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Survey of Service Difficulty Reports for In-service Damage in Transport Category Aircraft

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16. Abstract

A data mining tool (DMT) has been developed to extract data for in-service damage that occurs in transport category aircraft during typical part 121 revenue services from the FAA's Service Difficulty Report database. This project is conducted by the Sandia National Laboratories with close collaboration with the FAA William J. Hughes Technical Center and the FAA Transport Airplane Directorate. The DMT strategy and development, collected data, and the testing and validation of the DMT is discussed in details. An appendix is included that serves as the user manual for the developed tool.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AANC	Airworthiness Assurance Nondestructive Inspection Validation Center
AD	Airworthiness Directive
AIR	Aircraft Certification Service
ARAC	Aviation Rulemaking Advisory Committee
ATA	Air Transport Association of America
CFR	Code of Federal Regulations
COS	Continued Operational Safety
DMT	Data mining tool
DWP	Detailed Work Plan
FCBS	Fatigue critical baseline structure
GSHWG	General Structures Harmonization Working Group
JASC	Joint Aircraft System/Component
MSAD	Monitor Safety-Analyze Data
ND	(Conditional probability of) Not Detecting
NDI	Nondestructive inspection
NLP	Natural language processing
SDC	Structural Damage Capability
SDR	Service Difficulty Reports
SMS	Safety Management System
SRM	Structural Repair Manual
TARAM	Transport Airplane Risk Assessment Methodology

EXECUTIVE SUMMARY

A data mining tool (DMT) has been developed to extract data for in-service damage that occurs in transport category aircraft during typical part 121 revenue services from the FAA's Service Difficulty Report database. This project was conducted by Sandia National Laboratories with close collaboration by the FAA William J. Hughes Technical Center and the FAA Transport Airplane Directorate. The DMT strategy and development, collected data, and the testing and validation of the DMT is discussed in details. An appendix is included that serves as the user manual for the developed tool.

INTRODUCTION

The high-level goals of this project were to [1]:

- Provide the FAA with databases to support the estimates of the conditional probability of not detecting (ND) airplane structural fatigue damage before it becomes critical; used in Transport Airplane Risk Assessment Methodology (TARAM). This portion of the project is referred to as ND-TARAM in this report.
- Quantify and document the largest in-service cracks (fatigue or accidental) that occur in transport aircraft in support of a new Aviation Rulemaking Advisory Committee (ARAC) activity to reintroduce the concept of fail-safety in Title 14 Code of Federal Regulations (CFR) Part 25.571 via Structural Damage Capability (SDC).
- Provide the FAA with a data mining tool (DMT) that can be used in the future as additional Service Difficulty Reports (SDRs) are collected.

The first two goals are explored in more detail as follows. Afterwards, the remainder of this report is focused on the development, testing, and validation of the DMT.

ND-TARAM

In support of Safety Management System (SMS) development within the FAA and other international organizations, the Aircraft Certification Service (AIR) is revising existing processes to embrace the concept of a SMS. One of the most important efforts is the implementation of a Continued Operational Safety (COS) management process based on SMS concepts. AIR SMS Order 8110.107A was issued March 12, 2010 and became effective September 15, 2010. The Monitor Safety-Analyze Data (MSAD) is a standardized, COS process based on SMS principles. The MSAD process is used throughout AIR for the resolution of aircraft safety issues.

TARAM is the risk analysis process for transport category airplanes. TARAM defines a process for calculating the risk associated with all aspects of transport airplanes' design-related safety issues. TARAM is an integral part of the requirements contained in FAA Order 8110.107A, MSAD.

One of the parameters used in the TARAM analysis of an airplane's structure fatigue issue is ND, which is the conditional probability that an occurrence of a defect (fatigue crack) will not be detected before it leads to an unsafe outcome (i.e., airplane accident) [2]. There is a tendency for analysts to be extremely conservative in their estimates of ND. Because the calculated risk is directly proportional to ND, large errors in estimating ND will lead to large errors in the calculated risk. The calculated risk values are used to make safety decisions and to determine acceptable compliance times. Excessively conservative values for ND could lead to unnecessary Airworthiness Directives (ADs) or ADs with unnecessarily aggressive compliance times (ADs are legally enforceable regulations issued by FAA to correct an unsafe product). This is contrary to the intent of a TARAM risk analysis, which is to provide the best estimate of the risk and then base the safety decisions and risk management on the estimated risk.

Phase I of this project started by identifying the best source of data to be used in estimating the risk associated with ND of fatigue damage. After working with the air carrier maintenance industry

to obtain crack-finding information, the Airworthiness Assurance Nondestructive Inspection Validation Center (AANC) determined that the best and most readily available source of crack-finding data was already being collected and available in the SDR database. Moreover, the FAA SDR submittals were validated to be consistent between the operator and the FAA.

Having chosen the FAA SDR database as the source, a search protocol was developed to collect data efficiently and consistently while populating a TARAM crack-finding database. As the results of the efforts during Phase I, a TARAM crack-finding database was created for a Boeing 737-3H4 with a serial number (SN) of 22940 and 1984 date of manufacture. A total of 247 cracks were entered into the TARAM crack-finding database for airplane 22940. In order for the FAA staff to easily locate each crack entered, pictures were taken from the Structural Repair Manual (SRM) for that airplane and inserted into the corresponding crack-finding worksheet. Only a few pictures were incorporated into the crack-finding database, in part because of lack of location description in the SDR submittal and the time required to cull through the extensive information in the relevant SRM [3]. The finding during this effort was used later in verification of the automated data mining tool.

It was anticipated that the time required for creating and updating the ND-TARAM crack-finding database would reduce the time needed to find and enter each crack into the database because the groundwork is completed. The time per crack finding was estimated to be 15 minutes per crack [3].

ARAC SDC

The FAA recently issued a notice of a new tasking assignment for the ARAC on January 26, 2015. The task required the Transport Airplane Metallic and Composite Structure Working Group to provide recommendations regarding damage tolerance and fatigue requirements in the pertinent sections of 14 CFR for advanced metallic, composites, and hybrid materials [4]. In addition, the new tasking addresses the two remaining recommendations provided by the General Structures Harmonization Working Group (GSHWG) from 2003: 1) replace the prescriptive-based requirement for establishing inspection thresholds based on crack growth analysis to a performance-based requirement accounting for variations in manufacturing quality, and 2) include the fail-safe concepts in 14 CFR 25.571, pre-amendment 25–45, by adding a requirement showing structural capability in the presence of damage including partial structural failure, demonstrating the remaining structure can carry residual strength load with partial structural failure.

Data are needed to address the second GSHWG recommendation to reintroduce the concept of fail-safety back into 14 CFR 25.571 via SDC (i.e., the attribute of the structure that permits it to retain its required residual strength in the presence of large damage). It is proposed that all structures evaluated in accordance with the requirements of 14 CFR 25.571(b) also have a minimum specified level of SDC. The intent of this proposal is to mandate a minimum level of tolerance to damage regardless of type or source. Further background information is proved in the proposed rule by the GSHWG.

The development of the DMT is considered next.

DMT DEVELOPMENT

The DMT development strategy used the "scrum" methodology. A schematic of the scrum methodology is shown in figure 1, which explains the two-week development process that is repeated until the project is complete. First, a vision of all features ideal to have in the final product is compiled. Each feature is compiled in the "Product Backlog." Then there is a planning session where features are prioritized, and the most important ones are assigned into the current "Sprint Backlog," which is the work expected to be accomplished in the two-week development period. Each day within the two-week scrum process contains a short daily meeting to assess the progress of the sprint. Once the "Product Increment" is developed, a "Sprint Review" meeting is held to review the progress that has been made in the past two weeks. These "Sprint Review" meetings are held during the scheduled teleconferences throughout the project. Anything that is not finished goes back into the "Product Backlog," and the whole scrum process starts over.
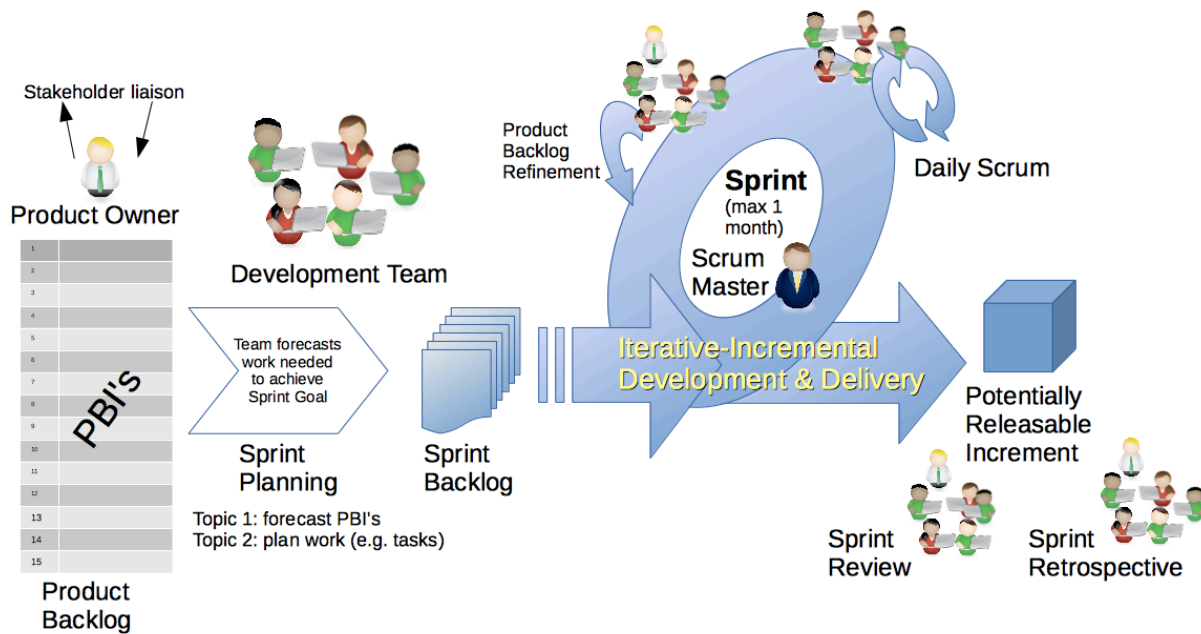

Figure 1. SCRUM methodology schematic

The DMT programming and data extraction was coded in C# using Microsoft® Visual Studio™ and Microsoft SQL Server™. The database containing data from the SDR included data from the Aviation Systems Branch (AFS-620). All reports generated by the DMT will be delivered in Microsoft Excel and DMT output options will include Excel format. The DMT was then tested and validated, which will be described in this report.

The use of natural language processing (NLP) was developed to extract data about location and length of cracks identified in the SDR discrepancy description field. Figure 2 is a schematic of the NLP process and description of each component.
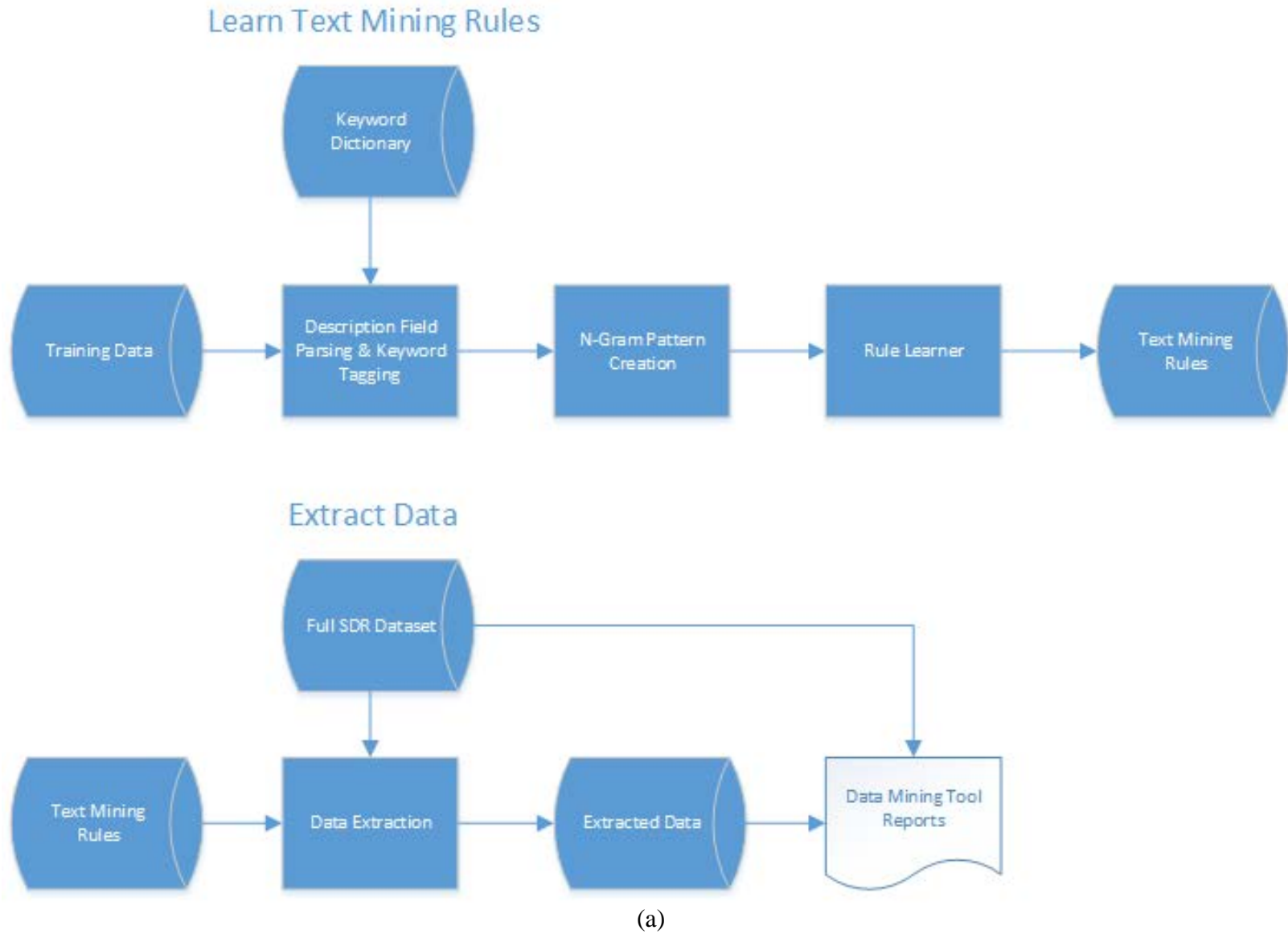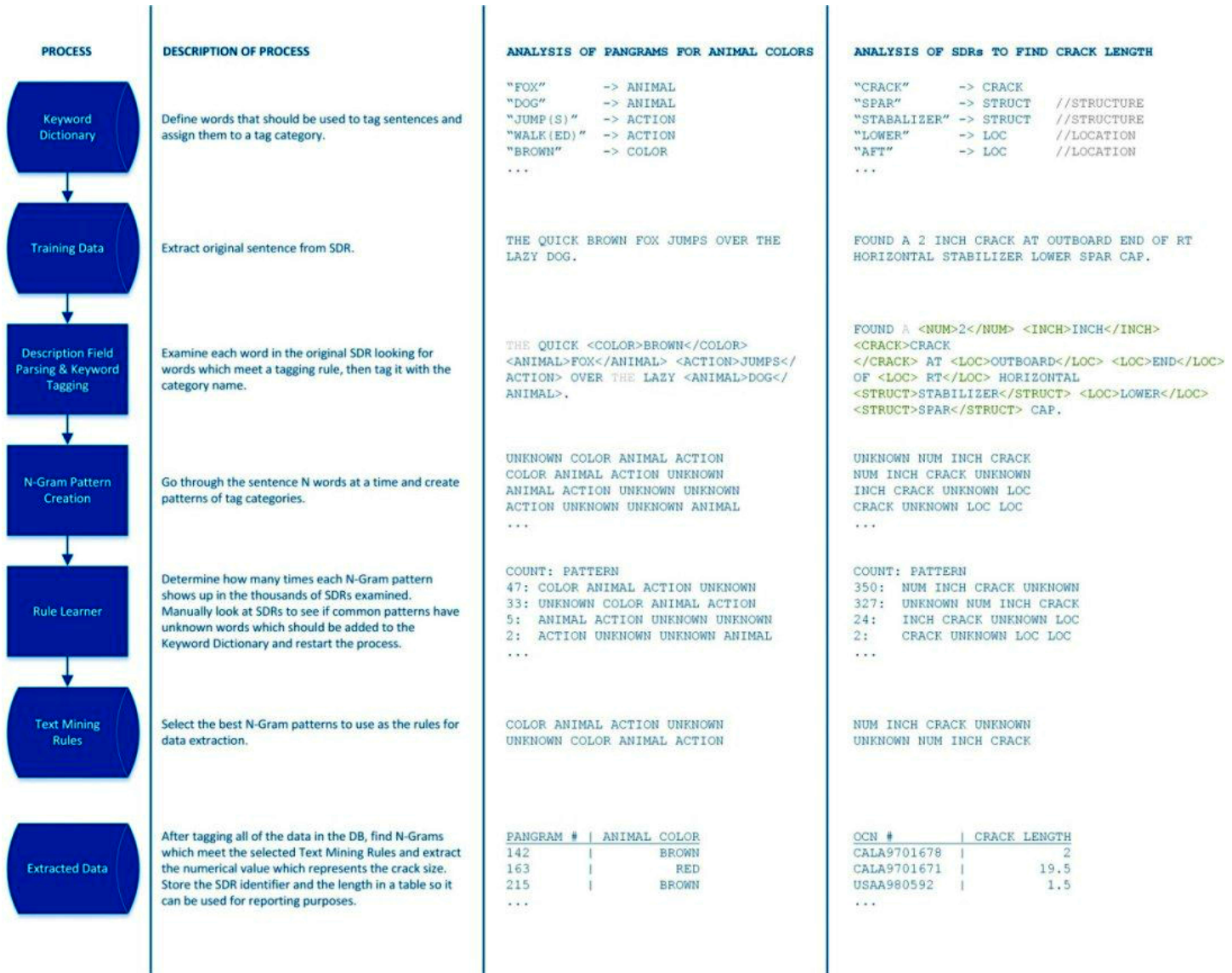
Figure 2. NLP extraction schematic of: (a) process, and (b) description

