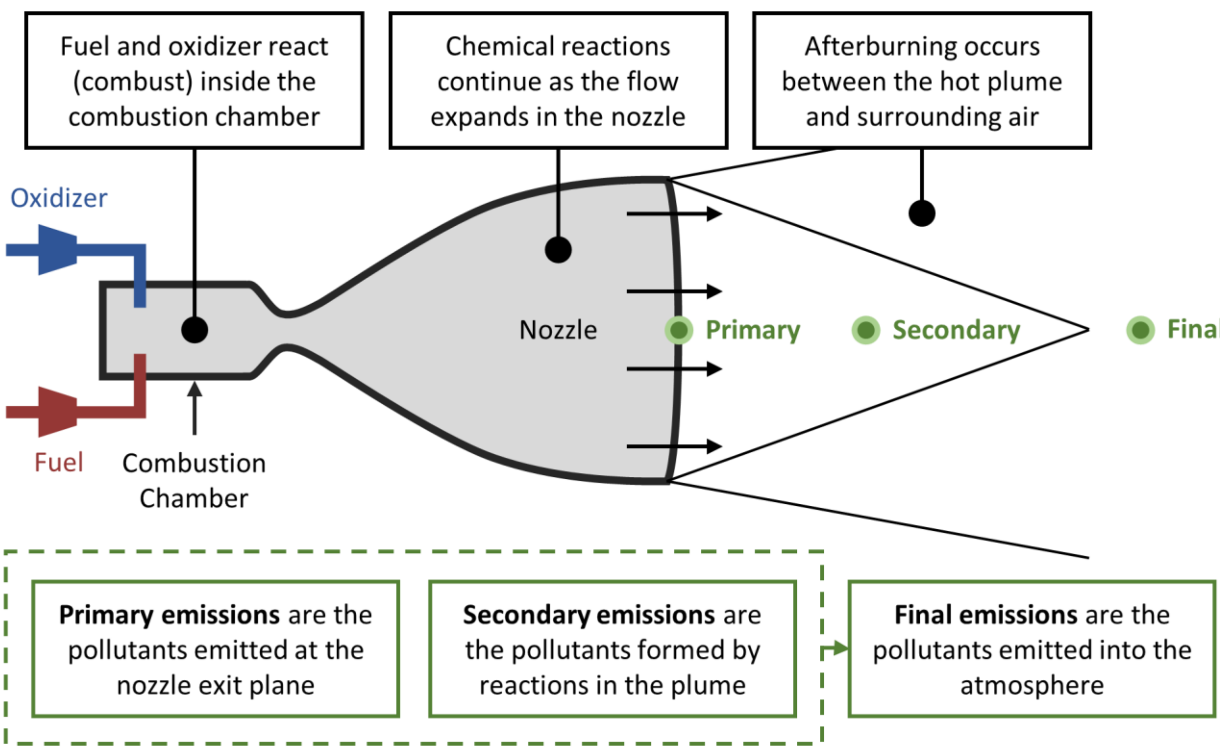


Figure 51. Diagram of the chemical processes in a rocket engine that produce the primary, secondary, and final emissions.

10.1 Emissions Modeling Methodology

The RUMBLE emissions model calculates the mass of propellant burned and the mass of each pollutant emitted by commercial space operations. The calculations are first performed at the most detailed level, and the detailed results are then aggregated to produce the propellant burn report and emissions inventory.

At the most detailed level, the propellant mass burned by a single engine during an individual trajectory segment is calculated by

$$\begin{bmatrix}\text{Propellant}\\ \text{Mass}\end{bmatrix} = \begin{bmatrix}\text{Propellant}\\ \text{Mass Flow Rate}\end{bmatrix} \times \begin{bmatrix}\text{Segment}\\ \text{Duration}\end{bmatrix}$$

where the duration of the trajectory segment is the time between successive points in the user-specified altitude profile. Launch and landing trajectories should be specified in detailed time steps, such as once every second, to provide high resolution for accurate emissions modeling. The propellant mass flow rate may be a time-varying quantity if it is specified by the user in the trajectory data; otherwise, the propellant mass flow rate is a constant value from the fleet database.

Next, the mass of each pollutant emitted by a single engine during an individual trajectory segment is calculated by

$$\begin{bmatrix}\text{Pollutant}\\ \text{Mass}\end{bmatrix} = \begin{bmatrix}\text{Emissions}\\ \text{Index}\end{bmatrix} \times \begin{bmatrix}\text{Propellant}\\ \text{Mass}\end{bmatrix}$$

The emissions indices are the factors that relate the amount of propellant burned to the amount of each pollutant emitted by the engine. The emissions indices are stored in the engine table of the fleet database for the specified rocket engine. Emissions indices are discussed in more detail in Section 10.2.

The outputs of the RUMBLE emissions model are the propellant burn report and the emissions inventory. The propellant burn report provides the propellant mass burned by each type of engine on commercial space vehicles. Similarly, the emissions inventory enumerates the masses of the various pollutants emitted as a result of commercial space operations. RUMBLE aggregates the detailed propellant and pollutant masses over the number of engines, trajectory segments, operations, and vehicles to calculate the total amounts of propellant burned and pollutants emitted.

10.2 Emissions Indices

RUMBLE uses emissions indices to estimate the total amounts of the various pollutants emitted by space vehicles. Emissions indices are the factors that relate the amount of propellant burned to the amount of each pollutant emitted by a rocket engine. The emissions index for a specific pollutant reports the outcome of the complex series of chemical reactions that occur within the rocket engine and exhaust plume as a single number.

10.2.1 Definition of Emissions Indices

In RUMBLE, the emissions index for a specific pollutant is defined as

$$\begin{bmatrix}\text{Emissions}\\ \text{Index}\end{bmatrix} = \frac{\text{Pollutant Mass Emitted (g)}}{\text{Propellant Mass Consumed (kg)}}$$

which has units of grams of pollutant emitted per kilograms of propellant consumed (abbreviated as g/kg). These units are adopted from AEDT, in which the emissions indices for aircraft are defined as the grams of pollutant emitted per kilograms of fuel consumed. However, the emissions indices for aircraft and spacecraft differ: emissions indices for aircraft are defined relative to *fuel* mass, whereas emissions indices for spacecraft are defined relative to *propellant* mass. The propellant includes the fuel plus the oxidizer.

The difference between the emissions indices for aircraft and spacecraft arises from the physical differences between jet engines and rocket engines. Jet engines carry their fuel on board the aircraft and ingest oxygen from the surrounding air, whereas rocket engines carry both their fuel and oxidizer on board the spacecraft. Thus, the emissions indices for both aircraft and spacecraft are defined based on the substance carried on board the vehicle.

10.2.2 Primary Emissions Indices

The primary emissions are the chemical species present at the nozzle exit plane due to processes that occur inside the rocket engine. The primary emissions indices are stored in the RUMBLE fleet database. If high-quality predictions or measurements of the primary emissions indices for a space vehicle are publicly available in the literature, the published values are used in the fleet database. However, the primary emissions indices are not publicly available for most commercial space vehicles because they are considered proprietary or have not been measured. Instead, the primary emissions indices for most vehicles in the fleet database were predicted using the computer program Chemical Equilibrium with Applications (CEA). CEA was developed at the NASA Glenn Research Center for the purpose of calculating the chemical equilibrium composition and thermodynamic properties of any chemical system. A key application of CEA is the prediction of theoretical rocket engine performance.

10.2.3 Final Emissions Indices

The chemical species in the high-temperature exhaust plume outside the rocket engine may continue to react with each other and with the surrounding air to produce secondary emissions. Thus, the primary emissions indices at the nozzle exit plane are not the final emissions indices used in the emissions model. RUMBLE calculates the final emissions indices based on the primary emissions indices and the altitude.

Prior results reported in the literature were used to develop first-order estimates for the final emissions indices. These studies showed that the formation of secondary emissions depends on the chemical composition of the rocket exhaust plume as well as the altitude. Thus, the first-order estimates require the primary emissions indices and altitude as input parameters. Due to the sparsity of high-quality data in the literature, the first-order estimates neglect the effects of other parameters such as the temperature and velocity of the exhaust plume and interactions between multiple plumes. Additionally, the uncertainty in the first-order estimates increases at high altitudes because no emissions measurements have been conducted above the lower stratosphere.

In the following sections, the development of the first-order estimates for the secondary emissions and the resulting final emissions indices are described for each of the major pollutant species emitted by rocket engines:

- Water vapor,
- Carbon monoxide and carbon dioxide,
- Alumina,
- Chlorine-containing species,
- Nitrogen oxides, and
- Black carbon.

The first-order estimates are based on the best available data in the literature. Furthermore, they provide a general method that can be applied to estimate the altitude-dependent final emissions indices for any commercial space vehicle.

Water Vapor

Previous studies [14, 15, 16] have shown that nearly all of the hydrogen (H and H_2) at the nozzle exit plane is converted to water vapor (H_2O) in the high-temperature exhaust plume due to chemical reactions with oxygen (O_2) molecules from the surrounding air. Additionally, the hydroxyl (OH) at the nozzle exit plane typically reacts with hydrogen in the exhaust plume to form H_2O. The H_2O present at the nozzle exit plane remains nearly unchanged through the exhaust plume. Based on these results, the final emissions indices for H, H_2, and OH are assumed to be zero. Furthermore, the final emissions index for H_2O under these assumptions is given by

$$EI_f(H_2O) = EI_p(H_2O) + \frac{MW(H_2O)}{MW(H)} EI_p(H) + \frac{MW(H_2O)}{MW(H_2)} EI_p(H_2) + EI_p(OH) \tag{1}$$

where EI_f is the final emissions index, EI_p is the primary emissions index, and MW is the molecular weight. The molecular weight ratios in Eq. (1) are required because the reactions between the hydrogen in the exhaust plume and the oxygen from the surrounding air add the mass of the oxygen molecules to the rocket exhaust products. However, the emissions index is defined relative to the propellant mass consumed, which does not include the mass of the oxygen molecules from the surrounding air. Thus, the final emissions index for H_2O may be greater than the sum of the primary emissions indices for H, H_2, OH, and H_2O.

No molecular weight ratio is needed for the hydroxyl term in Eq. (1) because the hydroxyl is assumed to react with hydrogen from the exhaust plume. This assumption violates the earlier assumption that the hydrogen in the exhaust plume reacts solely with oxygen molecules from the surrounding air. However, the amount of hydroxyl at the nozzle exit plane is typically much lower than the amount of water vapor or hydrogen, so the error introduced by this assumption is negligible.

Carbon Monoxide and Carbon Dioxide

Previous studies [14, 16] have shown that most of the carbon monoxide (CO) at the nozzle exit plane is oxidized to form carbon dioxide (CO_2) in the high-temperature exhaust plume due to chemical reactions

with oxygen (O_2) molecules from the surrounding air. However, the rate of oxidation decreases at high altitudes because fewer oxygen molecules are present in the surrounding air. Thus, a larger fraction of CO remains in the plume at high altitudes.

The first-order estimates for the final emissions indices of CO and CO_2 are based on previous studies that calculated the emissions downstream of the Space Shuttle solid rocket motors [14] and a solid rocket motor proposed by TRW Inc. [16]. Figure 52 shows the results from the literature at several different altitudes. The vertical axis presents the final mass fraction of CO relative to the combined mass of CO and CO_2.

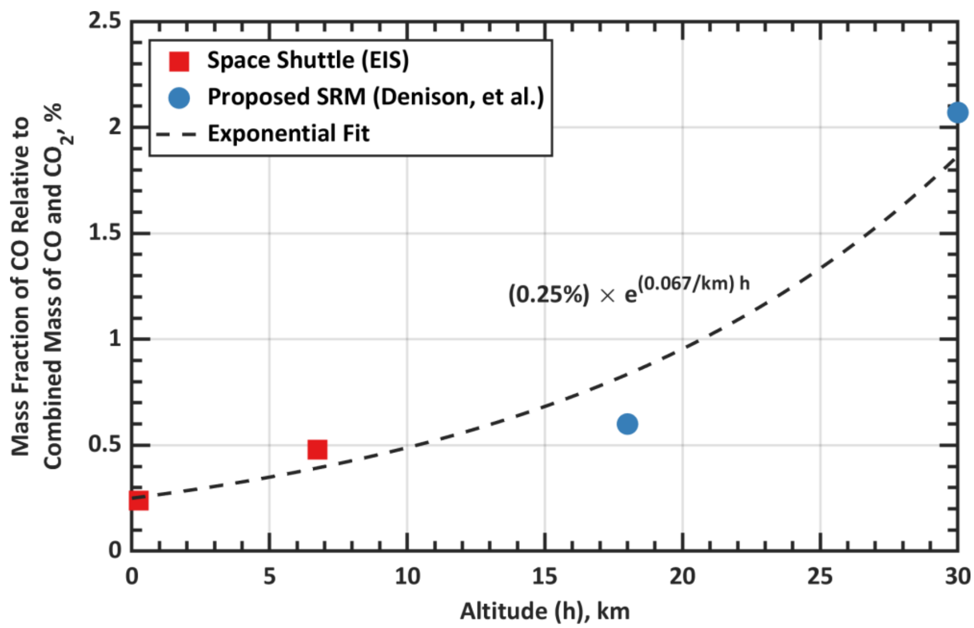


Figure 52. Mass fraction of CO relative to the combined mass of CO and CO_2 as a function of altitude [14, 16].