PROCESS	DESCRIPTION OF PROCESS	ANALYSIS OF PANGRAMS FOR ANIMAL COLORS	ANALYSIS OF SDRs TO FIND CRACK LENGTH

Keyword Dictionary	Define words that should be used to tag sentences and assign them to a tag category.	`"FOX"        -> ANIMAL`
		`"DOG"        -> ANIMAL`
		`"JUMP(S)"    -> ACTION`
		`"WALK(ED)"   -> ACTION`
		`"BROWN"      -> COLOR`
		`...`
			`"CRACK"        -> CRACK`
			`"SPAR"         -> STRUCT    //STRUCTURE`
			`"STABALIZER"   -> STRUCT    //STRUCTURE`
			`"LOWER"        -> LOC      //LOCATION`
			`"AFT"          -> LOC      //LOCATION`
			`...`

Training Data	Extract original sentence from SDR.	`THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG.`	`FOUND A 2 INCH CRACK AT OUTBOARD END OF RT HORIZONTAL STABILIZER LOWER SPAR CAP.`
Description Field Parsing & Keyword Tagging	Examine each word in the original SDR looking for words which meet a tagging rule, then tag it with the category name.	`THE QUICK <COLOR>BROWN</COLOR> <ANIMAL>FOX</ANIMAL> <ACTION>JUMPS</ACTION> OVER THE LAZY <ANIMAL>DOG</ANIMAL>.`	`FOUND A <NUM>2</NUM> <INCH>INCH</INCH> <CRACK>CRACK </CRACK> AT <LOC>OUTBOARD</LOC> <LOC>END</LOC> OF <LOC> RT</LOC> HORIZONTAL <STRUCT>STABILIZER</STRUCT> <LOC>LOWER</LOC> <STRUCT>SPAR</STRUCT> CAP.`

N-Gram Pattern Creation	Go through the sentence N words at a time and create patterns of tag categories.	`UNKNOWN COLOR ANIMAL ACTION`
		`COLOR ANIMAL ACTION UNKNOWN`
		`ANIMAL ACTION UNKNOWN UNKNOWN`
		`ACTION UNKNOWN UNKNOWN ANIMAL`
		`...`
			`UNKNOWN NUM INCH CRACK`
			`NUM INCH CRACK UNKNOWN`
			`INCH CRACK UNKNOWN LOC`
			`CRACK UNKNOWN LOC LOC`
			`...`

Rule Learner	Determine how many times each N-Gram pattern shows up in the thousands of SDRs examined. Manually look at SDRs to see if common patterns have unknown words which should be added to the Keyword Dictionary and restart the process.	`COUNT: PATTERN`
		`47: COLOR ANIMAL ACTION UNKNOWN`
		`33: UNKNOWN COLOR ANIMAL ACTION`
		`5:  ANIMAL ACTION UNKNOWN UNKNOWN`
		`2:  ACTION UNKNOWN UNKNOWN ANIMAL`
		`...`
			`COUNT: PATTERN`
			`350: NUM INCH CRACK UNKNOWN`
			`327: UNKNOWN NUM INCH CRACK`
			`24:  INCH CRACK UNKNOWN LOC`
			`2:   CRACK UNKNOWN LOC LOC`
			`...`

Text Mining Rules	Select the best N-Gram patterns to use as the rules for data extraction.	`COLOR ANIMAL ACTION UNKNOWN` `UNKNOWN COLOR ANIMAL ACTION`	`NUM INCH CRACK UNKNOWN` `UNKNOWN NUM INCH CRACK`
Extracted Data	After tagging all of the data in the DB, find N-Grams which meet the selected Text Mining Rules and extract the numerical value which represents the crack size. Store the SDR identifier and the length in a table so it can be used for reporting purposes.	`PANGRAM #	ANIMAL COLOR` `142	BROWN` `163	RED` `215	BROWN` `...`	`OCN #	CRACK LENGTH` `CALA9701678	2` `CALA9701671	19.5` `USAA980592	1.5` `...`

(b)

Figure 2. NLP extraction schematic of: (a) process, and (b) description (continued)

When using NLP to try to extract crack lengths, 1497 distinct 4-gram patterns were found. That included patterns that only occurred a single time in the 16,000 records containing a populated "Crack Length" value (a subset of the data from the Aviation Systems Branch [AFS-620]). Because patterns were found in hundreds of records, a low occurrence count was not thought to add significantly to the total extraction, so it was determined that a pattern must occur at least 20 times in the training data for it to be worth using against the full dataset. To avoid using bad patterns, a rule that did not extract a correct numerical value at least 85% of the time was dropped when running the final NLP extraction. Using that criteria, the actual NLP patterns used to find crack-length data were reduced down to 44 much more frequently occurring and accurate patterns, which still took more than 7 hours to process. Similarly, 395 potential "Number of Crack" patterns were reduced to 13 patterns actually used for data extraction.

COLLECTED DATA

Instructions for using the DMT are given under the "Help" menu and in Appendix A. The DMT was developed at Sandia National Laboratories to search the database for information by using the user-defined filtering and keyword-generation capability. Examples of some of the filters include Air Transport Association of America (ATA) codes, different aircraft models, and aircraft submodels. Examples of keywords already included in the DMT include those in the cracking keywords filter such as crack, crak, torn, split, crck, and tear. Once the keywords and filtering criteria are set up, then reports can be generated to be accessed on the DMT site or by exporting the reports to Excel™. Other capabilities of the DMT include its ability to extract the number of cracks, the crack length, and the location of the crack for the user-defined filtering and keyword parameters. Because of the large size of the tables in the reports, file names created and delivered to the FAA are included below:

- Report_A.xlsx
- Report A_Insufficient.xlsx
- Report_ARAC-1.xlsx
- TableA_Crack_Count_By_Model.xlsx
- Report_B_C_D.xlsx
- Report B_C_D_Insufficient.xlsx
- TableBandC.xlsx
- ARAC_ReportwithSDRs_TopFiveResults.xlsx
- ARAC_ReportwithSDRs_TopTenResults.xlsx
- FindSDRResultsForCrackingKeywords.xlsx

DMT TESTING AND VALIDATION

The DMT was developed in two phases. Each phase resulted in a version of the DMT with its own testing and validation.

TESTING AND VALIDATION OF DMT V1.0:

Steps in the testing of the SDR DMT included:

- Successfully transferring and installing files from inside Sandia to an external customer. Files included database files containing base SDR information, executable program files, and two downloadable software packages obtained from the open Internet (Visual Studio and SQL Server 2014 Express). The SDR DMT setup guide developed by the Sandia CS team was clear, concise, and complete, and guides the user through the multiple steps required to fully install and configure all the files. Full installation of all the software is not a simple process, and the guide is essential. Using the 64-bit instance of IIS Express in Visual Studio is essential to performing faster searches. The guide also includes instructions for downloading and installing subsequent SDR data updates into the database.

- Successfully loading and executing files on a standalone computer. After loading and configuring the software, the DMT was used to perform data extractions on a standalone computer. The computer used was a 2013 Dell® Inspiron™ desktop model with an Intel Core™ i5-4440 3.3GHz processor and 12 GB RAM, running Windows® 7 and using the Google® Chrome™ Web browser. The DMT operates based on the background operations of Visual Studio, but the user interface is the Google Chrome browser. Two browsers can be used with the DMT—Microsoft Internet Explorer™ and Google Chrome. Searches based on both preconfigured detailed work plan (DWP) requirements and customized filters are easily performed. Data from searches can be viewed and sorted directly in the DMT or easily exported into an Excel format for further use. An SDR DMT user guide was developed by the CS team and provides the necessary guidance to support an individual user in successfully performing data extractions from SDR data on their own. Operation was relatively quick in most cases, but can take up to 1 or 2 minutes to complete if all 1.4 million SDR records are being searched.

Validation of the DMT performance in extracting relevant and useful data for TARAM purposes consisted of:

- Successfully performing data extraction for one Boeing® 737, SN 22940 and comparing with results from a manual data extraction performed by Sandia in an earlier part of this project. During an earlier phase of this project, structural-cracking-occurrence data were extracted for a single Boeing 737-300, SN 22940. Initially those records were recorded in a custom-designed file to include attributes thought to be most useful at that time. Although that data were useful for showing that attempts to obtain ND estimates for fatigue-critical baseline structures would be very time consuming and labor intensive, it proved not useful for this comparison. The data content and format were too different from the SDR files to allow a valid comparison without going through all records and tying them back to their original SDR data record, and then comparing them to DMT extraction results. Therefore, a manual extraction of SDR data was performed. The SDR data for each year were filtered to include only records for SN 22940, then aggregated into one file. Additional filtering

was done based on filters tied columns c40 – ATA/Joint Aircraft System Component (JASC) codes; c130 – Airplane Manufacturer; c140 – Airplane Model; and c260 – Defect Condition (crack-related terms only). The manual extraction returned 227 records and took approximately 2 hours to complete. Then a DMT extraction was performed with filters set to include only data for SN 22940, and the same codes in the other four categories (c40, c130, c140, and c260). The DMT extraction returned 225 records, but only took approximately 2 minutes to perform. There were actually a total of four different records returned by the two extraction methods. Manual extraction contained three records not in the DMT extraction, and the DMT extraction contained one record not in the manual extraction. Data extraction results have been combined into a single Excel file that details how the one-to-one comparison of records was performed and lists the four different files, and all records for both extraction methods (see file named Extraction Comparison Data SN 22940 4-17-16.xls). The DMT keyword-cracking filter identified one record that had a condition of corroded, but contained the word "Broken" in the remarks section, so the record was included. The three records found only in the manual extraction were included because the ATA code 5322 was selected in the filter codes along with all the other ATA codes. [5] The DMT performs comparable data extractions to manual methods in terms of number and type of records, but is much faster and less tedious to use. The DMT also includes records that might be missed by manual filters because of the greater flexibility in selecting filter attributes. More importantly, the minor discrepancies seen in the two extraction methods should not prevent the DMT crack counts from being used for TARAM activities, at least when large numbers of cracks are being found. One concern from a statistical perspective is when only a small number of cracks are found for a particular "bucket" of applicable models and structures. The law of large numbers states that as the number of observations increases, the ratio of the number of events of interest to the number of observations will tend to approach the theoretical probability of the event for an individual case. Therefore, a small crack count over a large sample would indicate lower confidence in the estimate of ND. End users of the DMT may wish to explore a cutoff point (or minimum number of cracks required) that will yield a sufficiently tight confidence bound for TARAM purposes. The CS team has been alerted to the potential need for even more flexibility in filter selections to accommodate custom filtering by the FAA.

- Successfully performing data extraction for data from one year (1995 was randomly chosen) and comparing with results from a manual extraction. The DMT was used to extract SDR data based on filtering to include cracking keywords: Boeing 737 (all submodels), ATA/JASC codes between 5310 and 5347, and the year 1995 data. A separate manual extraction from the base SDR 1995 Excel file was performed by filtering the following columns of data: c40 – ATA/JASC Codes between 5310 and 5347; c130 – Airplane Manufacturer Boeing; c140 – Airplane Model 737 (all submodels found in the filter for the file); and c260 – Defect Condition (all crack-related terms available in the filter for the file). The results were very encouraging in that the DMT pulled 591 records whereas the manual extraction pulled 577 records. The 14-record difference was determined to be due to the slightly different filters selected in each respective data extraction method. The DMT has a more inclusive list of defect conditions that are

accepted. A quick comparison showed that the records were otherwise consistent between the data extraction methods. A complete one-to-one comparison between the two data sets was not performed as for the SN 22940 data comparison because it is clear that the minor differences in the two extraction methods were due to differences in filtering. What is clear though is that the DMT is a superior tool for extracting data from SDRs because it allows greater flexibility in filter selections. This feature will likely undergo continuous improvement over the course of the rest of this project. Additionally, the DMT is much faster to use and does not require tedious data compilation work across multiple years' worth of data.

Validation of the DMT performance in extracting relevant and useful data for ARAC purposes consisted of performing an extraction of crack-length values, with filters set to cracking keywords, all Boeing 737 submodels, 5300 fuselage ATA codes, and 1995 data. Data were returned that lists the five largest crack lengths found in the filtered data, broken up by each 737 submodel and ATA/JASC code. In cases where there were fewer than five cracks, only those lengths that were found were listed. One drawback on this search function at the current time is the filtering is not designed to provide large aggregate buckets, as discussed in prior paragraphs. Therefore, the data must be exported into Excel, and combined and sorted again to aggregate data into larger buckets. This is a relatively quick process. Validation of individual cracks will be performed in Phase 2.

SUMMARY OF TESTING AND VALIDATION OF DMT V1.0:

The SDR DMT v1.0 is ready for delivery to the FAA and works as well as manual data extraction in terms of number of records returned (data completeness) and data quality. It is much faster and less tedious than manual methods for acquiring data to support TARAM activities. It also includes a natural language processor for crack-length extraction that examines records for crack-length information to support ARAC activities. The DMT will require some additional revisions (as do most software applications) to provide all the filtering features ultimately needed by the FAA, but is in a form that can be immediately used for supporting FAA TARAM and ARAC activities.

FINAL TESTING AND VALIDATION OF DMT V2.0

Steps when testing DMT v2.0 include:

- Random sampling from SDR database using DMT v2.0. To verify that all data downloads and software update components are functioning correctly, filters were created, edited and used for data extraction using DMT v2.0. Tables for crack counts and crack size were generated in Excel. SDR searches and data extractions were performed and exported as Excel files. All software components were verified as functional.

- Recreation of reports extracted by the Sandia CS team using the remote version of the DMT:

    - Report B/C/D – Data extraction of SDRs filtered by cracking keywords, DWP ATA/JASC codes, and airplane models, which are now all the same. The reports were different based on the individual keywords but because the DMT has the flexibility to filter by whole groups of similar keywords easily defined by the user,

it becomes less of an issue. The filters used in this comparison were the cracking keywords, DWP ATA/JASC codes, and airplane model (see figure 5 of the DWP and as defined in v2.0 of the DMT software).

- Report B/C/D-Insufficient – Data extraction of SDRs that do not meet the criteria above (see figure 5 of the DWP).
- Table B/C (Combined phases 2 and 3) – Data extraction and export to Excel of crack counts sorted by DWP ATA/JASC codes and DWP models.
- Table D – Data extraction of crack counts sorted by the DWP airplane models.
- ARAC – Data extraction of the five largest cracks filtered by the cracking keywords, the DWP ATA/JASC codes, and the DWP airplane models.

- Results of data extractions using remote DMT:

  - Report B/C/D Comparison – Data extraction of SDRs filtered by DWP ATA/JASC codes and airplane models had the same number of records (75,941) as that created by the Sandia CS team. A spot check showed the same records on each row of the two exported Excel files at the beginning and end of the files, and for a few randomly chosen rows. A comparison of the SDR ID of each of the 75,941 records using the VLOOKUP function in Excel (=VLOOKUP(B2,$A$2:$A$75942,1,FALSE) showed that exactly the same SDR ID numbers, and therefore exactly the same data, were obtained in both extractions. See the following files for the full extraction results: "Report_B_C_D" – Sandia CS Team data extraction file, "Report B-C-D crackKWandDWPATAandDWPModel(1).xlsx" – Airframe Specialist data extraction file, and "VLookupFindSDR" for the SDR ID number comparison file using the VLOOKUP function.
  - Report B/C/D Comparison-Insufficient-Data extraction of SDRs filtered for having insufficient ATA/JASC Code information had the same number of records (2101) as that created by the Sandia CS team. A spot check showed the same records on each row of the two exported Excel files at the beginning and end of the files, and for a few randomly chosen rows. A comparison of the SDR ID of each of the 2101 records using the VLOOKUP function in Excel showed that exactly the same data were obtained in both extractions. See the following files for the full extraction results: "Report B_C_D_Insufficient" – Sandia CS Team file, and "Report B-C-D Insufficient ATA Codes.xls" – Airframe Specialist file, and "VLookUpInvalidATACode" – for the VLOOKUP comparison.
  - Table B/C Comparison – Data extraction of crack counts sorted DWP ATA/JASC codes, and the DWP models contained exactly the same data (3654 records) as that extracted by the CS team at Sandia. However, the user should be aware that the initial sorting and storing of the data by the DMT can vary from run to run. This means that data will need to be sorted with Excel after extraction using the same factors in the same way if two separate data extractions are to appear in the same order. The data are the same, just sometimes sorted differently by the DMT with each separate extraction. See the following files for the full extraction results: "TableBandC" – Sandia CS Team file, and "Table B-C

CrackCountByDWPAtaAndDWPModel" – Airframe Specialist file. The comparison results are found in the file "VLookUpReportB-C."

–   Table D Comparison – Data extraction of crack counts sorted by airplane models. Data extraction of crack counts filtered by the cracking keywords, the DWP ATA/JASC codes, and the DWP models contained exactly the same data (379 records) as that extracted by the CS team at Sandia. See the following files for the full extraction results: "CrackCountByModel" – Sandia CS Team file, and "Table D CrackCountByModelAS" – Airframe Specialist file. The comparison results are found in the file "VLookUpReportD".

–   ARAC Comparison – Data extraction of the five largest cracks sorted by the cracking keywords, the DWP ATA/JASC codes, and the DWP models contained exactly the same data (4317 records) as that extracted by the CS team at Sandia. A spot check of a few ATA code/airplane/model combinations showed the same crack lengths. However, a comparison of sorted SDR ID numbers showed slight differences in the selected records (some different SDR ID numbers). Because the report pulls the top five values for a given ATA code/airplane/model combination, but there is not any sort of criteria based on the SDR ID value, equivalent results in terms of the five largest crack lengths are obtained. However, there are slight differences in the individual SDRs extracted because the DMT sorted the local database on the standalone computer slightly differently than the DMT using the database on the Sandia server. Therefore, there is a return of a different record set, but the same five crack lengths. For example, if asked to select the top three values from the table below (see table 1), one would expect a result of 7, 6, 5. However, both data set (E, B, C) and set (E, B, D) would give the same data values and are both a correct answer to the question being asked. Adding additional filters will provide more specificity to the returns. The extracted crack-length value for SDR ID 693475 (Boeing 737-130 with ATA\JASC code of 5310) is 12 inches. For the purpose of this report that SDR is functionally equivalent to SDR ID 945417, which is the same airplane model and ATA\JASC code and also has a 12-inch crack. See the following files for the full extraction results: "LargestCracksByAtaAndModel_TopFiveResults" – Sandia CS Team file, "ARAC-LargestCracksByATAAndModel" – Airframe Specialist file, and "ARAC 5 largest crack comparisons."

Table 1. Example of data extraction

Identifier	Value
A	2
B	6
C	5
D	5
E	7

Validation of the DMT performance in extracting relevant and useful data for TARAM purposes consisted of comparing data extracted from the SDR database using an updated DMT to manually extracted data for a single airplane—Boeing 737-3H4, SN 22940. Data were extracted using DMT v2.0, filtering for serial number 22940, cracking keywords, and all 5000 ATA/JASC codes. These were the filtering criteria used in the original manual data extraction during the prior work from Phase 1 and in prior years. Results were in complete agreement with prior work in that 228 crack records were extracted by DMT v2.0, which is the same number extracted by DMT v1.0, and one more than was extracted by the original manual data extraction in 2014. The one additional record extracted by the DMT (both versions) was due to the use of the defect condition of corroded, with a crack being called out in the comments picked up by the DMT.

SUMMARY OF TESTING AND VALIDATION OF DMT V2.0

The DMT is fully functional in that it will sort the SDR database using filters defined by the FAA to provide relevant results for both TARAM and ARAC purposes. TARAM risk assessments can be immediately supported with crack counts filtered and sorted to FAA requirements. Much flexibility has been built into the filtering functions that allow the FAA user to implement custom filters based on any keywords of their choice, any ATA/JASC code, and any airplane model (including submodels). Additionally, ARAC analysis can be immediately supported with relatively high confidence that the largest cracks being extracted from the database are being selected. The same filtering tools are available.

REFERENCES

1. *Survey of Service Difficulty Reports for In-Service Damage in Transport Category Aircraft* [Statement of Work]. (2016, January 25).

2. TARAM. (2011). Transport Airplane Risk Assessment Methodology (TARAM) Handbook, *Transport Airplane Directorate*, pp. 19.

3. Dorado, A., Bode, M. (2015). Estimation of the Probability of Not Detecting (ND) Airplane Structure Fatigue Damage. (Draft TARAM ND Final Report_v5, draft of the final report for Phase I of TARAM ND project). Submitted to FAA, April 14, 2015.

4. Federal Register, Volume 80, No. 16, pages 4029- 4032, (January 26, 2015). Retrieved from http://www.faa.gov/regulations_policies/rulemaking/committees/documents/index.cfm/document/information/documentID/2023

5. FAA. (2008). Federal Aviation Administration Joint Aircraft System/Component Code Table and Definitions. Retrieved from http://av-info.faa.gov/sdrx/documents/JASC_Code.pdf

APPENDIX A—USER MANUAL

USER MANUAL INTRODUCTION

PURPOSE

The purpose of this document is to serve as a user guide for the Service Difficulty Report (SDR) Data Mining Tool (DMT) developed by Sandia National Laboratories Department 9523 in collaboration with Department 6626 and the FAA. The SDR data from 1974–1994 were obtained from a public FAA website, and the data from 1995–2015 were obtained from a different FAA site. The full dataset includes approximately 1.4 million SDR records.

HOME PAGE

DESCRIPTION

The application home page serves as a landing point when opening the application. There is no user input on this page.
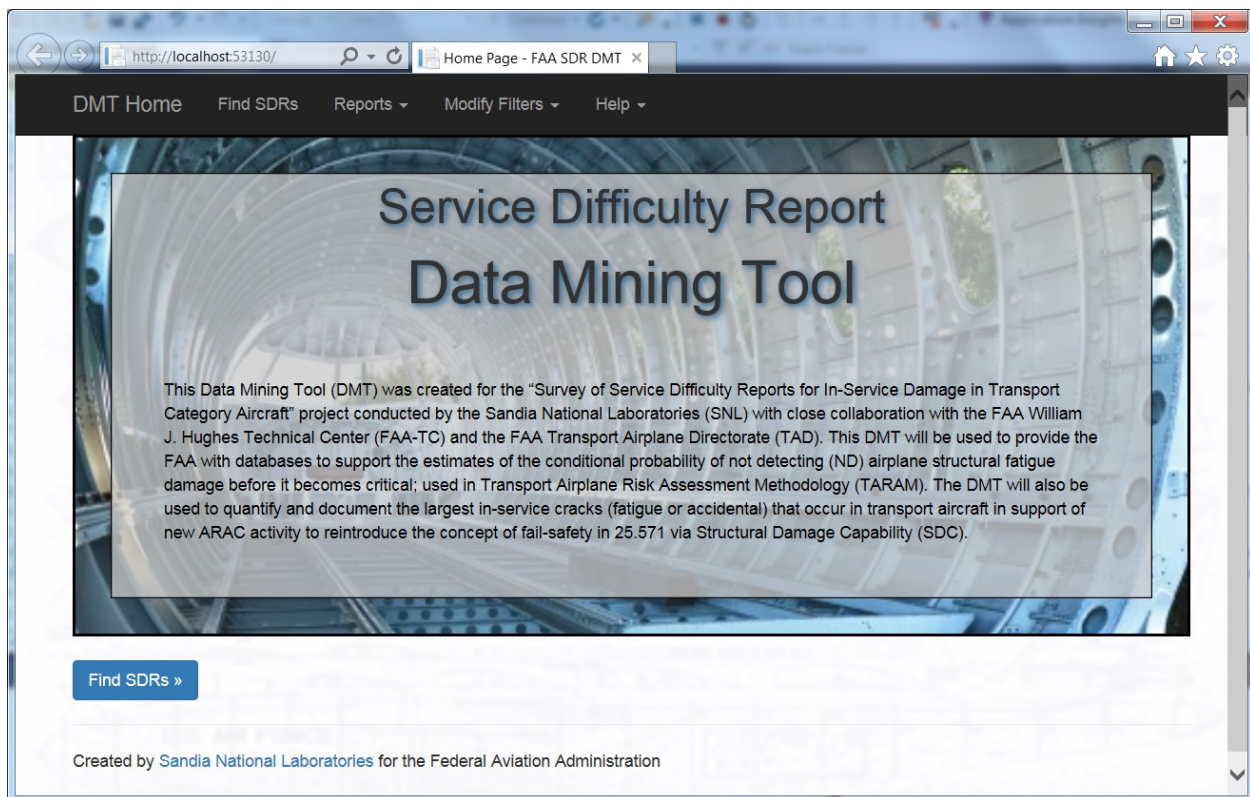
MODIFY FILTERS

DESCRIPTION

Filters allow users to save lists of selected data (e.g., aircraft of interest, specific ATA/JASC codes, or keywords). The filter data are saved to the database so they can be used repeatedly in application searches and when viewing reports. If a filter is selected, then the search/report results will be limited to the SDR data that meet the filter criteria.
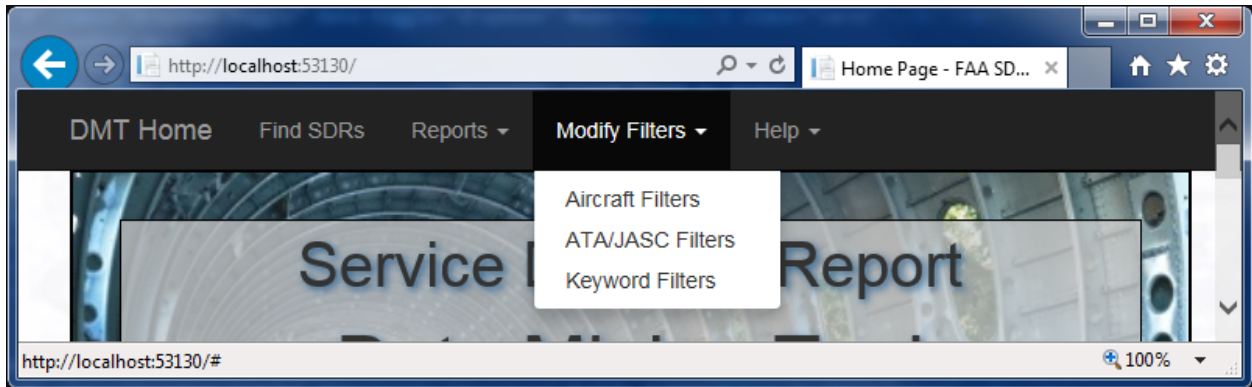
The various filters have some common functionality, including "Add New Filter," "Rename Filter," and "Delete Filter."