An exponential fit through the points shown in Figure 52 gives the final emissions index for CO as

$$EI_f(CO) = \min\{EI_p(CO), 0.0025e^{(0.067/km)h}[EI_p(CO) + EI_p(CO_2)]\} \tag{2}$$

where h is the altitude in kilometers, and the maximum value cannot be greater than the primary emissions index for CO.

Based on Eq. (2), the final emissions index for CO_2 is given by

$$EI_f(CO_2) = EI_p(CO_2) + \frac{MW(CO_2)}{MW(CO)}[EI_p(CO) - EI_f(CO)] \tag{3}$$

The ratio of molecular weights in Eq. (3) is required because external mass is added to the rocket exhaust products by the reactions between the CO in the plume and the O_2 from the surrounding air. Even though Eqs. (2)–(3) were developed based on data from solid rocket motors, the oxidation of CO to CO_2 occurs for carbon-containing liquid propellants, too. Thus, these first-order estimates are applied to all rocket engines with carbon-containing propellants.

Alumina

Previous studies have shown that alumina (Al_2O_3) is emitted from solid rocket motors as particles [17] and that the amount of alumina at the nozzle exit plane remains unchanged through the rocket exhaust plume [14, 15]. Thus, the final emissions index for alumina is equal to the primary emissions index calculated using CEA:

$$EI_f(Al_2O_3) = EI_p(Al_2O_3) \tag{4}$$

CEA predicts that alumina is emitted from solid rocket motors as liquid or solid particles. In fact, alumina is the dominant source of particulate matter for solid rocket motors (liquid propellants do not contain aluminum and hence do not emit alumina particles). However, little is known about the size distribution of the particles, though the mean particle size has been shown to scale with the diameter of the nozzle throat [17]. Because commercial solid rocket motors tend to be large, and based on the lack of additional information, it is assumed that all of the alumina particles are PM_{10} (particulate matter less than 10 µm in diameter).

Chlorine Species

The primary emissions indices predicted by CEA show that, for solid rocket motors, a significant amount of hydrogen chloride (HCl) and a small amount of atomic and diatomic chlorine (Cl and Cl_2) are present at the nozzle exit plane (liquid propellants do not contain chlorine and hence do not emit chlorine-containing species). Previous studies have shown that HCl is partially converted to Cl and Cl_2 in the rocket exhaust plume and that the amount of Cl and Cl_2 production increases with altitude [16, 18, 19]. However, the reactions that partition chlorine atoms between HCl, Cl, and Cl_2 are complex, and inconsistent quantitative results are presented in the literature.

Figure 53 shows the mass fractions of HCl, Cl, and Cl_2 relative to the total mass of chlorine-containing molecules. The data points are based on calculations from previous studies of the Space Shuttle solid rocket motors [15, 18], a proposed TRW solid rocket motor [16], and the Titan IV solid rocket motor [19]. The prior studies agree that an increasing amount of HCl is converted to Cl and Cl_2 at higher altitudes, but the computed mass fractions differ by a factor of 2–3 at an altitude of 30 km. Furthermore, the Titan IV results at an altitude of 40 km demonstrate that the conversion of HCl to Cl and Cl_2 is non-monotonic with altitude. Thus, a first-order model for the emissions indices of HCl, Cl, and Cl_2 based on these results would have high uncertainty.

Instead, a single emissions index is calculated to represent all chlorine-containing species. The total chlorine emissions are often reported as a single value in environmental documents, such as the Evolved Expendable Launch Vehicle EIS [20, 21]. The results predicted by CEA provide the individual primary emissions indices for HCl, Cl, and Cl_2, and no additional chorine is added in the plume. Thus, the final emissions index for all chlorine-containing species is given by

$$EI_f(Cl_x) = EI_p(HCl) + EI_p(Cl) + EI_p(Cl_2). \tag{5}$$

where Cl_x represents the sum of all chlorine-containing species.

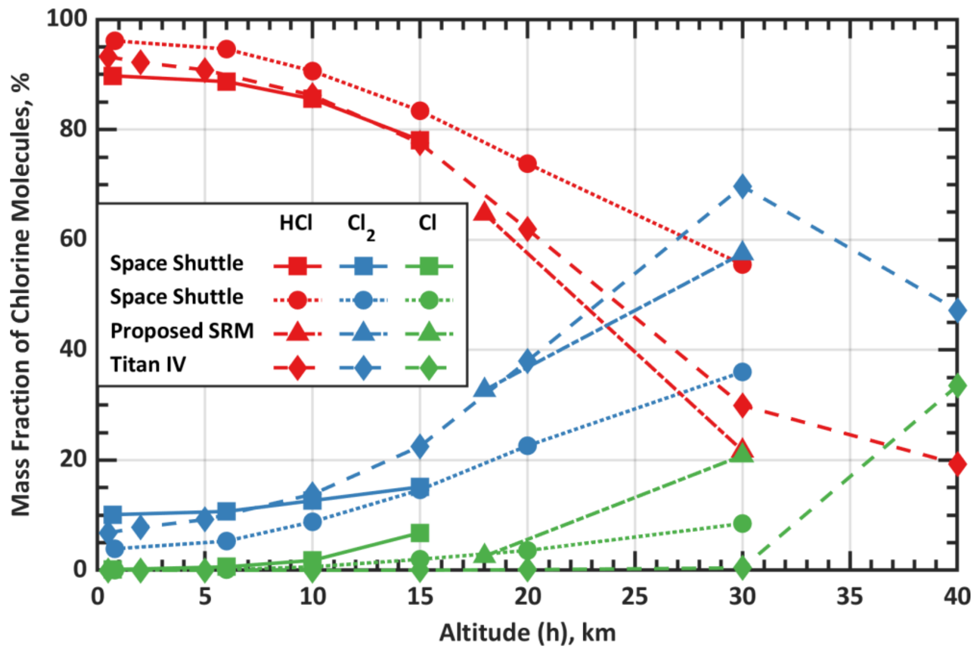


Figure 53. Mass fractions of HCl, Cl, and Cl_2 relative to the total mass of chlorine-containing molecules as functions of altitude [15, 16, 18, 19].

Nitrogen Oxides (NO_x)

The most commonly used liquid propellants are liquid oxygen as the oxidizer and liquid hydrogen, RP-1 (a highly refined form of kerosene), or methane as the fuel. Since none of these propellants contains nitrogen, NO_x cannot form inside liquid-propellant rocket engines unless impurities are present in the propellant. Impurities are typically minor and are not considered in the commercial space vehicle emissions model. Unlike liquid propellants, most solid, hypergolic, and hybrid propellants contain significant amounts of nitrogen. These propellants may produce a small amount of NO_x inside the rocket engine due to nonequilibrium processes and incomplete combustion.

Regardless of the type of propellant, NO_x forms outside the rocket engine due to reactions between the high-temperature rocket exhaust plume and the nitrogen (N_2) in the surrounding air. For solid, hypergolic, and hybrid propellants, the amount of NO_x formed in the exhaust plume at low altitudes is typically larger than the amount of NO_x formed inside the rocket engine. Thus, the final emissions index for NO_x is mostly due to the secondary emissions.

Figure 54 shows calculations of the NO_x secondary emissions index from previous studies of the Space Shuttle [15, 18] as well as the Atlas V RD-180 and Delta IV RS-68A liquid rocket engines [20, 21] at various altitudes. These literature sources demonstrate that NO_x production in the exhaust plume decreases with altitude and eventually becomes negligible in the stratosphere.

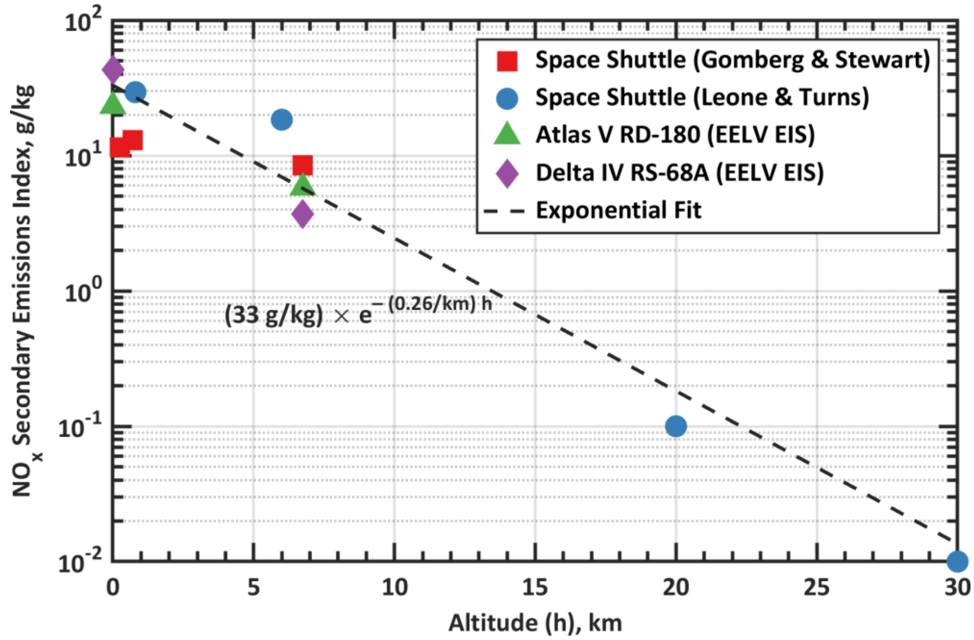


Figure 54. Secondary emissions index for NO_x as a function of altitude [15, 18, 20, 21].

An exponential fit was created based on the calculations performed by Leone and Turns [18] for the Space Shuttle. The NO_x emissions index at sea level was set equal to the mean value for the Atlas V and Delta IV engines to produce a more conservative estimate based on more recent data. This fit represents a first-order estimate for the production of NO_x in the exhaust plume as a function of altitude. Although the exponential fit neglects the effects of temperature, velocity, and interactions between multiple plumes on the production of NO_x, it represents the best estimate based on available data. The first-order estimate of the final emissions index for NO_x is given by

$$EI_f(NO_x) = EI_p(NO_x) + (33\ g/kg)e^{-(0.26/km)h} \tag{6}$$

where h is the altitude in kilometers. This first-order estimate is applied to all rocket engines in the engine database, regardless of propellant type.

Black Carbon

Black carbon (BC), also known as soot, is produced inside rocket engines by incomplete combustion of carbon-based propellants. Prior observations have shown that LOX/RP-1, solid, and hybrid propellants produce black carbon, and it is expected that LOX/methane engines will produce some black carbon as well. However, the nonequilibrium chemistry and inhomogeneous mixing processes involved in the formation of black carbon are still not completely understood [17], so little is known about the quantity of black carbon produced by different types of rocket propellants.

The only publicly available quantitative studies on black carbon emissions from rocket engines are for LOX/RP-1 propellants. These studies report values for the black carbon final emissions index that vary from 1–30 g/kg [17]. The black carbon emissions indices for different types of rocket propellants are unknown. However, it is well known that black carbon at the nozzle exit plane is partially oxidized to CO

and CO_2 due to afterburning in the high-temperature exhaust plume. Since oxidation requires O_2 molecules from the surrounding air, the amount of oxidation decreases at higher altitudes.

Figure 55 shows results from the few studies in the open literature that reported estimates of the final emissions index for black carbon at specific altitudes [17, 22, 23]. All of these results are for the Atlas II rocket, which used LOX/RP-1 propellant in a gas-generator cycle rocket engine. An exponential fit was created based on these results at altitudes above sea level. The fit was clamped to a minimum value of 1 g/kg, which is the lowest value for the black carbon final emissions index reported in the literature, and a maximum value of 25 g/kg, which is the average of the maximum values reported by several different studies [17, 23].

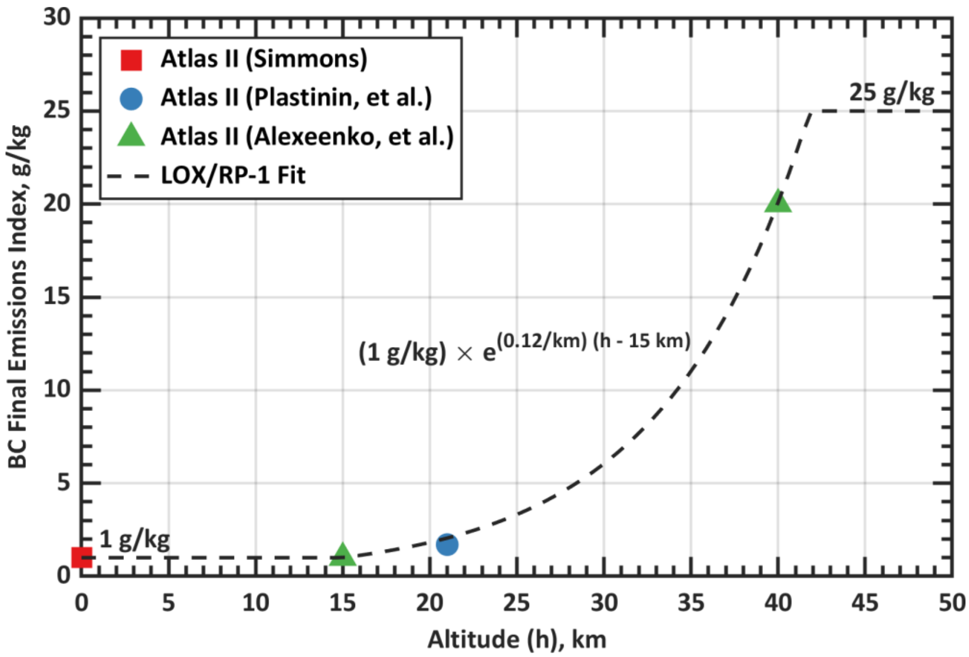


Figure 55. Final emissions index for black carbon in LOX/RP-1 engines as a function of altitude [17, 22, 23].