ADD NEW FILTER

When you select a filter from the "Modify Filters" navigation dropdown, you will see the home screen for that filter. The filter home pages each have a link near the top of the page to "Create New Filter." Clicking that link will open the page to set the name of the new filter.
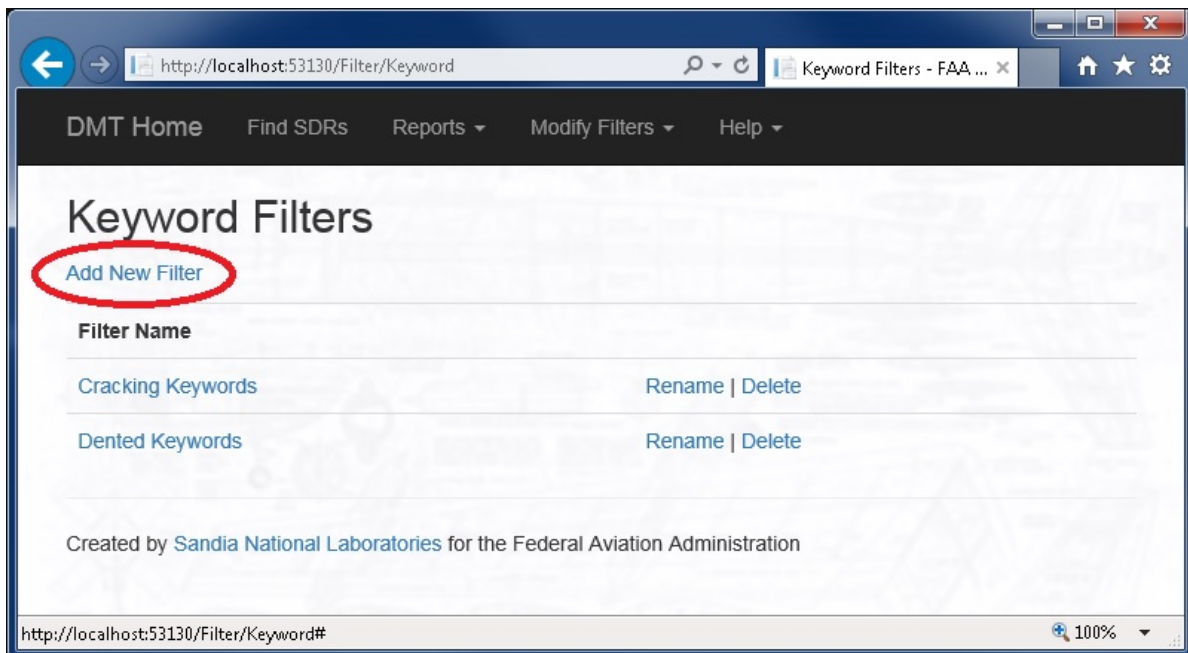
Type a name for the filter in the box and then click "Create". If you do not want to save the new filter, then click "Back to List". Filter names must be unique and less than 80 characters in length.
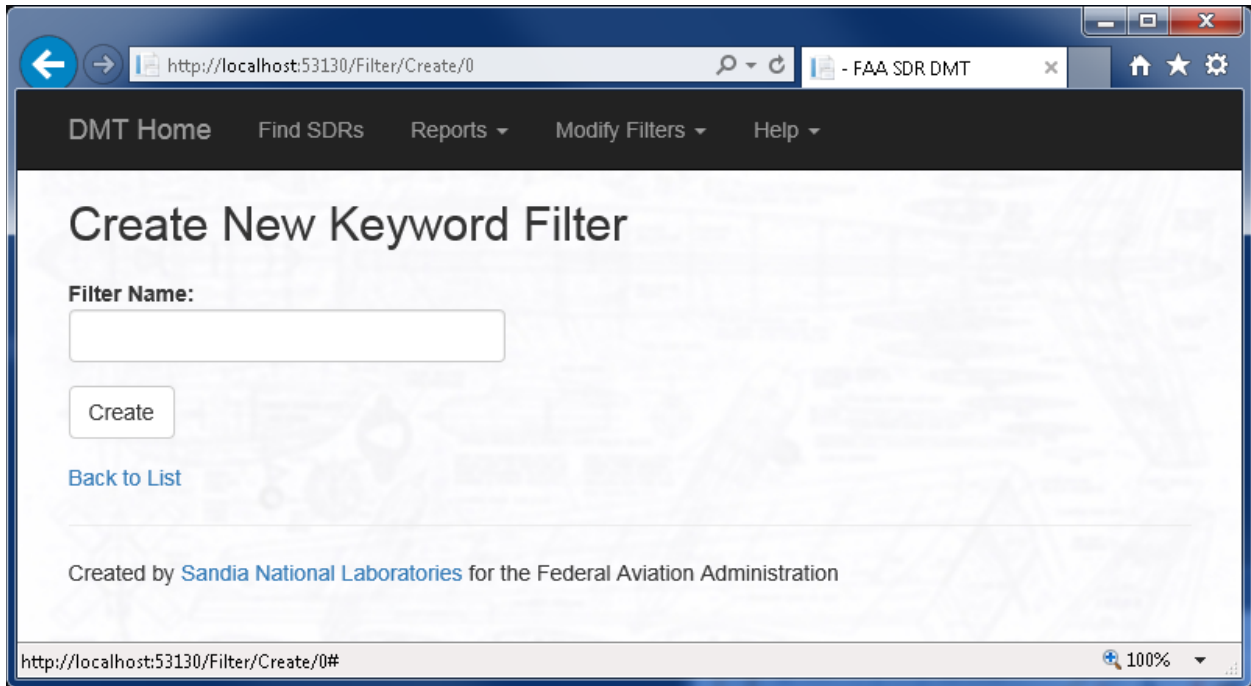
RENAME FILTER

If you want to change the name of an existing filter, click "Rename" on the filter home screen.
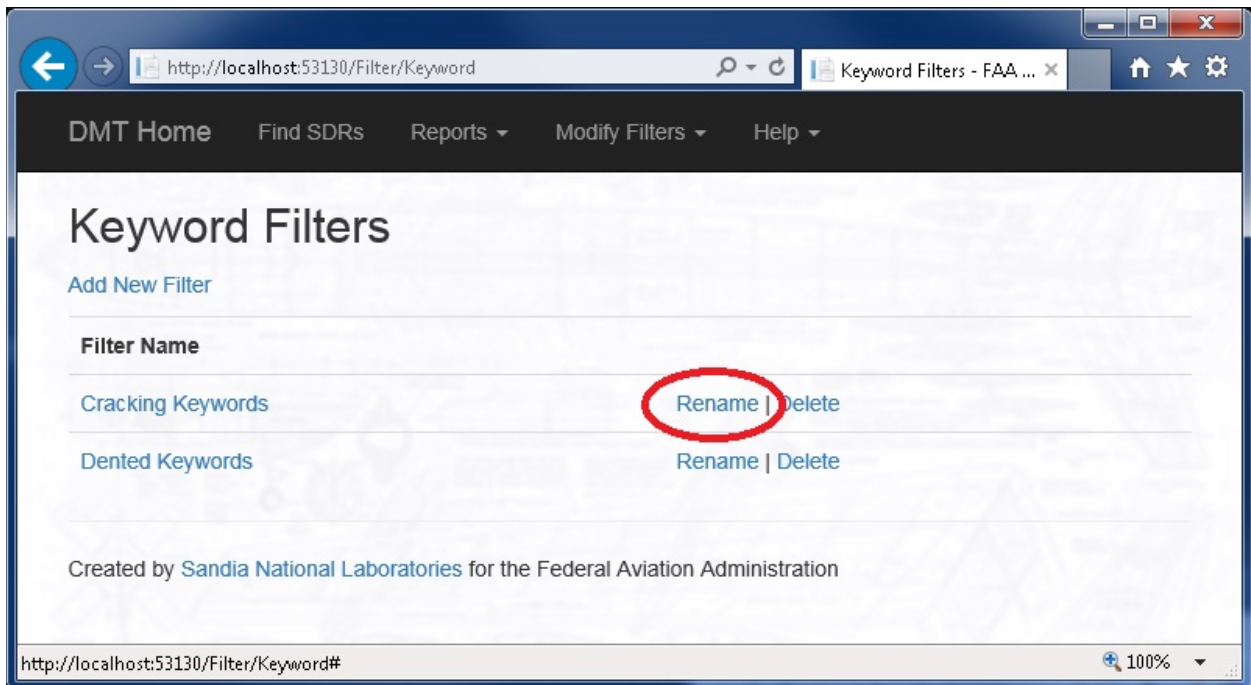
A new screen will allow you to revise the filter name. Click "Save" to rename the filter.
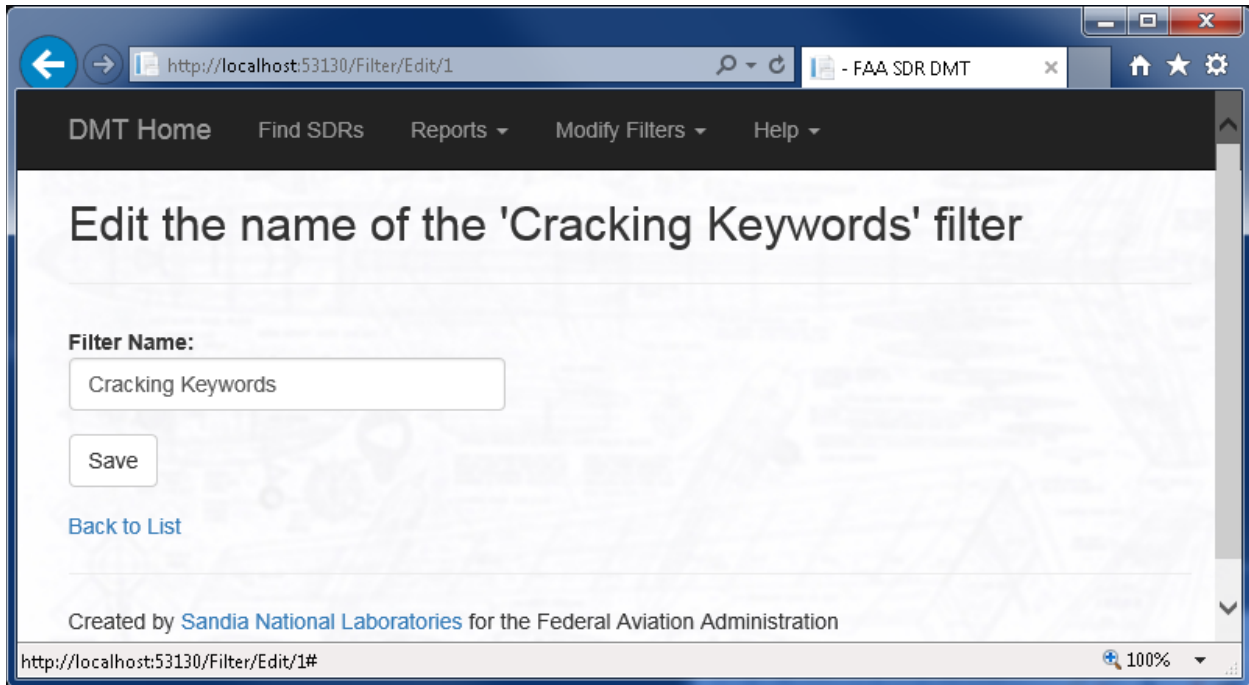
DELETE FILTER