A reasonable estimate for the primary emissions index of black carbon is given by the final emissions index at high altitudes, where afterburning is negligible. The results shown in Figure 55 suggest that the primary emissions index of black carbon is 25 g/kg for LOX/RP-1 propellants. Due to afterburning, the final emissions index of black carbon is reduced to as little as 4% of the primary emissions index at low altitudes. Thus, the first-order estimate of the final emissions index of black carbon is given by

$$EI_f(BC) = EI_p(BC)\max\left\{0.04, \min\left[1, 0.04e^{(0.12/\text{km})(h-15\text{ km})}\right]\right\} \quad (7)$$

where the primary emissions index of black carbon is assumed to be 25 g/kg for LOX/RP-1 propellants. Due to a lack of data, this estimate neglects differences between gas-generator and staged-combustion engine cycles, which are expected to produce different amounts of black carbon.

No quantitative data are available in the open literature to estimate the black carbon emissions indices for other types of rocket propellants. One study [24] assumed that solid rocket motors produce similar

amounts of black carbon as LOX/RP-1 engines, so the black carbon primary emissions index is assumed to be 25 g/kg for solid rocket motors, too. Due to a lack of data, the same estimate is also applied to hypergolic and hybrid propellants. Table 5 summarizes the assumed values of the black carbon primary emissions indices for different types of rocket propellants.

As indicated by Table 5, LOX/methane engines are expected to produce less black carbon than LOX/RP-1 engines. Results from the automotive industry have shown that, under optimal conditions, black carbon emissions from internal combustion engines can be reduced by more than 80% by switching from gasoline to natural gas, which is primarily composed of methane [25]. However, rocket engines are limited by performance constraints that favor fuel-rich combustion, so results from internal combustion engines may not be directly transferable to rocket engines. Additionally, several prominent LOX/methane rocket engines currently under development utilize staged-combustion cycles, whereas the LOX/RP-1 engines shown in Figure 55 use gas-generator cycles. The staged-combustion cycle is expected to generate less black carbon than the fuel-rich gas-generator cycle, but the reduction in black carbon emissions has not been quantified. Since no other quantitative data are available, the black carbon primary emissions index for LOX/methane engines is assumed to be 20% of the value for LOX/RP-1 engines based on the reduction observed for internal combustion engines.

Table 5. Primary emissions index of black carbon for different types of rocket propellants.

Propellant	EI_p(BC), g/kg	Notes
LOX/Hydrogen	0	LOX/Hydrogen propellants do not contain carbon
LOX/RP-1	25	Based on the data shown in Figure 55
LOX/Methane	5	Based on results from internal combustion engines [25]
Solid (HTPB or PBAN)	25	Based on a single assumption in the literature [24]
Hypergolic	25	Assumed due to lack of data
Hybrid	25	Assumed due to lack of data

The first-order estimate of the black carbon emissions index for LOX/RP-1 engines is already highly uncertain, and the estimates for the other propellants have an even greater amount of uncertainty. Future measurements will be required to reduce the uncertainty and provide more accurate black carbon emissions indices for different types of propellants.

11 RSIF Reference Guide

11.1 Introduction

The RUMBLE Standard Input File (RSIF) provides a standard file format to allow for the import of data into a RUMBLE study. A RSIF can be used to create new RUMBLE studies and to update existing studies. This chapter provides a description of the RSIF format for the RSIF schema version 3.0 which was based on AEDT's ASIF schema version 1.2.11. It also provides an overview of RSIF usage and annotated sample studies. The guide is intended for analysts and programmers who wish to create RSIFs.

11.1.1 Overview of the RSIF Format

The RSIF format allows users to import a complete RUMBLE study. Users can also use a partial RSIF file to import fleet, trajectory, or atmospheric profile data.

RSIF is based on the XML file format. XML is a text-based file format that is readable by both humans and computers. Data values are tagged with elements and organized in a hierarchical manner such that the elements can contain other elements or data. XML elements can also have attributes which provide metadata that affect how the RSIF importer processes the data in the XML file. This document assumes users have basic familiarity with the XML file format. For additional information about XML, see http://xmlfiles.com/xml/. A RSIF can be created and edited in a standard XML editor. The *XML Notepad* and *Notepad++* are XML editors that can be downloaded for free online and may also be used to validate RSIF against the XML Schema Definition (XSD).

11.1.2 RSIF Schema Documentation and Sample RSIFs

The *C:\Program Files\BRRC\RUMBLE\application\Examples* directory contains the following:

- RSIF schema (.xsd) files.
- Sample RSIF files.

11.2 XML Hierarchy

There are two types of RSIF import files: a full-study import and a partial-study import. The following sections describe each type of import file.

11.2.1 Create New Study with RSIF

RUMBLE supports the creation of new studies via RSIF. For a full-study import, the ***content*** attribute of the <RsifXML> element must be set to "study." The RSIF schema describes the hierarchical relationship of structural XML elements within the RSIF import file; some elements are optional.

11.2.2 Partial RSIF Import

Partial RSIF is used to import specific pieces of data into an existing RUMBLE study. A partial RSIF file is organized similarly to a full RSIF, except that it contains a single type of data – the ***content*** attribute of the <RsifXML> element must specify the data type. There are three data types that can compose a partial ASIF: fleet, trajectorySet, and atmosphericProfile.

The format for a partial RSIF is outlined below. The header is the same as a full RSIF, except that the ***content*** attribute is not "study." Instead, the ***content*** attribute should specify the data element that appears in the file.

```
<?xml version="3.0" encoding="UTF-8"?>
<RsifXml xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" version="3.0"
content="ENTER_CONTENT_TYPE_HERE">
<!-- The content code block follows here: -->
<*content type here*>
...
</*end content type*>
</RsifXml>
```

11.3 RSIF Examples

This section provides simple steps to assist in the creation of RSIFs for possible studies.

11.3.1 Create a Simple Study

Follow the steps below to develop an RSIF for a simple RUMBLE study:

1. Create an empty study file,
2. Populate the spaceport section,
3. Create a receptor set,
4. Create a scenario and case hierarchy,
5. Populate the scenario's cases with tracks and air operations,
6. Create a scenario annualization tree.

The hierarchy for a simple RUMBLE study is outlined below, resulting from the above steps.

```
<?xml version="1.0" encoding="utf-8"?>
<RsifXml xmlns:RsifXml="RSIF.xsd" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" content="study"
version="1">
  <study>
          <name>My KSC Study</name>
          <studyType>Noise</studyType>
          <description>My Kennedy Space Center study</description>
          <spaceportLayout>...</spaceportLayout>
          <receptorSet>...</ receptorSet >
          <fleet>...</fleet >
          <scenario>
                    <name>Baseline</name>
                    <caseSet>...</caseSet>
                    <annualization>...</annualization>
          </scenario>
  </study>
</RsifXml>
```

11.4 Notation

This section describes the notation used in the schema.

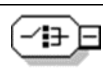
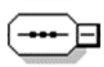
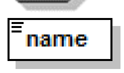
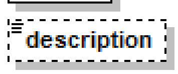
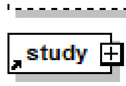
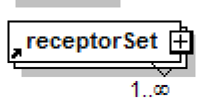
Table 6. Notation for RSIF XML tag types.

Type	Description
integer, double	The standard numeric types.
string	A string with up to N characters.
-	A complex type that contains other elements.

Table 7. Notation for the required number of elements.

Num	Description
+	1 or more instances are required.
*	0 or more instances are required, implying the element is optional if 0 elements are desired.
?	0 or 1 instance is required, again implying an optional element.

Table 8. Notation for schema diagram.

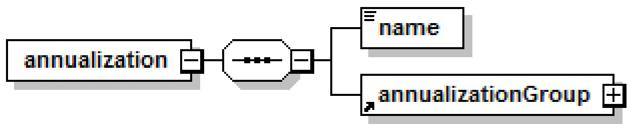
Notation	Icon	Description
Choice Indicator		Only one of the elements contained in the selected group can be present.
Sequence Indicator		Child elements must appear in the specified sequence.
Element		Represented by a rectangle with solid or dotted border: Solid rectangle – required element Dotted rectangle – optional element
Element with (+) Sign		Indicates that the element has child element(s) and/or attribute(s).
Element with Min/Max Bound		Specifies the min/max number of times an element can occur in the parent element.

Some element descriptions include a Choice column. This column indicates the need to choose between one of the elements associated with the same choice letter. For example, referring to the table in section latlonCoordGroup, choice “a” refers to a choice between the latitude and latitudeDMS elements, and choice “b” refers to the longitude and longitudeDMS elements. When creating a tag of type latlonCoordGroup, you can include one element from choice “a”, and one element from choice “b.”

Some ASIF elements contain attributes. The following section describes attributes when they are defined for a particular element. The schema diagram illustrates the structure and contents of each XML element. It facilitates understanding of the relationship between XML elements, and the rules and properties of each element.

11.5 Element Descriptions

11.5.1 annualization



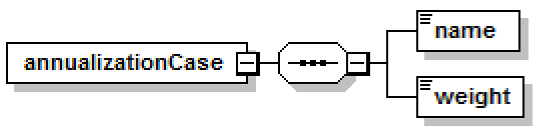
Contains annualizations.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	string255	1	Name of annualization
annualizationGroup	-	1	Contains one or more weighted annualization group cases. See annualizationGroup.

Attributes: None.

11.5.2 annualizationCase



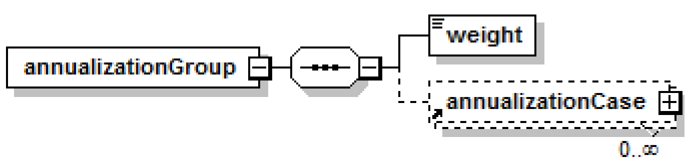
Collection of study cases whose results are weighted in the scenario annualization rollup.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	string255	1	Description of the case.
weight	xs:double	1	Weight associated with the case.

Attributes: None.

11.5.3 annualizationGroup



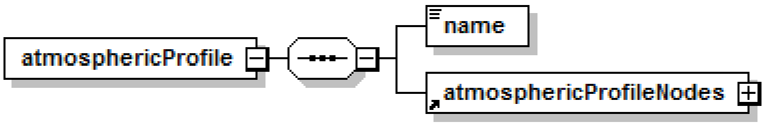
Contains one or more weighted annualization cases.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
weight	xs:double	1	Weight associated with the annualization group.
annualizationCase	-	*	Collection of study cases whose results are weighted in the scenario annualization rollup. See annualizationCase.

Attributes: None.

11.5.4 atmosphericProfile



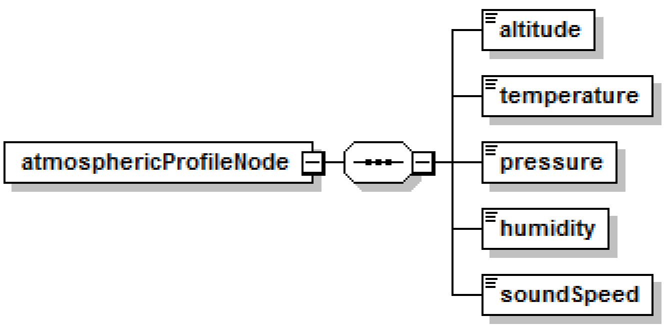
Contains one or more atmospheric profile descriptions.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	xs:double	1	Name of atmospheric profile.
atmosphericProfileNodes	-	1	A set of atmospheric profile nodes. See atmosphericProfileNodes.

Attributes: None.

11.5.5 atmosphericProfileNode

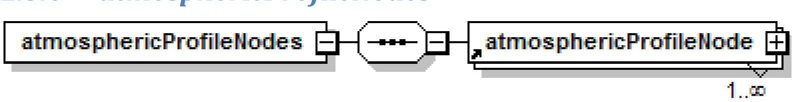


Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
altitude	xs:double	1	Node altitude (ft).
temperature	xs:double	1	Node temperature (°F).
pressure	xs:double	1	Node atmospheric pressure (in Hg).
humidity	xs:double	1	Node relative humidity (%).
soundSpeed	xs:double	1	Node sound speed (ft/sec).

Attributes: None.

11.5.6 atmosphericProfileNodes



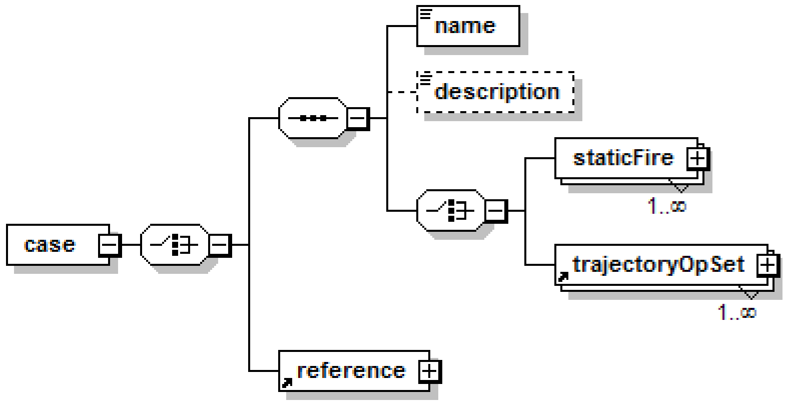
A set of atmospheric profile nodes.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
atmosphericProfileNodes	-	1	An atmospheric profile node. See atmosphericProfileNode.

Attributes: None.

11.5.7 case



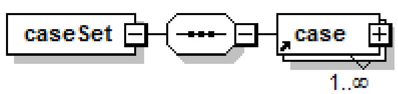
Describes general parameters for a case.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Choice	Description
name	string255	1	a	The case name (must be unique within the scenario).
description	string255	*	a	The case description.
staticFire	-	*	b	A spacecraft static fire operation. See staticFire.
trajectoryOpSet	-	*	b	Lists trajectories and associated operations. See trajectoryOpSet.
reference	-	1	a	Refers to a case by its scenario name and case name. Conditions required: the referenced case must have a unique name in the new scenario. See reference.

Attributes: None.

11.5.8 caseSet



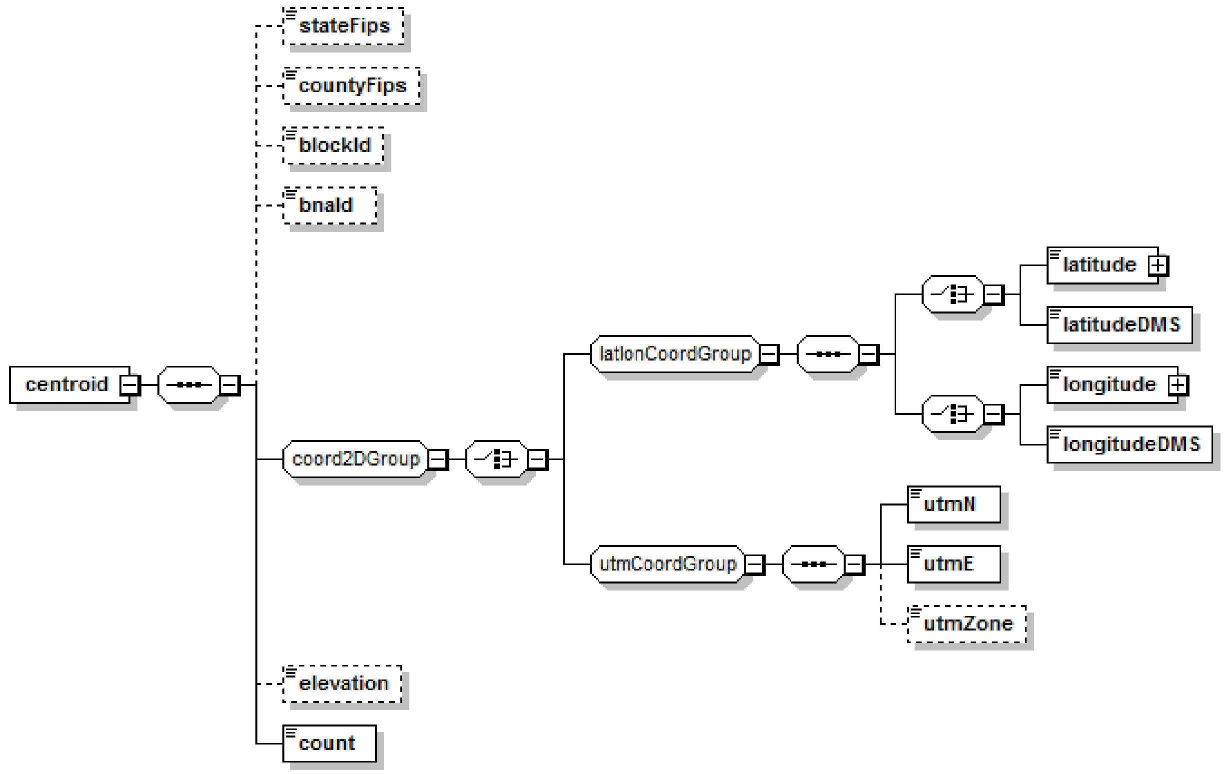
Placeholder for one or more cases.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
case	-	*	Describes general parameters for a case. See case.

Attributes: None.

11.5.9 centroid



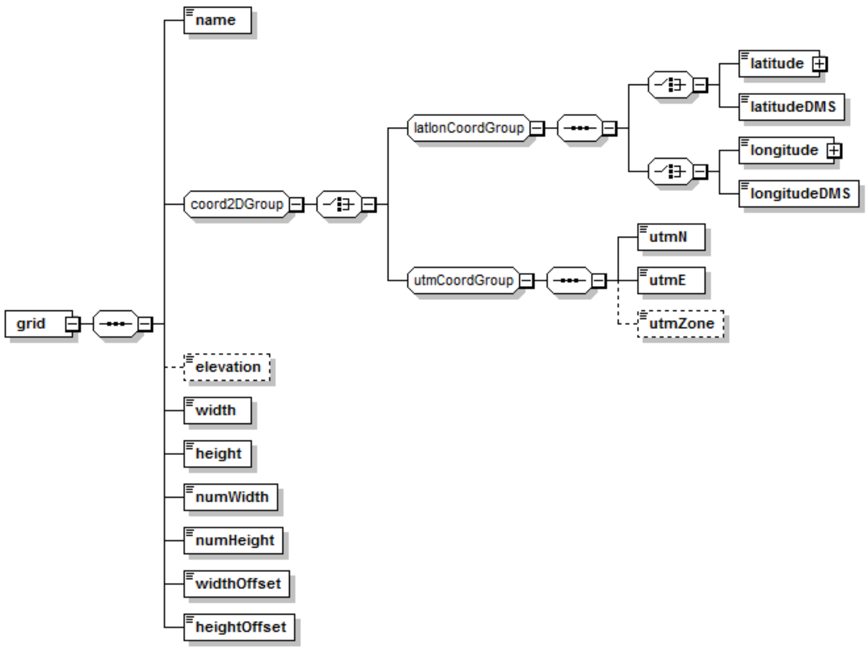
Describes the geometric center of a polygon.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
stateFips	xs:int	1	Optional census state identifier.
countyFips	xs:int	1	Optional census county identifier.
blockId	xs:int	1	Optional census BLOCK ID.
bnaId	string6	1	Optional census BNA ID.
coord2DGroup	-	1	Indicates how a two-dimensional group is specified. See coord2DGroup.
elevation	xs:double	*	The centroid's elevation above MSL (ft). If not specified, RUMBLE will use elevation of spaceport.
count	xs:int	1	The population count of the centroid. Valid values: 0 to 999999.

Attributes: None.

11.5.10 grid



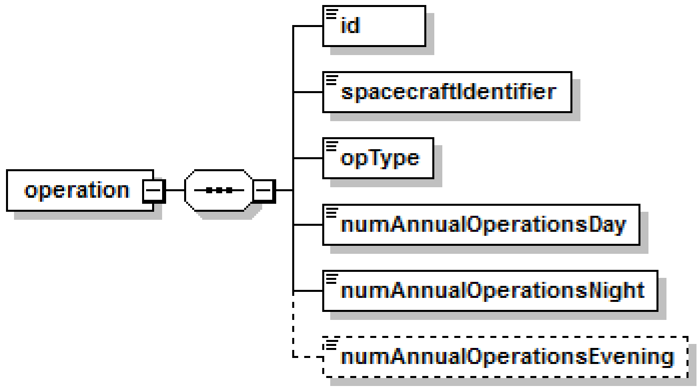
Describes a grid of points.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	string255	1	A string up to 255 characters long.
coord2DGroup	-	1	Indicates how a two-dimensional group is specified. See coord2DGroup.
elevation	xs:double	*	The centroid's elevation above MSL (ft). If not specified, RUMBLE will use the elevation of the spaceport.
width	xs:double	1	Width of the grid (nmi).
height	xs:double	1	Height of the grid (nmi).
numWidth	xs:int	1	Number of points to spread across the width of the grid. The total number of points in the grid is numWidth x numHeight. Points will be located along width of grid using the formula: i x (width÷numWidth) where i is the index of the point (0 … numWidth-1). Valid values: 1 to 999.
numHeight	xs:int	*	Number of points to spread across the height of the grid. The total number of points in the grid is numWidth x numHeight. Points will be located along height of grid using the formula: i x (height÷numHeight) where i is the index of the point (0 … numHeight-1). Valid values: 1 to 999.
widthOffset	xs:double	1	Width offset from the spaceport origin to describe the location of the south-west corner of the grid.
heightOffset	xs:double	1	Height offset from the spaceport origin to describe the location of the south-west corner of the grid.

Attributes: None.

11.5.11 operation



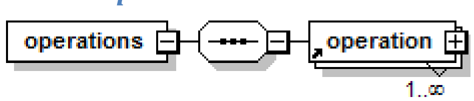
Describes a spacecraft flight operation.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
Id	string16	1	User specified identifier for the operation.
spacecraftIdentifier	spacecraftId	1	Spacecraft identifier.
opType	opType	1	Type of operation.
numAnnualOperationsDay	xs:double	1	Number of annual acoustic daytime operations comprising this operation, where daytime hours are: (07:00 am to 10:00 pm) OR (07:00 am to 07:00 pm) when evening operations are defined.
numAnnualOperationsNight	xs:double	1	Number of acoustic annual nighttime operations comprising this operation, where nighttime hours are: (10:00 pm to 07:00 am).
numAnnualOperationsEvening	xs:double	*	Number of annual acoustic evening operations comprising this operation, where evening hours are: (07:00 pm to 10:00 pm).

Attributes: None.

11.5.12 operations



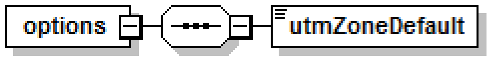
Contains a list of spacecraft flight operations.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
operation	-	*	Describes a spacecraft flight operations. See operation.

Attributes: None.

11.5.13 options



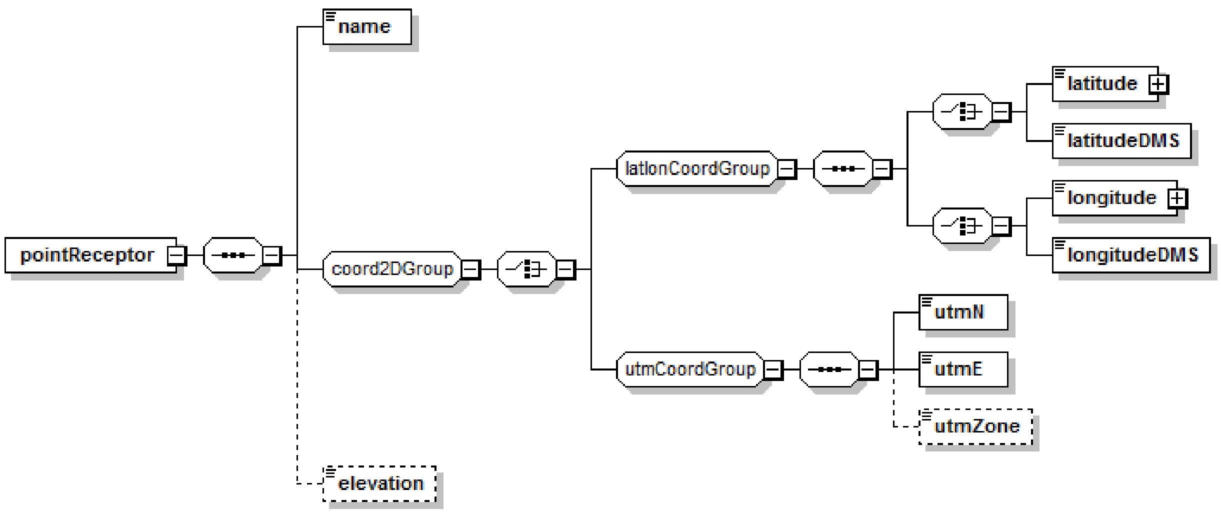
Contains default option values applied to the study.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
utmZoneDefault	xs:int	1	Default UTM zone number. Default: -1.

Attributes: None.