If you want to permanently remove a filter, click "Delete" to the right of the filter name.
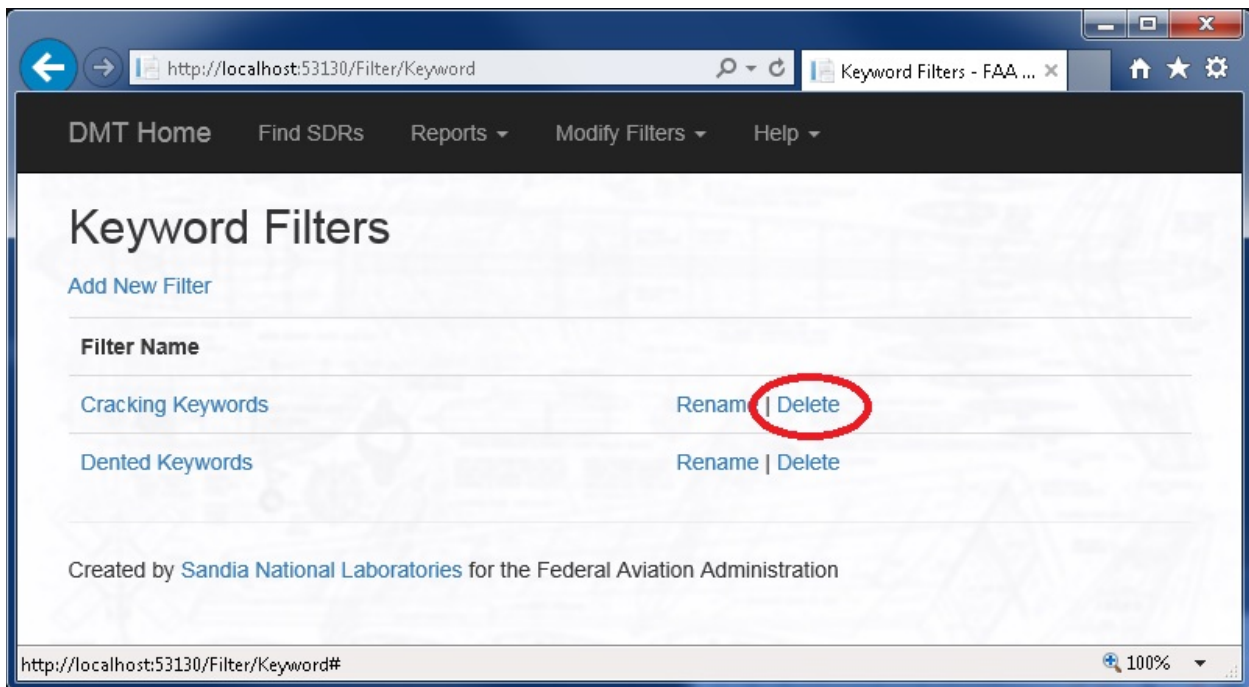
You will receive a confirmation page. Selecting "Delete" will remove the filter from the application.
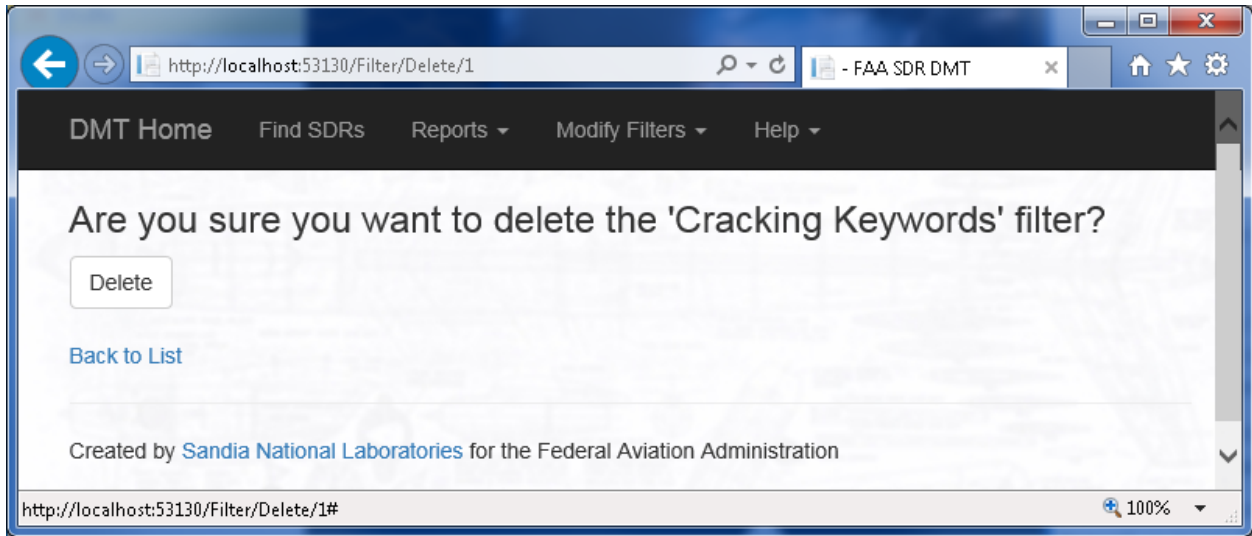
MODIFY FILTERS – AIRCRAFT FILTERS

DESCRIPTION

The Aircraft Filters section allows users to create and modify custom filters to restrict search/report results to specific series and models of aircraft. If the "All Sub Models" box is selected, the search looks for matching series contained in the "c140_aircraft_group" field. If specific models are selected, the search will compare the selected model against the "c150_aircraft_model" field.

MODIFY AIRCRAFT FILTER

Click the name of an aircraft filter to start modifying the contents of that filter.
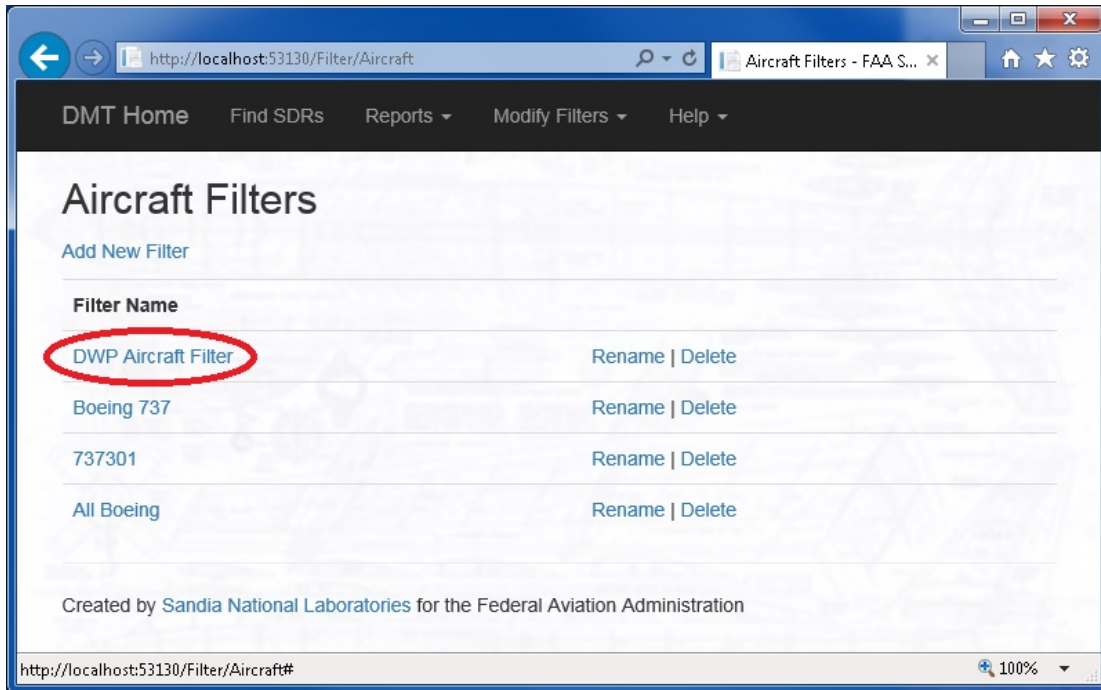
If you select a filter that already has data such as the "DWP Aircraft Filter," then you will see a summary screen showing the aircraft make/series/models. The "DWP Aircraft Filter" has been preloaded with the make/series/models documented in the Detailed Work Plan (DWP). The other filters have been used for various application tests during development and can be deleted.

If you select a newly created filter, you will see an empty screen. Select "Add New Aircraft Make" to choose a new make to add to the filter.
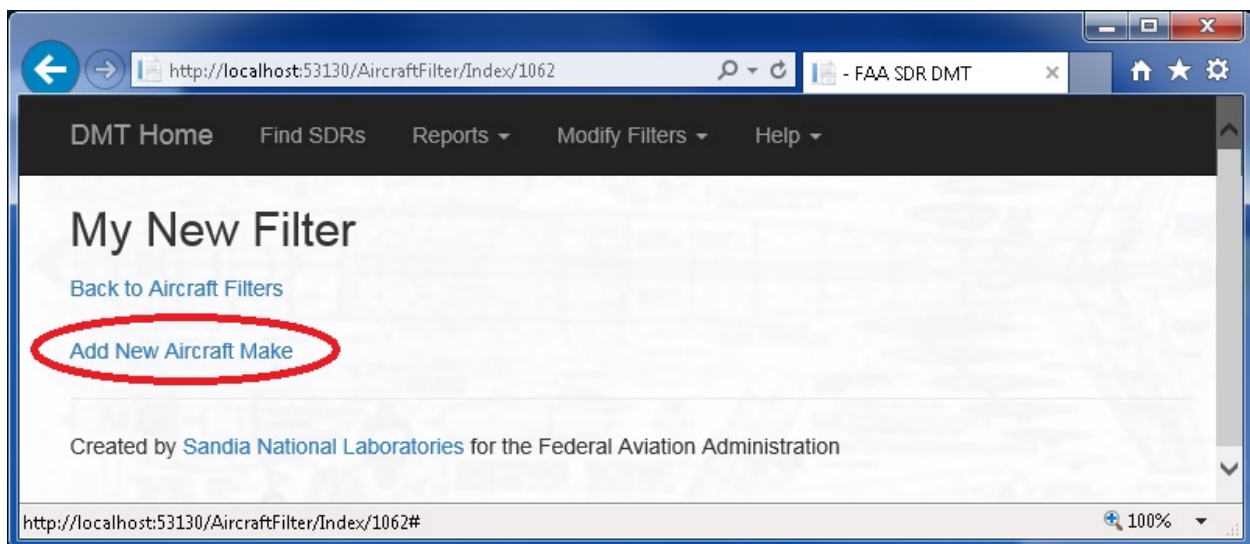
The application will then display a list of makes found within the SDR data. You can use the browser's find functionality (Ctrl + F) to search for a value in the list, or scroll to find the manufacturer. Click on a manufacturer name to add it to the filter.
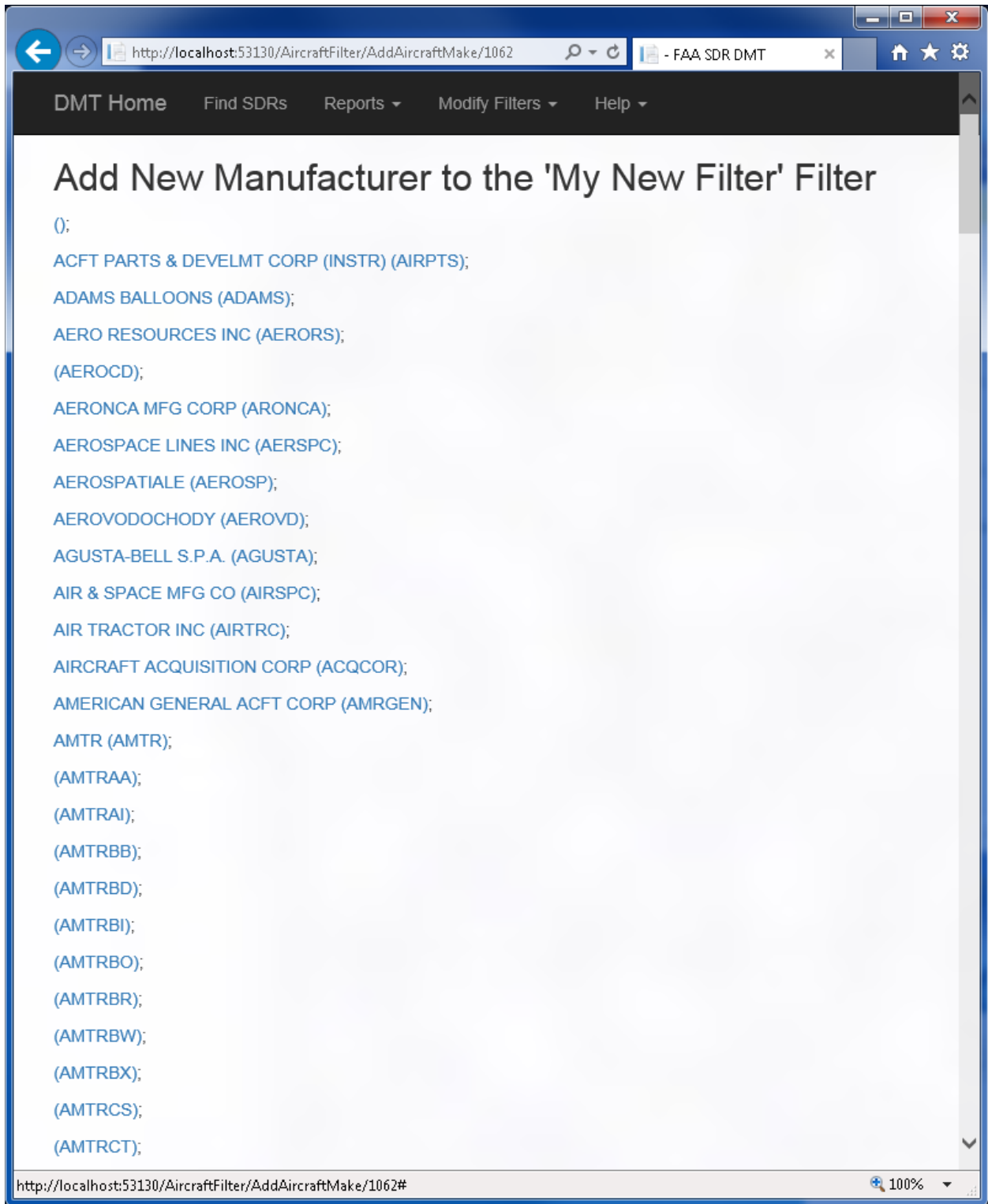
Once you select a name from the list (e.g., GROUP ECONOMIQUE AIRBUS INDUSTRIE AIRBUS), you will see a list of series values for that manufacturer.
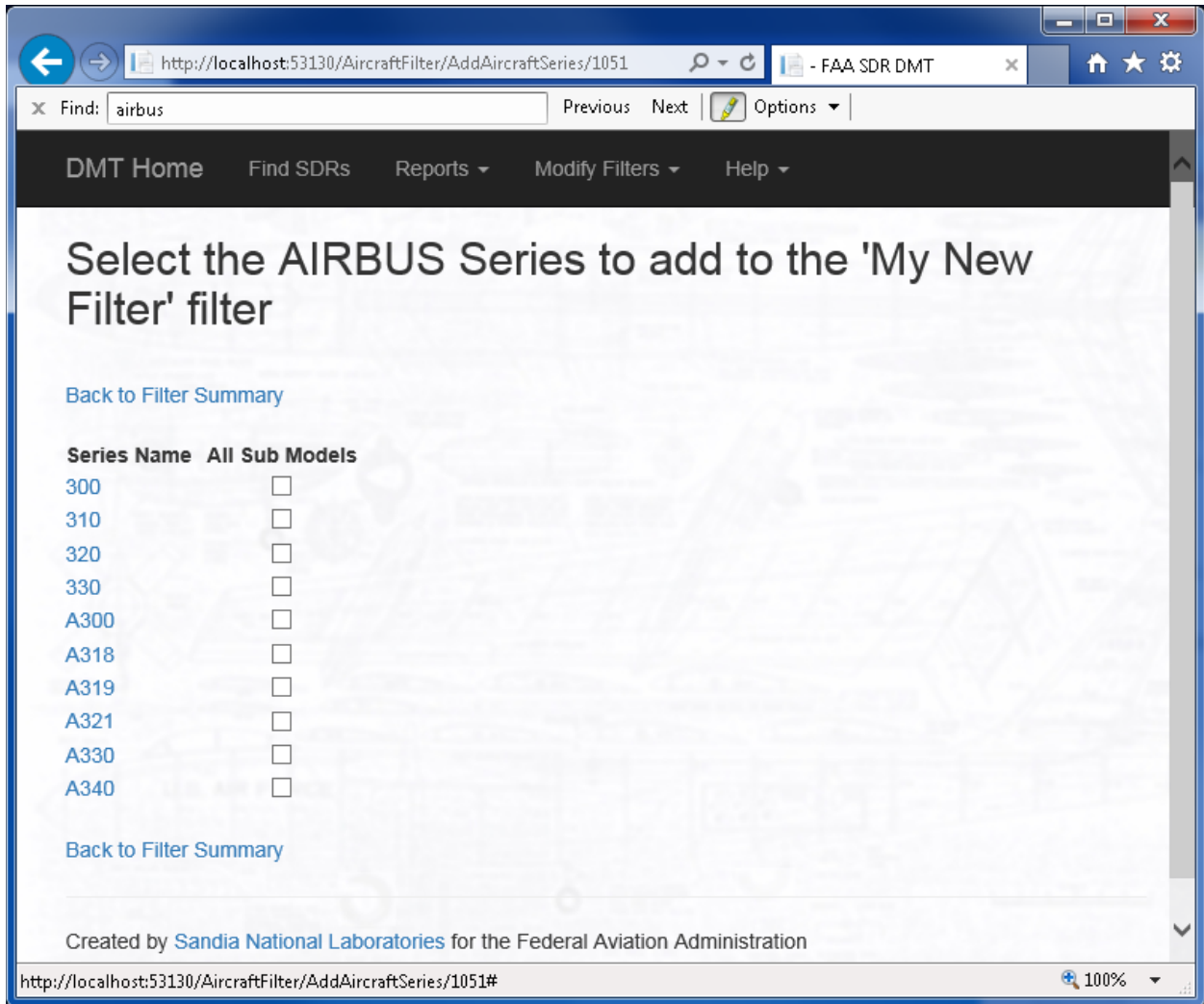
If you want to select all of the models within a series, check the box next to the series name. With that box selected, the application will include all SDRs with that series value.