11.5.14 pointReceptor



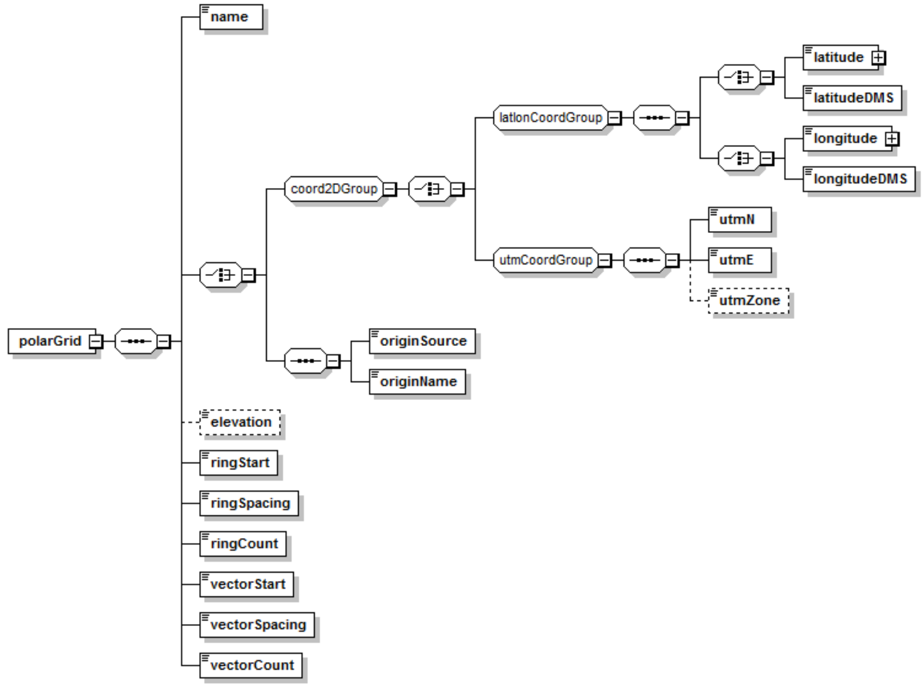
Element specification for a point receptor.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	string255	1	A string up to 255 characters long.
coord2DGroup	-	1	Indicates how a two-dimensional group is specified. See coord2DGroup.
elevation	xs:double	*	The point's elevation above MSL (ft). If not specified, RUMBLE will use elevation of spaceport.

Attributes: None.

11.5.15 polarGrid



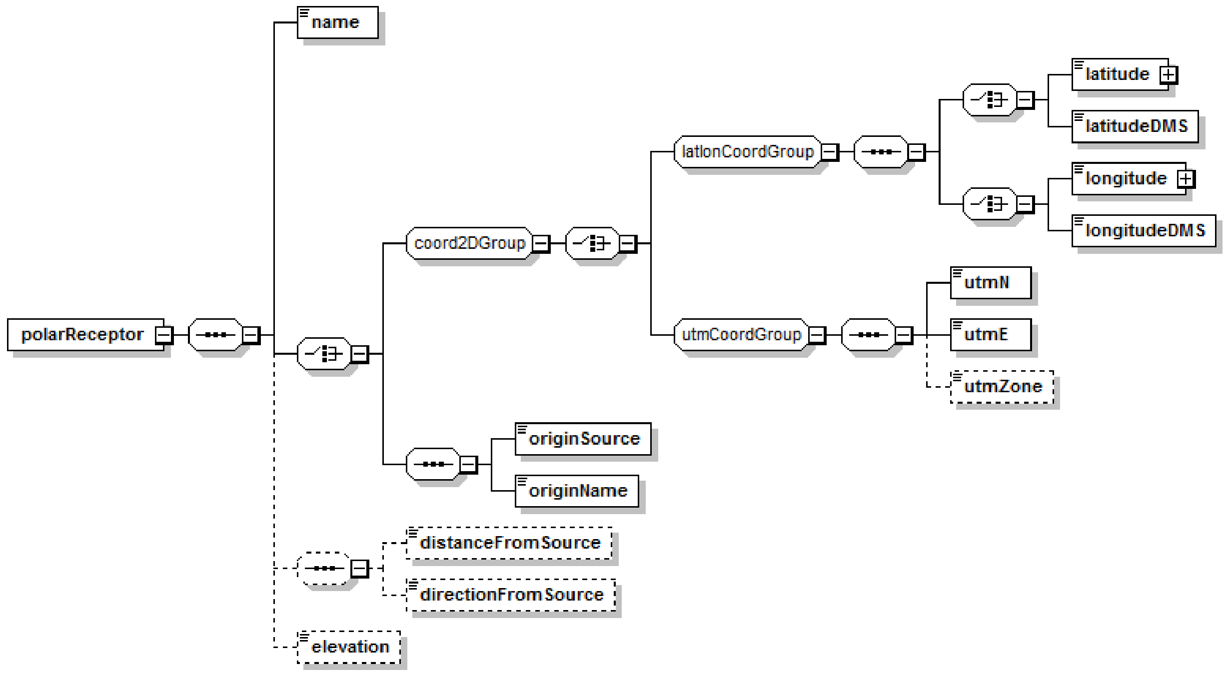
Describes a two-dimensional grid of individual receptors over an annular sector (polar) of the study area.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Choice	Description
name	string255	1		A string up to 255 characters long.
coord2DGroup	-	1	a	Indicates how a two-dimensional group is specified. See coord2DGroup.
originSource	originSourceType	*	a	Origin source name for the polar grid (must match a unique name of a specific source reference).
originName	string40	*		Refers to an existing spaceport.
elevation	xs:double	*		The centroid's elevation above MSL (ft). If not specified, RUMBLE will use elevation of spaceport.
ringStart	xs:double	*		Initial radius of the first ring from the center point. Default: 1.
rightSpacing	xs:double	*		Spacing between rings starting from the first ring. Valid values: 0 to 1000. Default: 1.
ringCount	xs:int	*		Total number of rings, including first ring. Valid values: 0 to 100. Default: 1.
vectorStart	xs:double	*		Angle of point along a ring. 0 = north. Valid values: 0 to 360. (degrees) Default: 0.
vectorSpacing	xs:double	*		Number of degrees between receptors. Valid values: 0 to 90. (degrees) Default: 1.
vectorCount	xs:int	*		Number of receptors along the ring. Valid values: 1 to 36. Default: 1.

Attributes: None.

11.5.16 polarReceptor



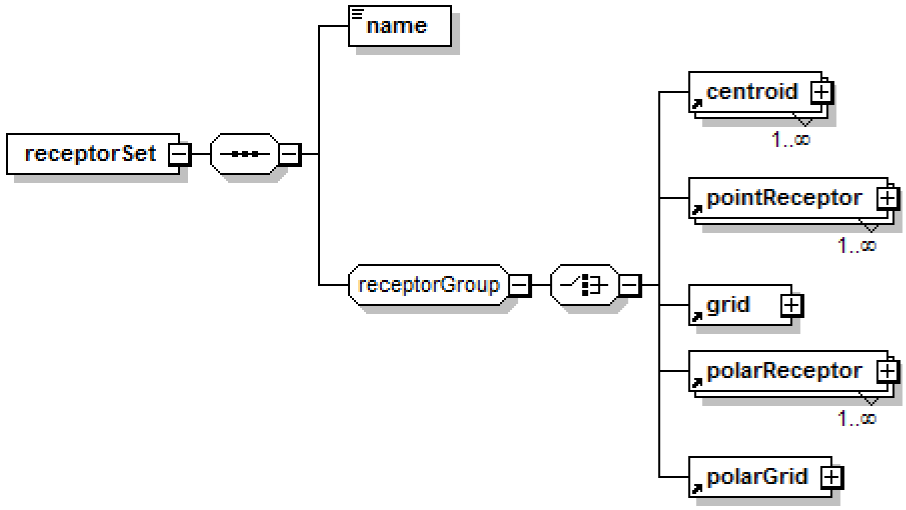
Defines receptor points within a polar grid.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Choice	Description
name	string255	1		A string up to 255 characters long.
coord2DGroup	-	1	a	Indicates how a two-dimensional group is specified. See coord2DGroup.
originSource	originSourceType	*	a	Origin source name for the polar grid (must match a unique name of a specific source reference).
originName	string40	*		Refers to an existing spaceport.
distanceFromSource	xs:double	*		Distance of point form polar origin. Valid values: 0 through 999999.999999 (ft).
directionFromSource	xs:double	*		Direction of point from polar origin. Value values: 0 through 360 (degrees).
elevation	xs:double	*		The point's elevation above MSL (ft). If not specified, RUMBLE will use elevation of spaceport.

Attributes: None.

11.5.17 receptorSet



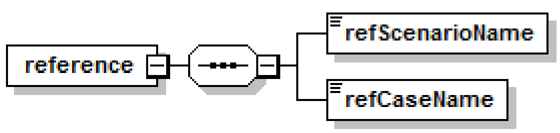
Contains one or more receptor sets at various locations.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	string255	1	Descriptive name of the receptor set.
coord2DGroup	-	1	Description of a receptor group. See receptorGroup.

Attributes: None.

11.5.18 reference



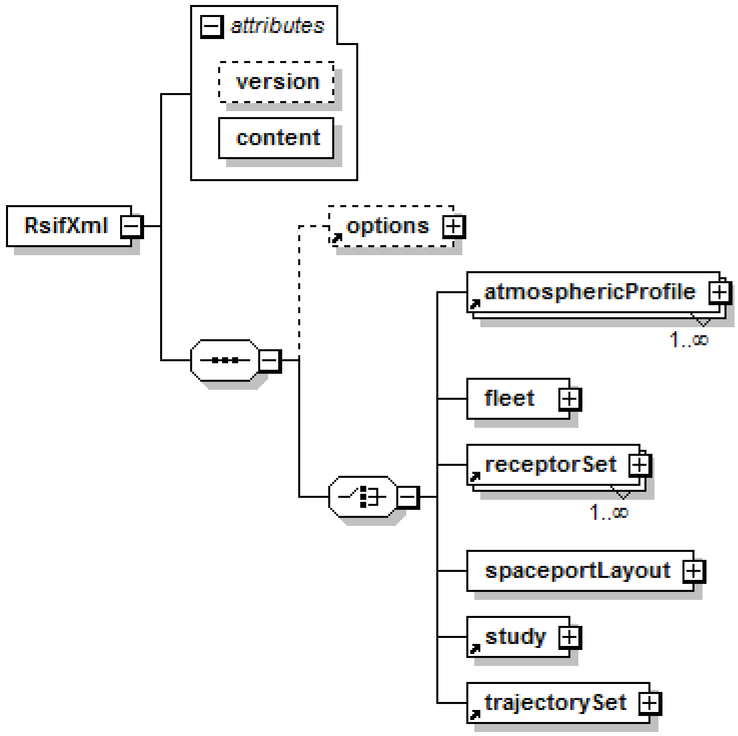
Refers to a case by its scenario name and case name. Conditions required: the referenced case must have a unique name in the new scenario.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
refScenarioName	string255	1	Scenario under which an existing case appears.
refCaseName	string255	1	Existing case that appears under the refScenario.

Attributes: None.

11.5.19 RsifXml



Root node of the RSIF tree.

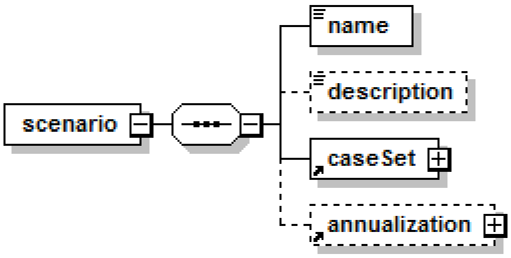
Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Choice	Description
options	-	?		Contains default option values applied to the study. See options.
atmosphericProfile	-	1	a	Contains one or more atmospheric profile descriptions.
fleet	fleet	?	a	Contains study fleet data for RSIF partial import into existing study. See fleet.
receptorSet	-	*	a	Contains one or more receptor sets at various locations. See receptorSet.
spaceportLayout	spaceportLayoutType	1	a	Contains spaceport layout.
study	-	1	a	Contains specific information about a study. See study.
trajectorySet	-	1	a	A set of flight trajectories. See trajectorySet.

Attributes

XML Tag	Type	Use	Description
version	string16	optional	A string up to 16 characters long.
content	xs:string	required	Valid values: atmosphericProfile, fleet, receptorSet, spaceportLayout, study, and trajectorySet.

11.5.20 scenario



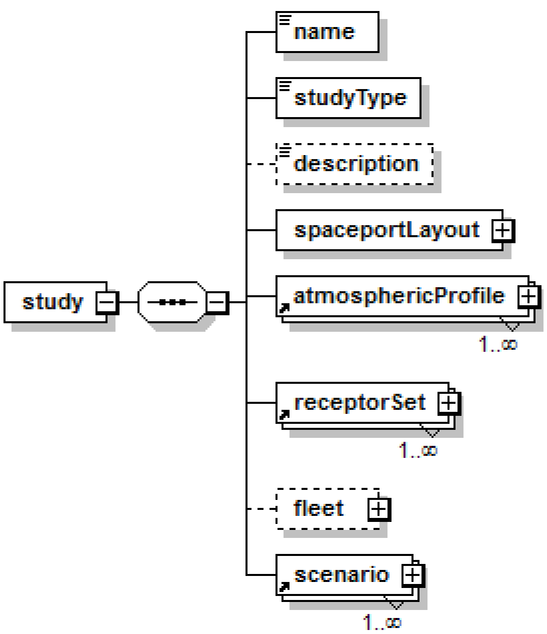
Encapsulates a scenario – such as Baseline or Alternative.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	string255	1	Scenario under which an existing case appears.
description	string255	*	A description of the scenario.
caseSet	-	1	Placeholder for one or more cases. See caseSet.
annualization	-	1	Contains annualizations. See annualization.

Attributes: None.

11.5.21 study



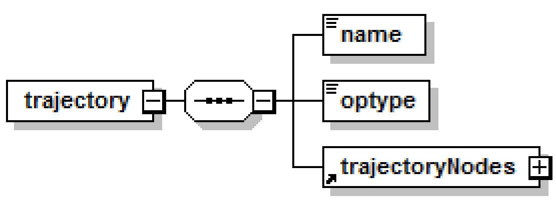
Contains specific information about a study.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	string40	1	Name of the study.
studyType	studyType	1	Type of study. Note that RUMBLE 3.0 only supports the Noise value.
description	string255	*	Optional description of the study.
spaceportLayout	spaceportLayoutType	1	Contains information about the available layout of each spaceport in the study.
atmosphericProfile	-	1	Contains one or more atmospheric profile descriptions. See atmosphericProfile.
receptorSet	-	1	Contains one or more receptor sets at various locations. See receptorSet.
fleet	fleet	*	User-defined spacecraft fleet participating in the study. See fleet.
scenario	-	1	Encapsulates a scenario – such as Baseline or Alternative. See scenario.

Attributes: None.

11.5.22 trajectory



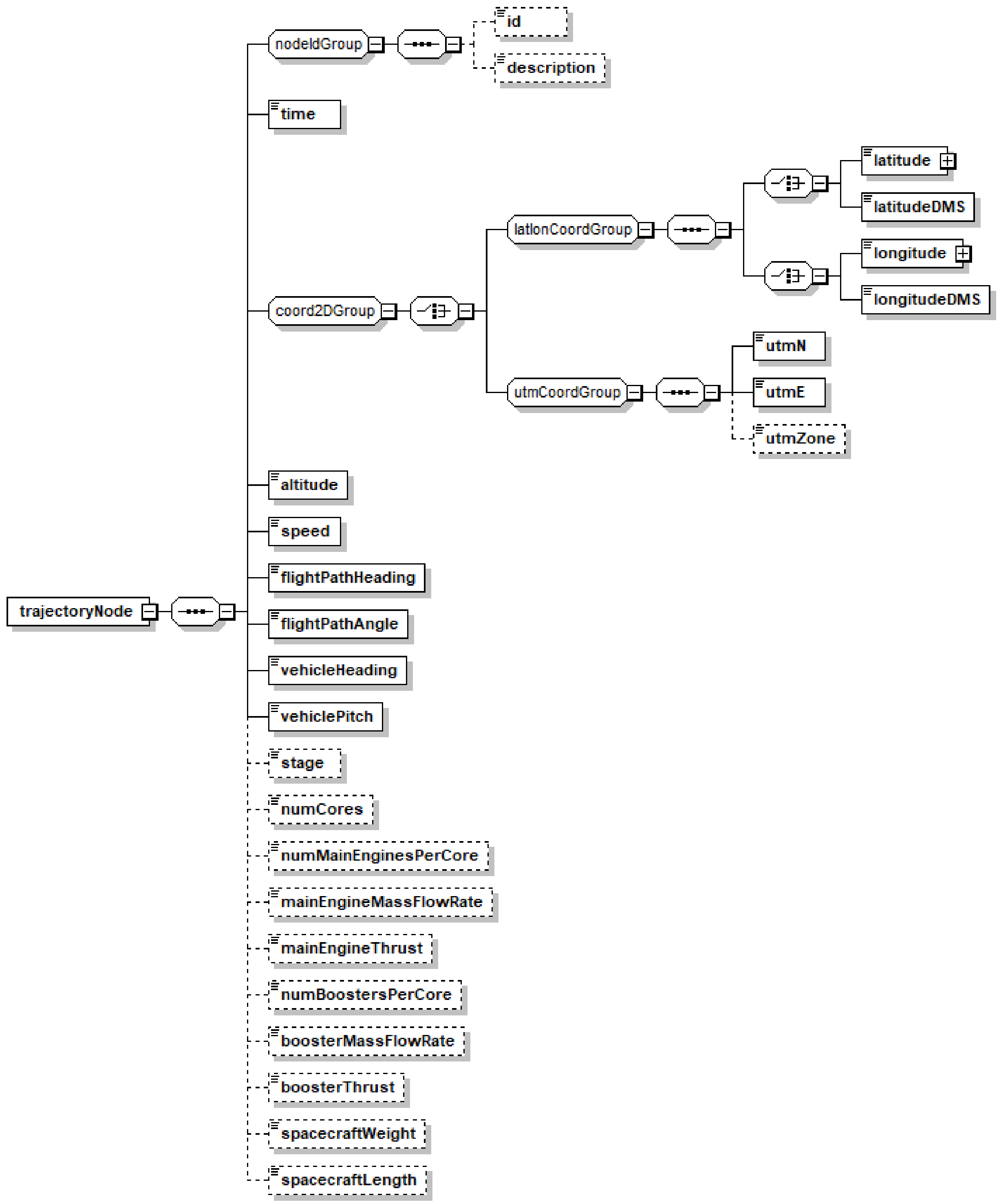
A flight trajectory that can be used for flight operations.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	string64	1	The name of the trajectory
opType	opType	1	Type of operation (Launch, Landing, Static).
trajectoryNodes	-	*	A set of flight trajectory nodes. See trajectoryNodes.

Attributes: None.

11.5.23 trajectoryNode



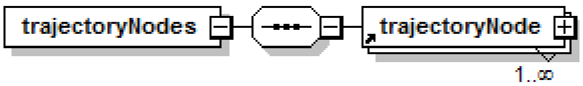
A flight trajectory node.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
nodeIdGroup	-	1	A group of nodes. See nodeIdGroup.
time	xs:double		Elapsed time (seconds).
coord2DGroup	-	1	Indicates how a two-dimensional group is specified. See coord2DGroup.
altitude	xs:double	1	Node's altitude above MSL (ft).
speed	xs:double	1	Speed of spacecraft at node (ft/s). Valid values: nonnegative.
flightPathHeading	xs:double	1	Heading of flight path measured clockwise relative to True North (degrees).
flightPathAngle	xs:double	1	Angle of flight path measured relative to the horizon (positive value indicates climb) (degrees).
vehicleHeading	xs:double	1	Heading of vehicle measured clockwise relative to True North (degrees). If not specified, assume value equivalent to flightPathHeading.
vehiclePitch	xs:double	1	Pitch of vehicle measured relative to the horizon (positive value indicates climb) (degrees). If not specified, assume value equivalent to flightPathAngle.
stage	xs:double	*	Stage number of trajectory segment. Must match stage number specified for the selected spacecraft. If not specified, model will use first stage engines defined in Fleet database.
numCores	xs:double	*	Number of spacecraft cores (main engines + booster). If not specified, assume number of cores defined in the Fleet database.
numMainEnginesPerCore	xs:double	*	Number of main engines per core. If not specified, assume number of main engines defined in Fleet database.
mainEngineMassFlowRate	xs:double	*	Mass flow rate for the spacecraft's main engine(s) (kg/s). Supports user-defined time-varying mass flow rate. If not specified, assume mass flow rate defined in fleet database.
mainEngineThrust	xs:double	*	Net thrust for the spacecraft's main engine(s) (lbf). Supports user-defined time-varying thrust. If not specified, assume thrust defined in fleet database.
numBoostersPerCore	xs:double	*	Number of boosters per core. If not specified, assume number of boosters defined in Fleet database.
boosterMassFlowRate			
boosterThrust	xs:double	*	Net thrust for the spacecraft's boosters (lbf). Supports user-defined time-varying thrust. If not specified, assume thrust defined in fleet database.
massFlowRate	xs:double	*	Mass flow rate for the spacecraft's boosters (kg/s). Supports user-defined time-varying mass flow rate. If not specified, assume mass flow rate defined in fleet database.
spacecraftWeight	xs:double	*	Net weight of the spacecraft (lbs). Supports user-defined time-varying weight. If not specified, assume weight defined in fleet database.
spacecraftLength	xs:double	*	Length of the spacecraft (ft). Supports user-defined time-varying length. If not specified, assume length defined in fleet database.

Attributes: None.

11.5.24 trajectoryNodes



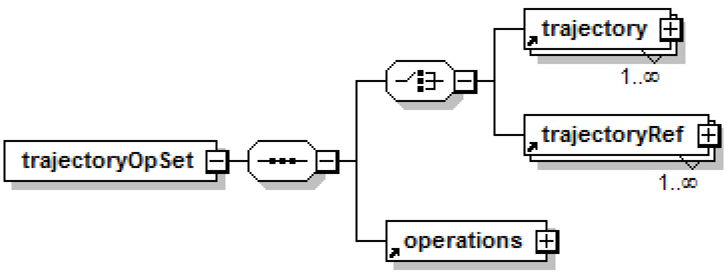
A set of flight trajectory nodes.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
trackNode	-	*	A flight trajectory node. See trajectoryNode.

Attributes: None.

11.5.25 trajectoryOpSet



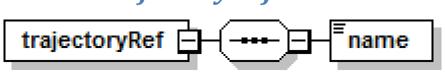
Lists trajectories and associated operations.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Choice	Description
trajectory	-	*	a	A flight trajectory that can be used for flight operations. See trajectory.
trajectoryRef	-	1	a	Reference to a flight trajectory. See trajectoryRef.
operations	-	1		Contains a list of spacecraft flight operations. See operations.

Attributes: None.

11.5.26 trajectoryRef



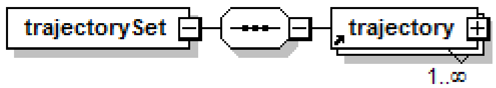
Reference to a flight trajectory.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	string64	1	Name of trajectory.

Attributes: None.

11.5.27 trajectorySet



A set of flight trajectories.

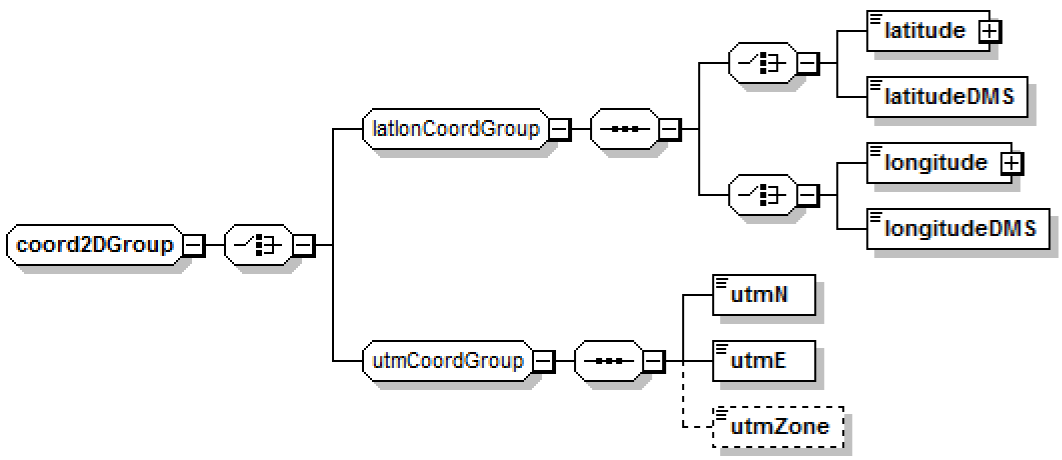
Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
trajectory	-	1	A flight trajectory that can be used for flight operations. See trajectory.

Attributes: None.

11.6 Group Descriptions

11.6.1 coord2DGroup



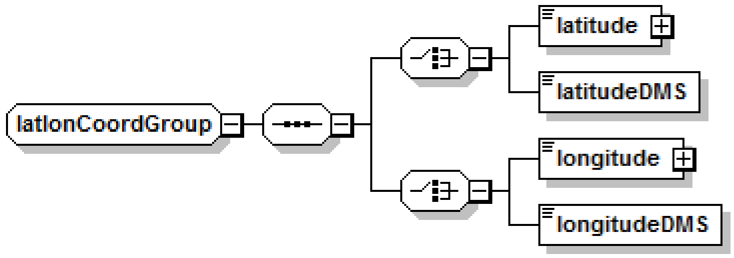
Indicates how a two-dimensional group is specified.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Choice	Description
latlonCoordGroup	-	1	a	Specifies a coordinate using latitude and longitude. See latlonCoordGroup.
utmCoordGroup	-	1	a	Specifies a point using Universal Transverse Mercator coordinates. See utmCoordGroup.

Attributes: None.

11.6.2 latlonCoordGroup



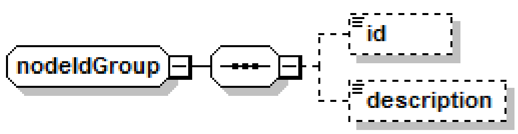
Specifies a coordinate using latitude and longitude.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Choice	Description
latitude	latitudeDecimalType	1	a	Latitude specified as degrees in decimal format. Can include optional attribute positive. See latitudeDecimalType.
latitudeDMS	latitudeDMSType	1	a	Latitude expressed as dd"mm'sss with optional indicator N, n, S, s. See latitudeDMSType.
longitude	longitudeDecimalType	1	b	Longitude specified as degrees in decimal format. Can include optional attribute positive. See longitudeDecimalType.
longitudeDMS	longitudeDMSType	1	b	Longitude expressed as dd"mm'sss with optional indicator E, e, W, w. See longitudeDMSType.

Attributes: None.

11.6.3 nodeIdGroup



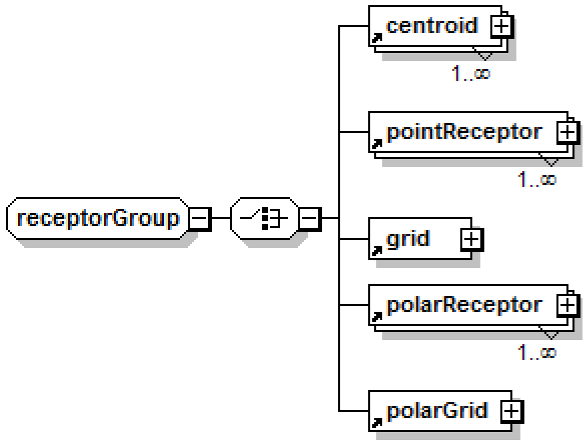
A group of nodes.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
id	string16	*	String identifier for the grouping of nodes.
description	string16	*	An optional description for the grouping of nodes.