If you only want to return a subset of models within a given series, then click on the series name (e.g., 330) to view a list of models within that series. You then have the option to select the specific models to add to your filter. Unchecked models will not appear in your search/report results when this filter is chosen. Make sure to click the "Save" button after making your selections.
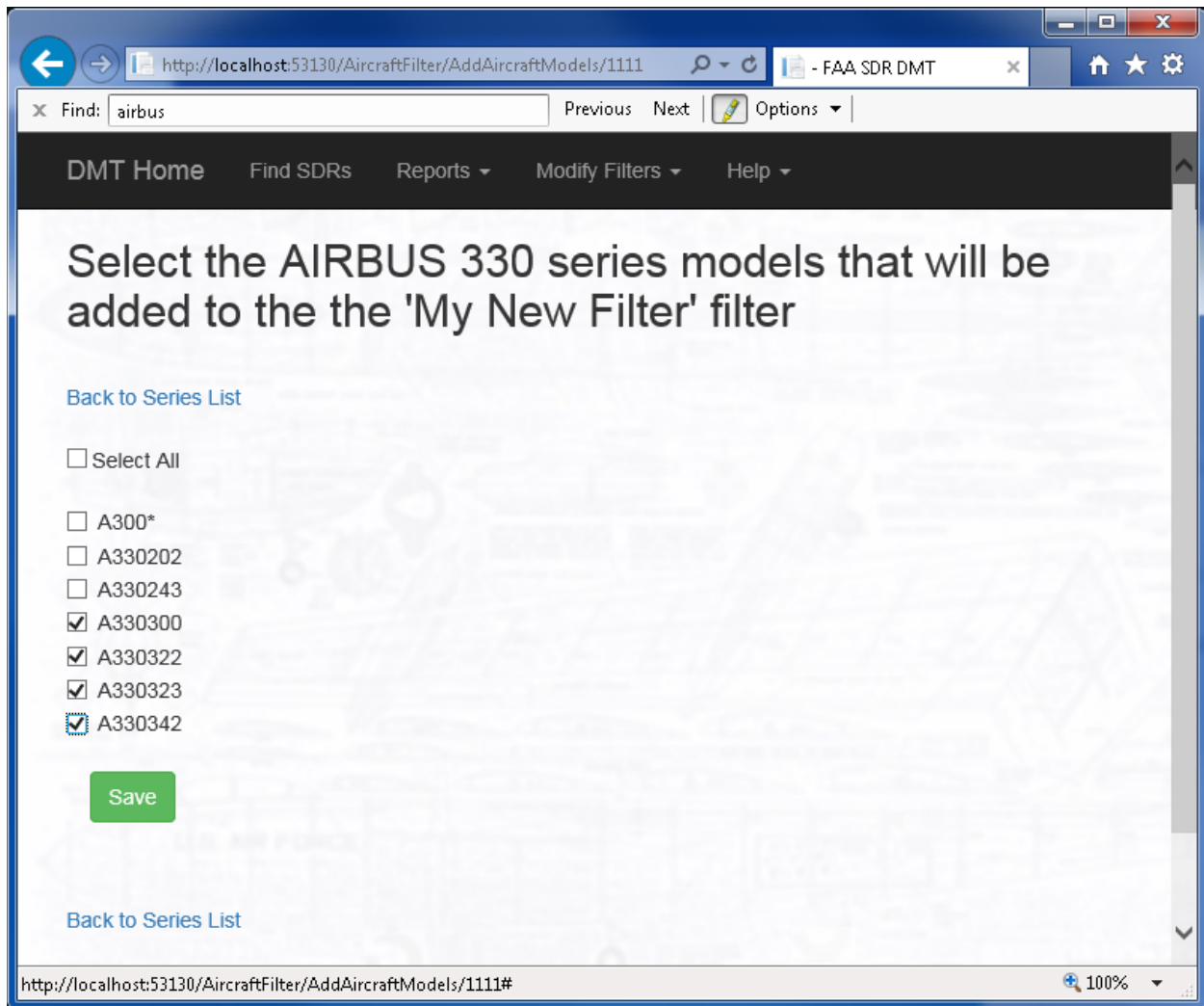
"Select All" is provided for convenience for times when you want to choose most of the models within a series without having to check each individual box. However, if you want to select every model for a given series, use "All Sub Models" on the previous screen instead of selecting each model individually as search performance will be improved.

Once you have data added to an aircraft filter, the summary screen will show additional links.
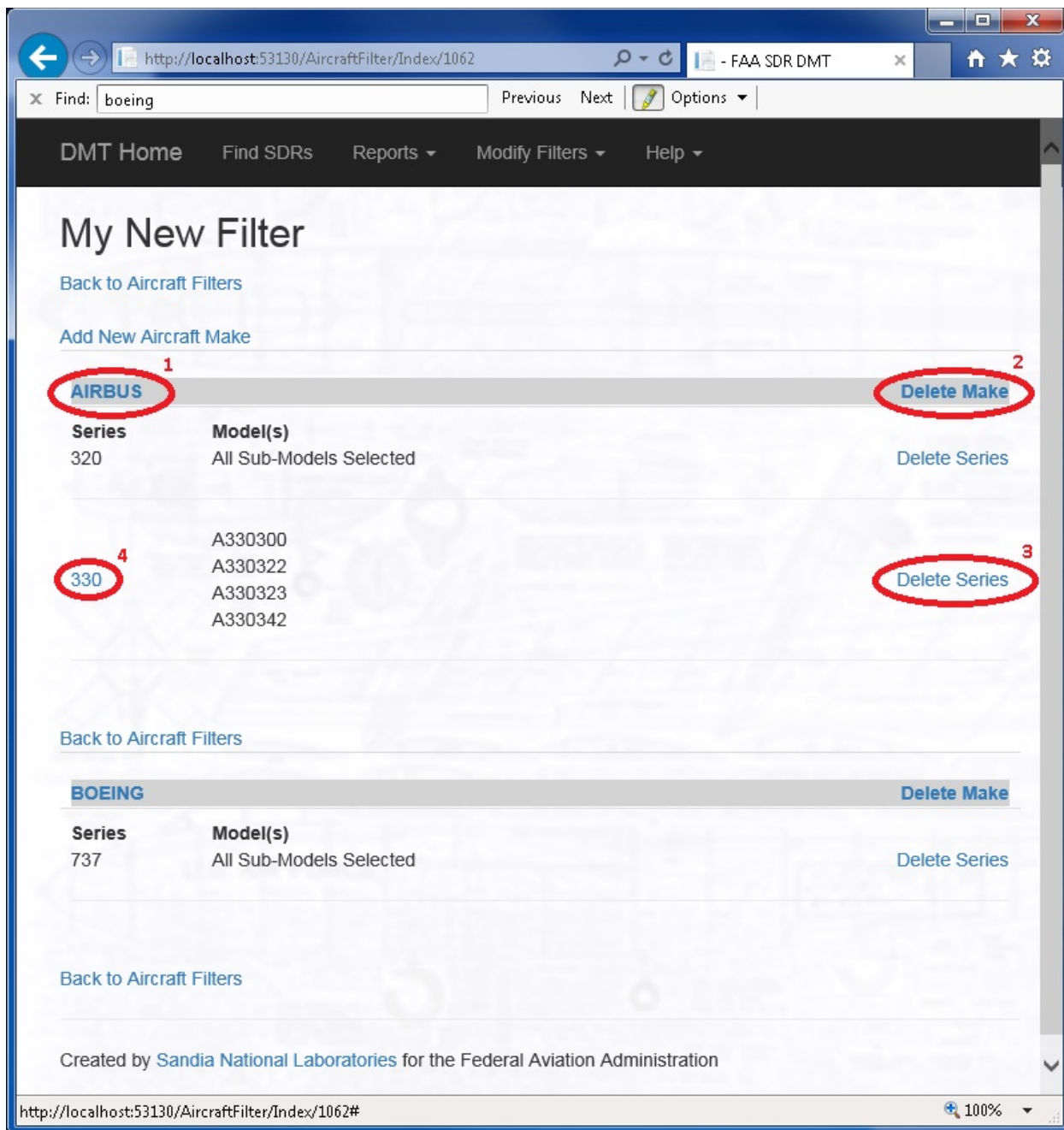
<u>Link 1: Manufacturer Name</u>

Selecting the name of a manufacturer (e.g., "Airbus") will take you to the page where you can modify the aircraft series values for that manufacturer.

<u>Link 2: Delete Make</u>

Selecting "Delete Make" will remove all of the selected model and series information for that manufacturer from your filter and then remove the manufacturer name.

      <u>Link 3: Delete Series</u>

Selecting "Delete Series" will remove all selected submodels and the series name from your filter.

      <u>Link 4: Series Name</u>

Selecting a series name (e.g., "330") will take you to the page where you can edit the models for that series.

<u>MODIFY FILTERS – ATA/JASC FILTERS</u>

<u>DESCRIPTION</u>

The ATA/JASC Code Filters section allows users to create and modify custom filters to restrict search/report results to SDRs containing the selected code(s). The ATA/JASC search compares the selected filter values against the "c40_ata_code" field in the dbo.sdr table.

<u>MODIFY ATA/JASC FILTER</u>

Click the name of an ATA/JASC filter to start modifying the contents of that filter. The "DWP Codes (all structures)" filter has been pre-populated with all of the ATA values specified in the DWP (pp. 34-35). The other filters have been created based on the data in the DWP broken out by category. It is recommended for the user to validate that the codes selected within each of these filters are accurately set prior to using the system for data analysis.
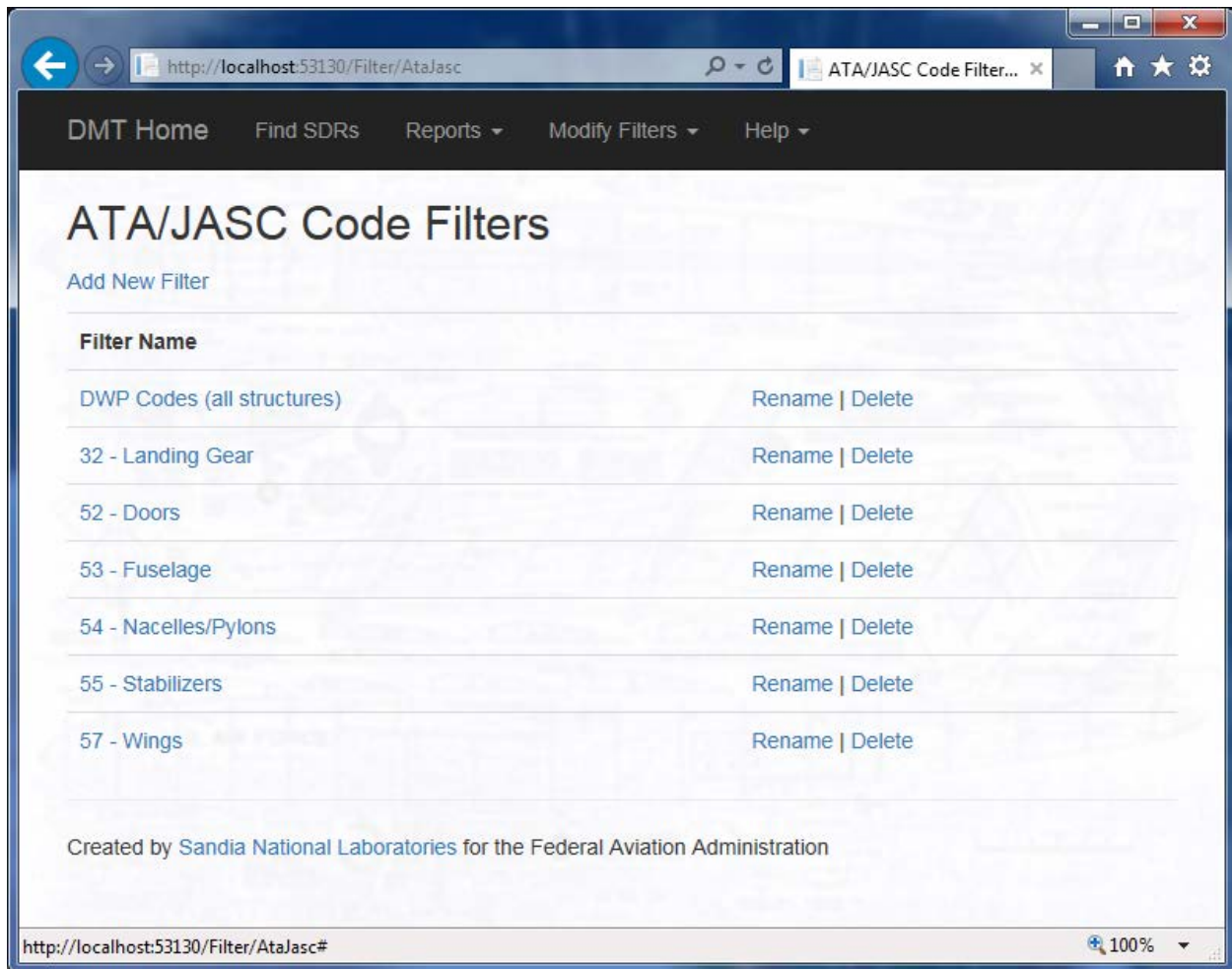
After you select an ATA/JASC code filter name (e.g., "32 – Landing Gear") you will see a list of ATA codes that can be included as part of that filter. Check the codes included in your search/report results and make sure to click "Save" at the bottom of the screen, which will take you back to the ATA/JASC Code Filter home screen.

http://localhost:53130/AtaFilter/Index/1065

32 - Landing Gear - FA... ✕

DMT Home   Find SDRs   Reports ▾   Modify Filters ▾   Help ▾

Select the ATA codes that will be returned using the '32 - Landing Gear' filter

If you make any updates to the values in this list make sure you click the "Save" button at the bottom of the screen to store your changes.