Attributes: None.

11.6.4 receptorGroup



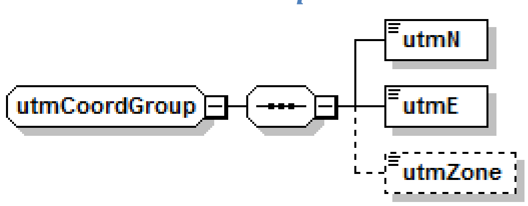
Description of a receptor group.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Choice	Description
centroid	-	1	a	Describes the geometric center of a polygon. See centroid.
pointReceptor	-	1	a	Element specification for a point receptor. See pointReceptor.
grid	-	1	a	Describes a grid of points. See grid.
polarReceptor	-	1	a	Defines receptor points within a polar grid. See polarReceptor.
polarGrid	-	1	a	Describes a two-dimensional grid of individual receptors over an annular sector (polar) of the study area. See polarGrid.

Attributes: None.

11.6.5 utmCoordGroup



Specifies a point using Universal Transverse Mercator coordinates.

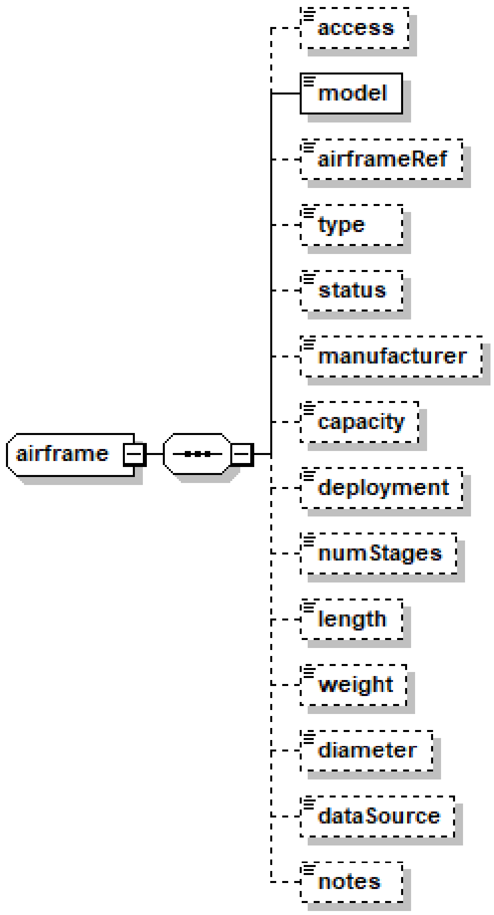
Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
utmN	xs:double	1	UTM Northing of the point in decimal meters north of the equator.
utmE	xs:double	1	UTM Easting of the point in decimal meters east from a central meridian.
utmZone	xs:int	?	UTM Zone of the point. A default zone can be set in the <options> tag. Default: -1.

Attributes: None.

11.7 Complex Type Descriptions

11.7.1 airframe



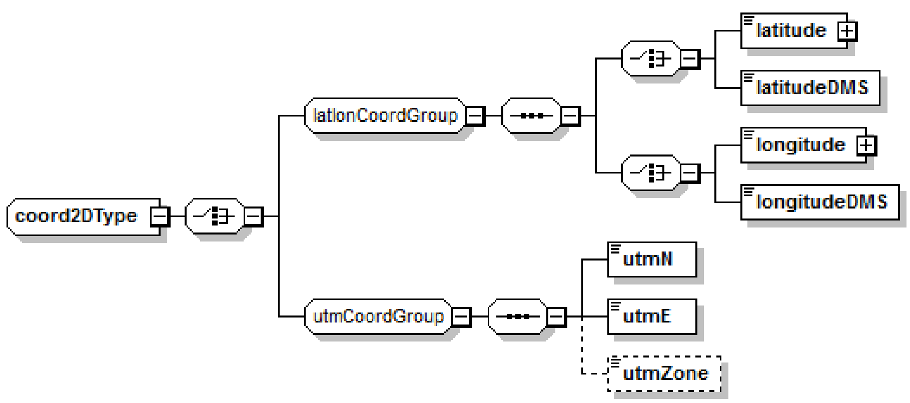
This element supports the definition of custom airframes.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
model	airframeModel	1	Unique description of airframe.
airframeRef	xs:int	*	AST STAR Database reference.
type	string40	*	AST STAR Database type designation: Expendable Launch Vehicle (ELV), Reusable Launch Vehicle (RLV), Suborbital.
status	string40	*	AST STAR Database status designation: Design/Development, No Longer in Service, and Operational.
manufacturer	string100	*	Airframe manufacturer.
capacity	string40	*	AST STAR Database capacity designation: Heavy, Intermediate, Medium, Small, and Suborbital.
deployment	string40	*	AST STAR Database deployment designation: Orbital and Suborbital.
numStages	xs:int	*	Number of Stages.
length	xs:double	*	Length of this airframe (ft).
weight	xs:double	*	Weight of this airframe (lbs).
diameter	xs:double	*	Diameter of this airframe (ft).
dataSource	string100	*	Source of airframe data.
notes	string200	*	Free-text notes for the airframe.
access	string40	*	Data access description: public or non-public.

Attributes: None.

11.7.2 coord2DType



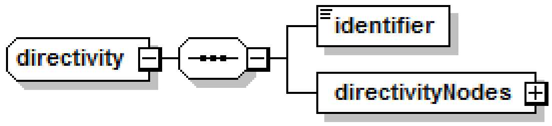
A 2D point coordinate.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Choice	Description
latlonCoordGroup	-	1	a	Specifies a coordinate using latitude and longitude. See latlonCoordGroup.
utmCoordGroup	-	1	a	Specifies a point using Universal Transvers Mercator coordinates. See utmCoordGroup.

Attributes: None.

11.7.3 directivity



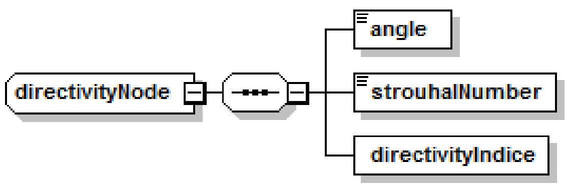
This element supports the definition of custom directivities.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
Identifier	string40	1	The unique identifier for this user defined directivity.
directivityNodes	directivityNodes	1	A set of directivity nodes. See directivityNodes.

Attributes: None.

11.7.4 directivityNode



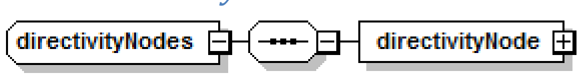
A directivity node.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
angle	xs:double	1	Angle measured from the plume exit angle to the receptor (degrees).
strouhalNumber	xs:double	1	Strouhal number = frequency times nozzle exit diameter divided by nozzle exit velocity (dimensionless).
directivityIndice	xs:double	1	Directivity indice characterizes directivity of sound radiation for the angle and strouhal number (dB).

Attributes: None.

11.7.5 directivityNodes



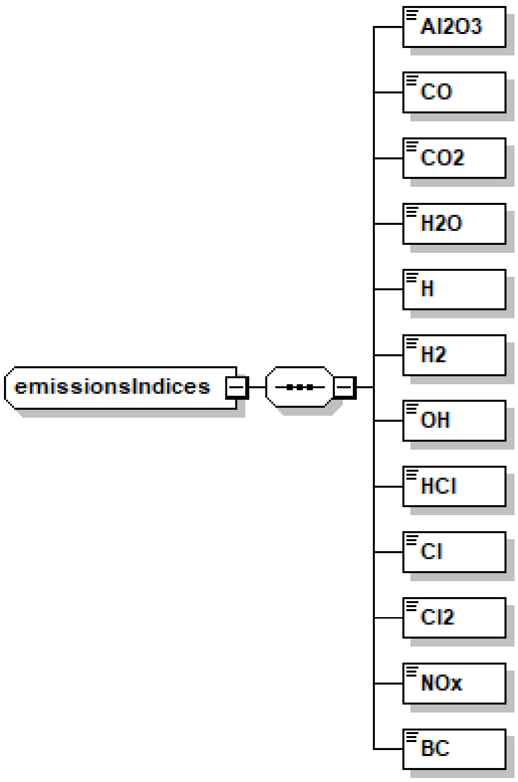
A set of directivity nodes.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
directivityNode	directivityNode	1	A directivity node. See directivityNode.

Attributes: None.

11.7.6 emissionsIndices



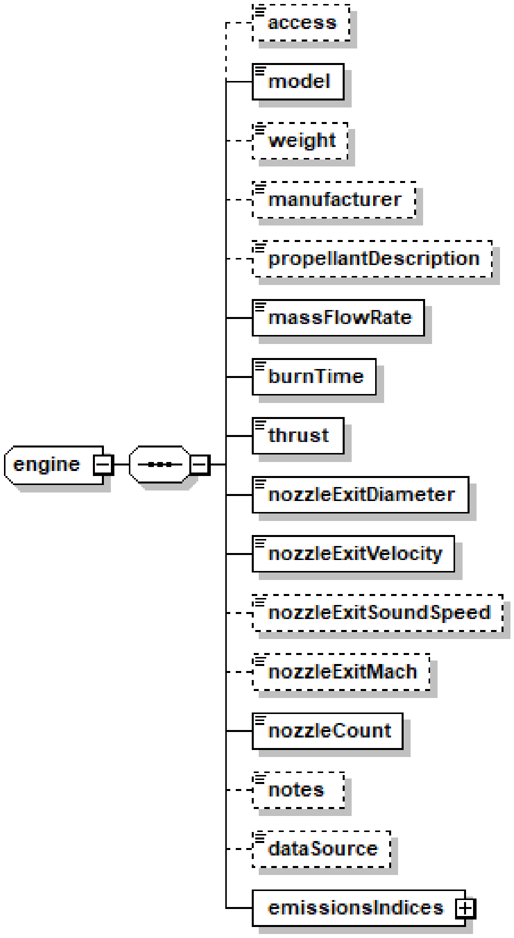
This block describes the engines primary emissions indices.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
Al2O3	xs:double	1	Primary emissions index for Aluminum Oxide (Al_2O_3) (g/kg).
CO	xs:double	1	Primary emissions index for Carbon Monoxide (CO) (g/kg).
CO2	xs:double	1	Primary emissions index for Carbon Dioxide (CO_2) (g/kg).
H2O	xs:double	1	Primary emissions index for water (H_2O) (g/kg).
H	xs:double	1	Primary emissions index for Atomic Hydrogen (H) (g/kg).
H2	xs:double	1	Primary emissions index for Diatomic Hydrogen (H_2) (g/kg).
OH	xs:double	1	Primary emissions index for Hydroxyl (OH) (g/kg).
HCl	xs:double	1	Primary emissions index for Hydrogen Chloride (HCl) (g/kg).
Cl	xs:double	1	Primary emissions index for Atomic Chlorine (Cl) (g/kg).
Cl2	xs:double	1	Primary emissions index for Diatomic (Cl_2) (g/kg).
NOx	xs:double	1	Primary emissions index for Nitrogen Oxides (NOx) (g/kg).
BC	xs:double	1	Primary emissions index for Black Carbon (BC) (g/kg).

Attributes: None.

11.7.7 engine



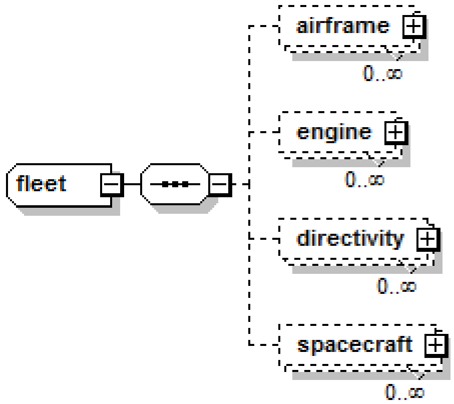
User-defined engine information containing custom parameters that reflect a spacecraft engine. This engine definition can be used within a user-defined spacecraft.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
model	engineModel	1	Engine model.
weight	xs:double	*	Dry weight of this engine (lbs).
manufacturer	string100	*	Engine manufacturer.
propellantDescription	string255	*	Description of engine propellant.
massFlowRate	xs:double	1	Mass flow rate of engine propellant (kg/s).
burnTime	xs:double	1	Burn time of engine (sec).
thrust	xs:double	1	Net thrust for the engine (lbf).
nozzleExitDiameter	xs:double	1	Nozzle exit diameter for the engine (ft).
nozzleExitVelocity	xs:double	1	Nozzle exit velocity for the engine (ft/sec).
nozzleExitSoundSpeed	xs:double	*	Nozzle exit sound speed for the engine (ft/sec).
nozzleExitMach	xs:double	*	Nozzle exit Mach for the engine (nozzleExitVelocity ÷ nozzleExitSoundSpeed).
nozzleCount	xs:int	1	Number of nozzles for the engine.
notes	string200	*	Free-text notes for the engine.
dataSource	string100	*	Source of engine data.
access	string40	*	Data access description: public or non-public.
emissionsIndices	emissionsIndices	*	This block describes the primary emissions indices. See emissionsIndices.