Back to ATA Filter Home

11
- ☐ 1100 - PLACARDS AND MARKINGS

12
- ☐ 1210 - FUEL SERVICING
- ☐ 1220 - OIL SERVICING
- ☐ 1230 - HYDRAULIC FLUID SERVICING
- ☐ 1240 - COOLANT SERVICING

14
- ☐ 1400 - MISCELLANEOUS HARDWARE
- ☐ 1410 - HOSES AND TUBES
- ☐ 1420 - ELECTRICAL CONNECTORS
- ☐ 1430 - FASTENERS
- ☐ 1497 - MISCELLANEOUS WIRING

18
- ☐ 1800 - HELICOPTER VIB/NOISE ANALYSIS
- ☐ 1810 - HELICOPTER VIBRATION ANALYSIS
- ☐ 1820 - HELICOPTER NOISE ANALYSIS

http://localhost:53130/AtaFilter/Index/1065#

🔍 100% ▾

MODIFY FILTERS – KEYWORD FILTERS

DESCRIPTION

The Keyword Filters section allows users to create and modify custom keyword filters to restrict search/report results to SDRs that contain at least one word from the keyword list. The search is based on an SQL LIKE query and is not case sensitive (i.e., a word like "dent" added to a keyword filter will return records containing words such as "DENT," "Dented," "denting," and "indented"). The keyword search looks for matching words contained in either the "c260_condition" or "c510_remarks" fields. The "Cracking Keywords" filter has been pre-populated with values specified in the DWP along with other relevant terms as discussed during sprint review meetings. The "Dented Keywords" filter was used for testing purposes and can be safely deleted.

MODIFY KEYWORD FILTER

Click the name of a filter to start modifying the contents of that filter.
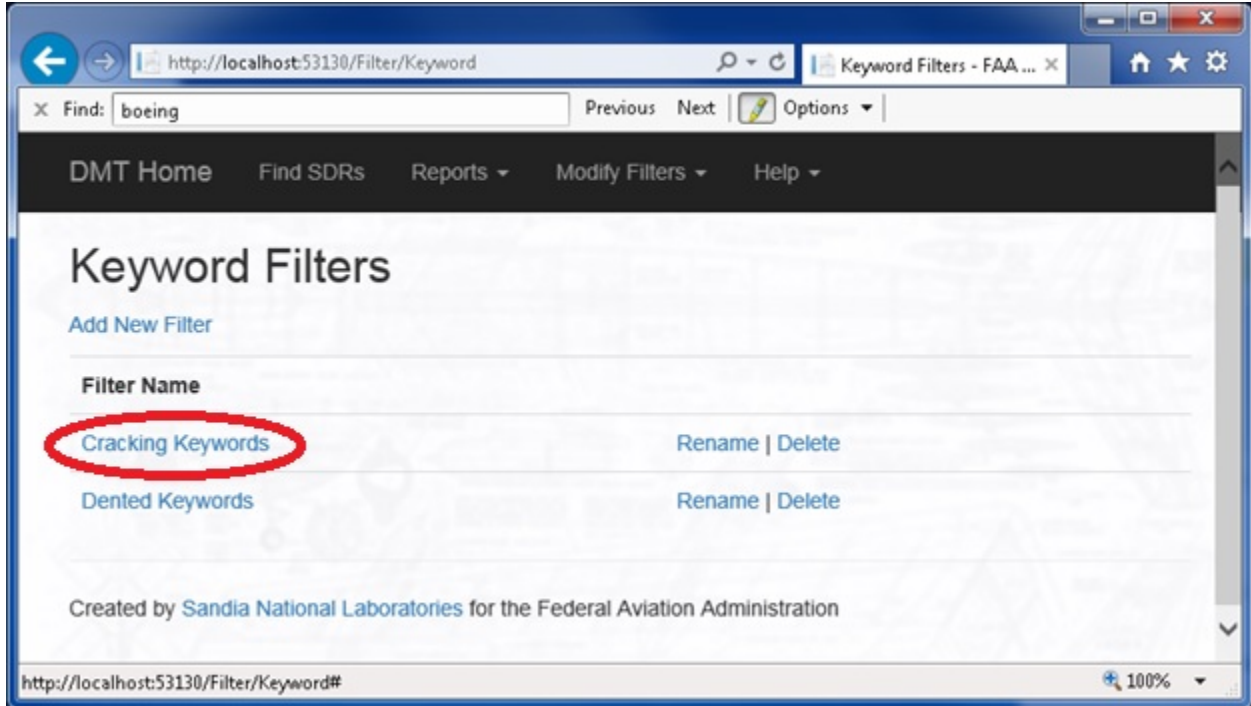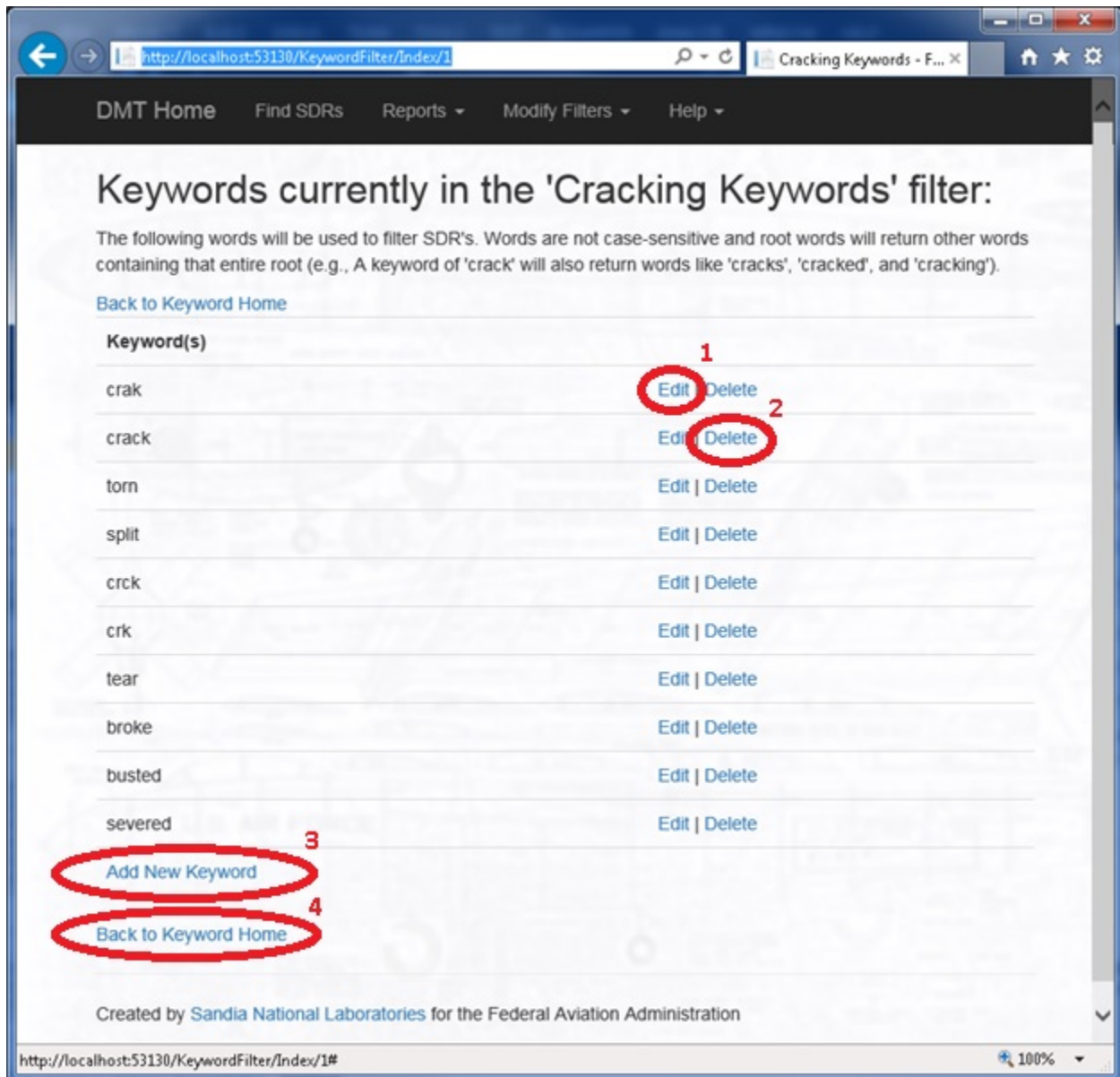
<u>Link 1: Edit</u>

Clicking "Edit" will display a page that allows you to modify that keyword. Update the value and click "Save", or click "Back to List" if you do not want to make any changes.
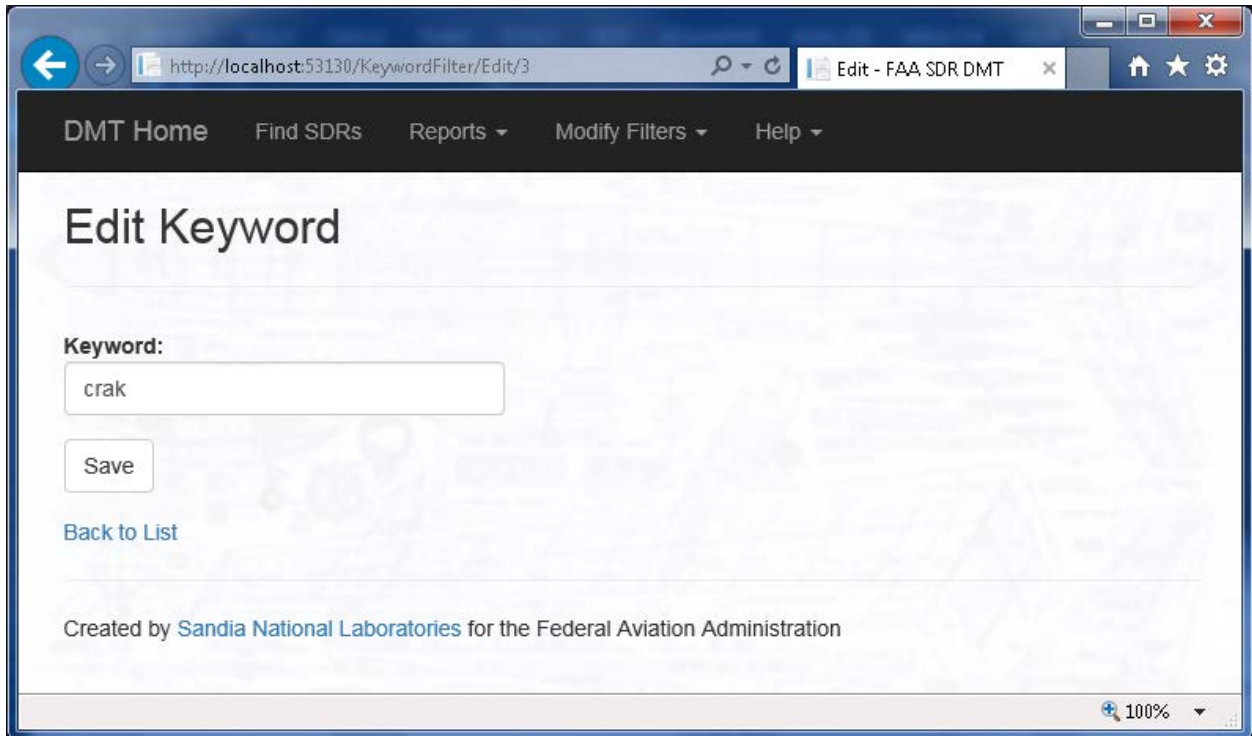
Link 2: Delete

Clicking "Delete" will display a confirmation page. If you want to permanently delete that keyword entry from the list, select "Delete" again. If you want to keep the value, click "Back to List."
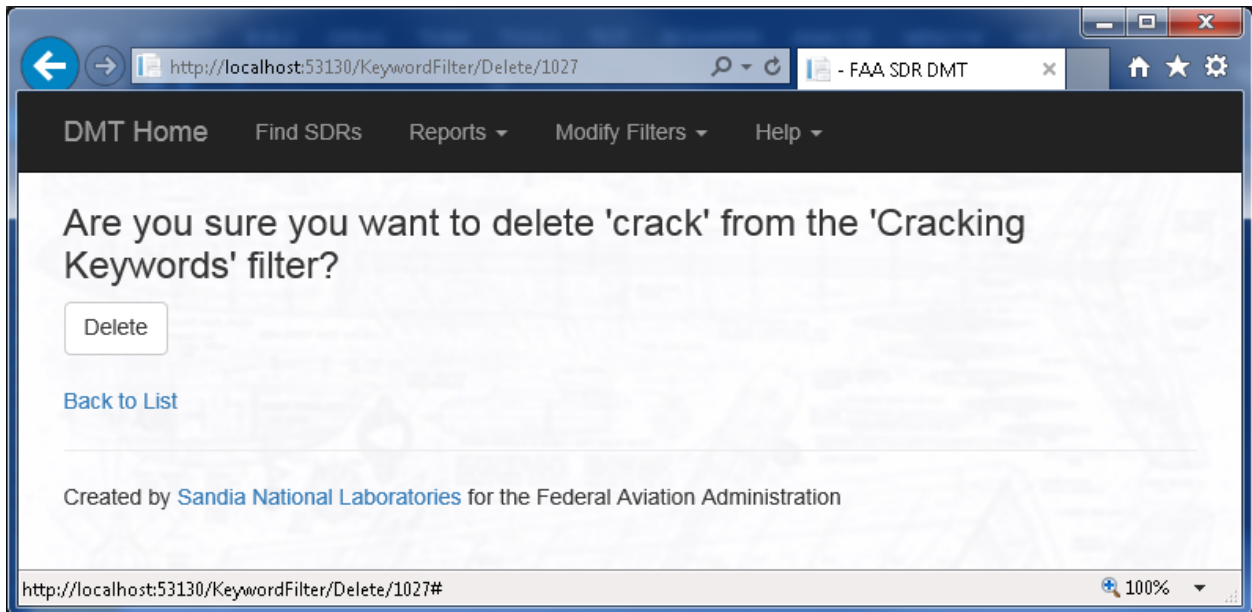
<u>Link 3: Add New Keyword</u>