Attributes: None.

11.7.8 fleet



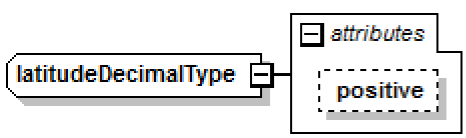
Main block for creating user defined fleet/spacecraft data.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
airframe	airframe	*	Supports the definition of custom airframes. See airframe.
engine	engine	*	User defined engine information containing custom parameters that reflect an engine. This engine definition can then be used within a user-defined spacecraft. See engine.
directivity	directivity	*	This element supports the definition of custom directivities. See directivity.
spacecraft	spacecraft	*	A block used to create new user defined AEDT aircraft. See spacecraft.

Attributes: None.

11.7.9 latitudeDecimalType

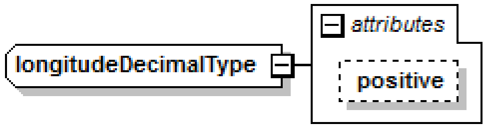


Latitude specified as degrees in decimal format. Can include optional attribute positive. (decimal degrees)

Attributes

XML Tag	Type	Use	Description
positive	xs:string	optional	Valid values: N, n, S, s.

11.7.10 longitudeDecimalType

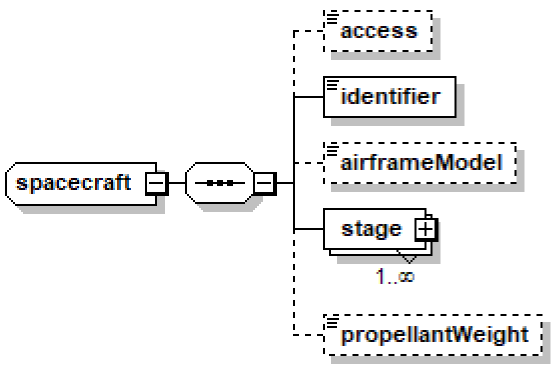


Longitude specified as degrees in decimal format. Can include optional attribute positive. (decimal degrees)

Attributes

XML Tag	Type	Use	Description
positive	xs:string	optional	Valid values: E, e, W, w.

11.7.11 spacecraft



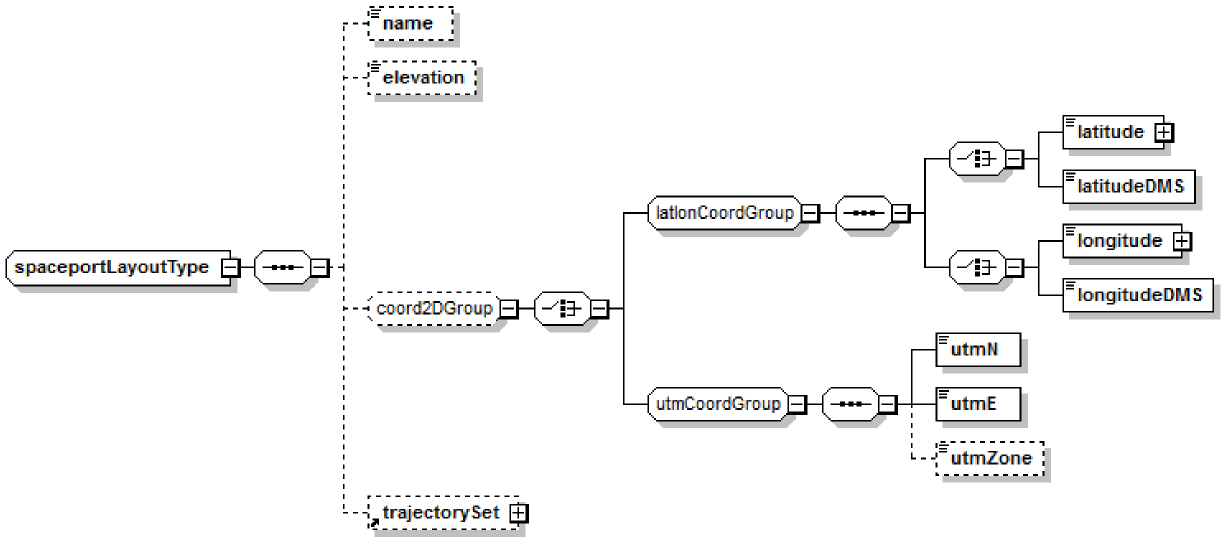
Main block for creating new user defined spacecraft.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
identifier	spacecraftId	*	The unique identifier for this user defined spacecraft.
description	string255	*	The description for this user defined spacecraft.
airframeModel	airframeModel	*	The airframe model used for this user defined spacecraft.
stage	stage	1	This block describes each stage.
propellantWeight	xs:double	*	Total weight of propellant for this spacecraft (lbs).
access	string40	*	Data access description: public or non-public.

Attributes: None.

11.7.12 spaceportLayoutType



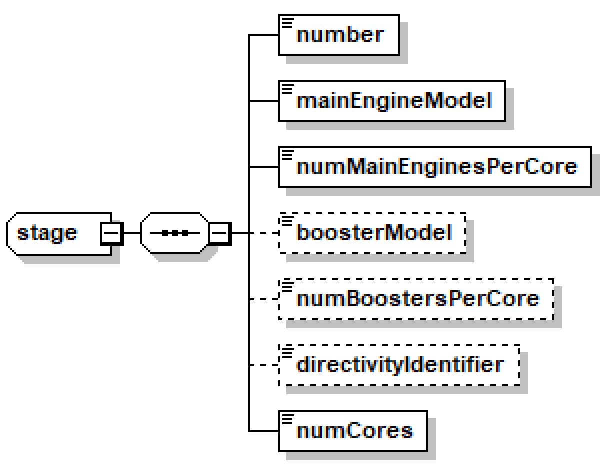
Fields defining a spaceport and its layout.

Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
name	string255	*	Id of the layout. Must be unique.
elevation	xs:double	*	The elevation above MSL (ft).
coord2DGroup	-	*	Indicates how a two-dimensional group is specified. See coord2DGroup.
trajectorySet	-	*	A set of flight trajectories. See trajectorySet.

Attributes: None.

11.7.13 stage

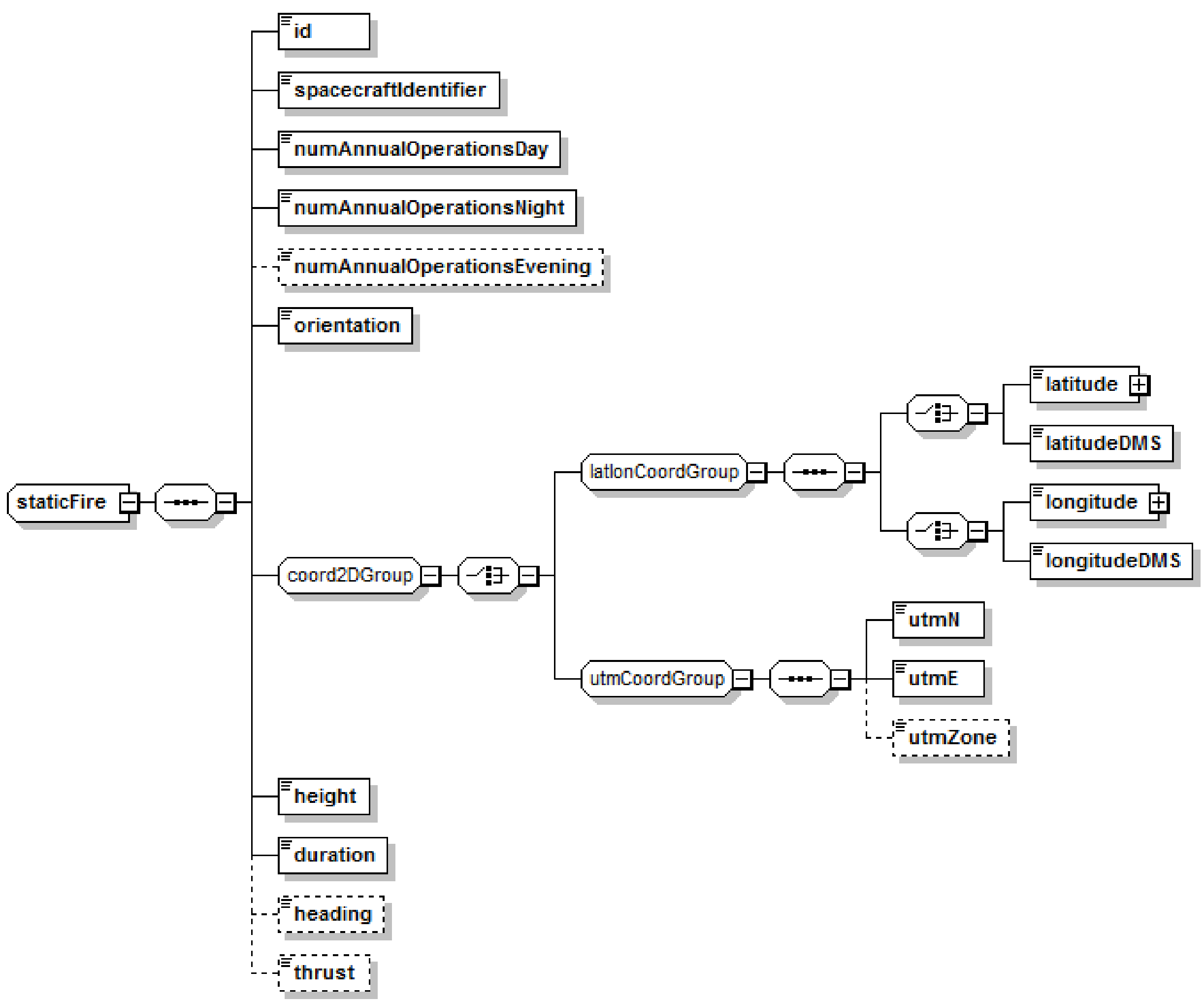


Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
number	xs:double	1	Stage number.
mainEngineModel	engineModel	1	The main engine model used for this stage.
numMainEnginesPerCore	xs:double		Number of main engines per core for this stage.
boosterModel	engineModel		The booster model used for this stage.
numBoostersPerCore	xs:double		Number of boosters per core for this stage.
directivityIdentifier	directivityId		The unique identifier for directivity for this stage.
numCores	xs:double	1	Number of cores for this stage.

Attributes: None.

11.7.14 staticFire



Structure (see Notation for information about reading this table).

XML Tag	Type	Num	Description
Id	string16	1	User specified identifier for the static fire operation.
spacecraftIdentifier	spacecraftId	1	Spacecraft identifier.
numAnnualOperationsDay	xs:double	1	Number of annual acoustic daytime operations comprising this operation, where daytime hours are: (7:00 am to 10:00 pm) or (7:00 am to 7:00 pm) when evening operations are defined.
numAnnualOperationsNight	xs:double	1	Number of acoustic annual nighttime operations comprising this operation, where nighttime hours are: (10:00 pm to 7:00 am).
numAnnualOperationsEvening	xs:double	*	Number of annual acoustic evening operations comprising this operation, where evening hours are: (7:00 pm to 10:00 pm).
orientation	string16	1	Orientation of vehicle (vertical or horizontal).
coord2DGroup	-	1	Indicates how a two-dimensional group is specified. See coord2DGroup.
height	xs:double	1	The height of the vehicle above ground (ft).
duration	xs:double	1	The duration of the static fire.
heading	xs:double	*	The orientation of the spacecraft (degrees). If not specified, vehicle orientation is vertical.
thrust	xs:double	*	The thrust employed for this static fire operation (lbf). If not specified, model will use thrust from fleet database.

Attributes: None.

11.8 Simple Type Descriptions

11.8.1 airframeModel

Refers to an existing airframe model.

Attributes: None.

11.8.2 engineModel

Attributes: None.

11.8.3 engineType

Type of engine on this airframe.

Attributes: None.

11.8.4 directivityId

ID of directivity data. Must be a new, unique value.

Attributes: None.

11.8.5 latitudeDMSType
Latitude expressed as dd"mm'sss with optional indicator N, n, S, s (degrees).

Attributes: None.

11.8.6 longitudeDMSType
Longitude expressed as dd"mm'sss with optional indicator N, n, S, s (degrees).

Attributes: None.

11.8.7 opType
Type of operation.

Valid values: Launch, Landing, and Static Fire.

Attributes: None.

11.8.8 originSourceType
Supports the polarReceptor source type. Original source type can be spaceport.

Valid values: Spaceport.

Attributes: None.

11.8.9 spacecraftId
ID of spacecraft. Must be a new, unique value.

Attributes: None.

11.8.10 string100
A string up to 100 characters long.

Attributes: None.

11.8.11 string16
A string up to 16 characters long.

Attributes: None.

11.8.12 string200
A string up to 200 characters long.

Attributes: None.

11.8.13 string255
A string up to 255 characters long.

Attributes: None.

11.8.14 string40
A string up to 40 characters long.

Attributes: None.

11.8.15 string6
A string up to six characters long.

Attributes: None.

11.8.16 string64
A string up to 64 characters long.

Attributes: None.

11.8.17 string8
A string up to eight characters long.

Attributes: None.

11.8.18 studyType
Type of study.

Valid values: Noise, Emissions.

Attributes: None.

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