Clicking "Add New Keyword" will display a new page allowing you to enter a keyword value. Add a single word or phrase, which must be fully matched, in the input box, and click "Save" to add the new word to the keyword filter list.
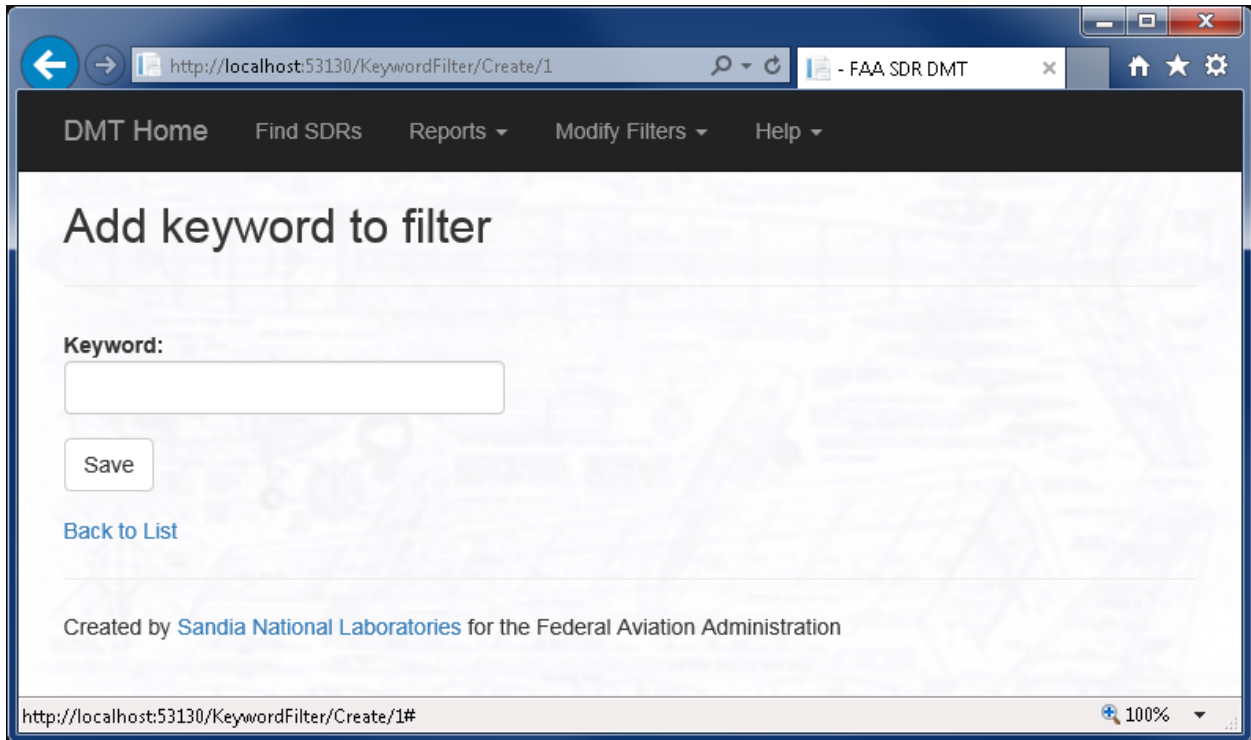
<u>Link 4: Back to Keyword Home</u>

Clicking "Back to Keyword Home" will take you back to the screen displaying all of the keyword filter names.

<u>FIND SDRS</u>

<u>DESCRIPTION</u>

Clicking "Find SDRs" in the top navigation menu will display the "Find SDRs" page. This page allows you to search for SDR records that meet selected criteria. The search criteria entered on this form must all be met. The results will return the intersection of records that meet all the search criteria.
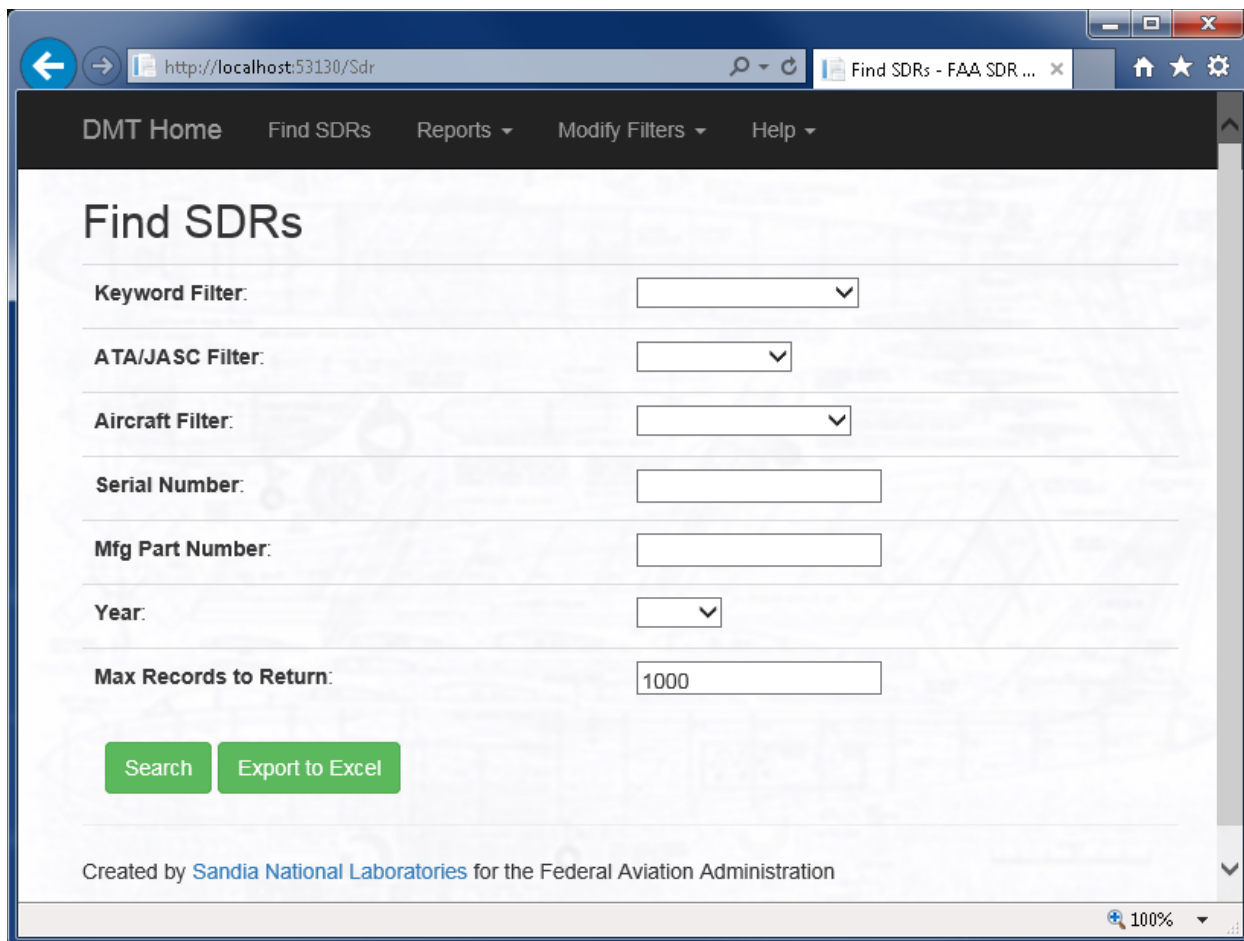
SEARCH OPTIONS

Keyword Filter

The "Keyword Filter" dropdown will display the names of the keyword filters you have defined using the "Modify Filters - Keyword Filters" functionality. This filter will limit the search results to SDRs matching a word contained within the selected keyword list.

ATA/JASC Filter

The "ATA/JASC Filter" dropdown will display the names of the ATA/JASC filters you have defined using the "Modify Filters - ATA/JASC Filters" functionality. This filter will limit the search results to only those SDRs that have an ATA code checked in the selected ATA/JASC filter list.

Aircraft Filter

The "Aircraft Filter" dropdown will display the names of the aircraft filters you have defined using the "Modify Filters - Aircraft Filters" functionality. This filter will limit the search results to only those SDRs that have an aircraft series or model code added to the selected aircraft filter list.

Serial Number

The "Serial Number" field will limit the search results to matching values contained in the "c440_aircraft_serial_num" field in the SDR table. It can be used to return information about an individual aircraft, but may need to be combined with a very restrictive "Aircraft Filter" in the event multiple aircraft manufacturers have used the same serial numbers.

Mfg Part Number

Similar to the "Serial Number" search, the "Mfg Part Number" field can be used to limit the results to SDRs with a specific manufacturer part number specified in the "c90_mfg_part_num" field.

Max Records to Return

Because loading a large amount of data to the page can take some time, the "Max Records to Return" field can be used to limit the number of results returned on the results page. Setting this value to "0" (or higher than the number of actual results found) will allow all of the search results to be displayed.

SEARCH ACTIONS

Search Button

The "Search" button will use the supplied search parameters to find matching records and then display the "SDR Search Results" page.

Export to Excel

The "Export to Excel" button will use the supplied search parameters to find matching records and then load all of the SDR information into an Excel document.

SDR SEARCH RESULTS

After you select the "Search" button on the "Find SDRs" page, you will be taken to the "SDR Search Results" page. This page shows a list of the SDRs matching all of the search parameters you specified.

Clicking a column heading that has triangle(s) next to the name will sort the results by that value. Clicking the column heading again will reverse the sort order. The currently sorted column will have a darker triangle indicating the sort order. Clicking an Ocn value will take you to the "SDR Details" page for that SDR.

SDR DETAILS PAGE

After clicking an Ocn number on the search results page, you will be redirected to the "SDR Details" page. This page shows all of the information in the database for that SDR.

DMT Home   Find SDRs   Reports ▾   Modify Filters ▾   Help ▾

Details for 2000UALA00568

sdr_id	198735
c5_date_seq	2000112900239
c10_receipt_date	20001129
c12_seq_num	00239
c14_region	
c14_desc	
c15_year	2000
c16_month	11
c17_day	29
c18_ocn	2000UALA00568
c20_segment	4
c20_desc	COMPONENT
c25_occurrence_date	20000927
c35_type	A
c35_desc	AIR CARRIER
c40_ata_code	3435
c40_desc	HEADS UP DISPLAY SYSTEM
c90_mfg_part_num	
c100_part_name	INDICATOR
c110_component_mfg	
c110_desc	
c120_component_mo...	
c130_aircraft_mfg	BOEING
c130_desc	THE BOEING CO
c140_aircraft_group	777
c150_aircraft_model	777222
c152_aircraft_make_...	1385219
c160_aircraft_region	NM
c160_desc	NORTHWEST MOUNTAIN
c170_engine_mfg	PWA
c170_desc	PRATT WHITNEY AIRCRAFT DIV UNITED AC
c180_engine_group	4090
c190_engine_model	PW4090
c192_engine_make_...	52119
c200_engine_region	NE
c200_desc	NEW ENGLAND
c210_propeller_mfg	
c210_desc	
c220_propeller_group	

DMT Home　　Find SDRs　　Reports ▾　　Modify Filters ▾　　Help ▾

c652_propeller_power	
c654_propeller_type	
c660_propeller_ccn	
AircraftTotalTime	15794
AircraftTotalCycles	2493
EngineTotalTime	
EngineTotalCycles	
PropellerTotalTime	
PropellerTotalCycles	
PartMake	
PartSerialNumber	
PartTotalCycles	
PartTotalTime	
PartTimeSince	
PartSinceCode	
ComponentName	
ComponentPartNumber	
ComponentSerialNu…	
ComponentLocation	
ComponentTotalTime	
ComponentTotalCycles	
ComponentTimeSince	
ComponentSinceCode	
EquipmentMake	BOEING
EquipmentGroup	777
EquipmentModel	777222
FuselageStationFrom	
FuselageStationTo	
StringerFrom	
StringerFromSide	
StringerTo	
StringerToSide	
WingStationFrom	
WingStationFromSide	
WingStationTo	
WingStationToSide	
ButtLineFrom	
ButtLineFromSide	
ButtlineTo	
ButtlineToSide	
WaterLineFrom	
WaterLineTo	
CrackLength	
NumberOfCracks	

A-22

SDR DATA STRUCTURE – TECHNICAL BACKGROUND

When the annual SDR data were downloaded from the FAA website, all of the information was contained in records with column headings having a format of "c" followed by a numerical code (e.g., the "c40" column in the downloaded data contains ATA code information, and "c130" contains the aircraft manufacturer). To make the data easier to work with, we appended an additional description value to each code (e.g., "c40" was expanded to "c40_ata_code").

We also found information on the FAA website that resolved some of the data values to more descriptive terms, and that information was loaded into a lookup table. For the columns where we had lookup information available, we added another column for that code to the SDR database ending with "_desc" and loaded the descriptive term into that additional field. In the above example, the "3435" value in the "c40_ata_code" field was used to find the corresponding lookup value and populate the more descriptive "HEADS UP DISPLAY SYSTEM" text stored in the new, SNL-created "c40_desc" column.

The "sdr_id" value at the top of the "SDR Details" page is the primary key value for that record in the DMT database. The "c5_date_seq" and "c18_ocn" fields have been used by the FAA as primary key values with "c18" being the key for recent records. To use the "c18_ocn" field as a natural key for future data import activities and prevent duplicate SDR entries, that field needed to be identified as a distinct value in the DMT database. Because the older historical SDR data did not contain values in the "c18" field, we defaulted blank values to "SNL_<sdr_id>" so each record would have a unique "c18" operator control number value.

The fields in the database that do not start with a "cXX" value (e.g., "AircraftTotalTime," "StringerFrom," etc.) were obtained from additional SDR data provided by Aviation Systems Branch (AFS-620). These data were merged with the downloaded data based on a match with either the "c5_date_seq" or "c18_ocn" field so all of the available information from both the original download and additional data could be stored in a single SDR table.

DATA REPORTS

General Information

Many of the report screens start with a page that shows search criteria similar to the "Find SDRs" screen. Selecting the desired filters and specifying search criteria works the same way on the report screens as it does on the "Find SDRs" screen, and allows the user to customize the report results.
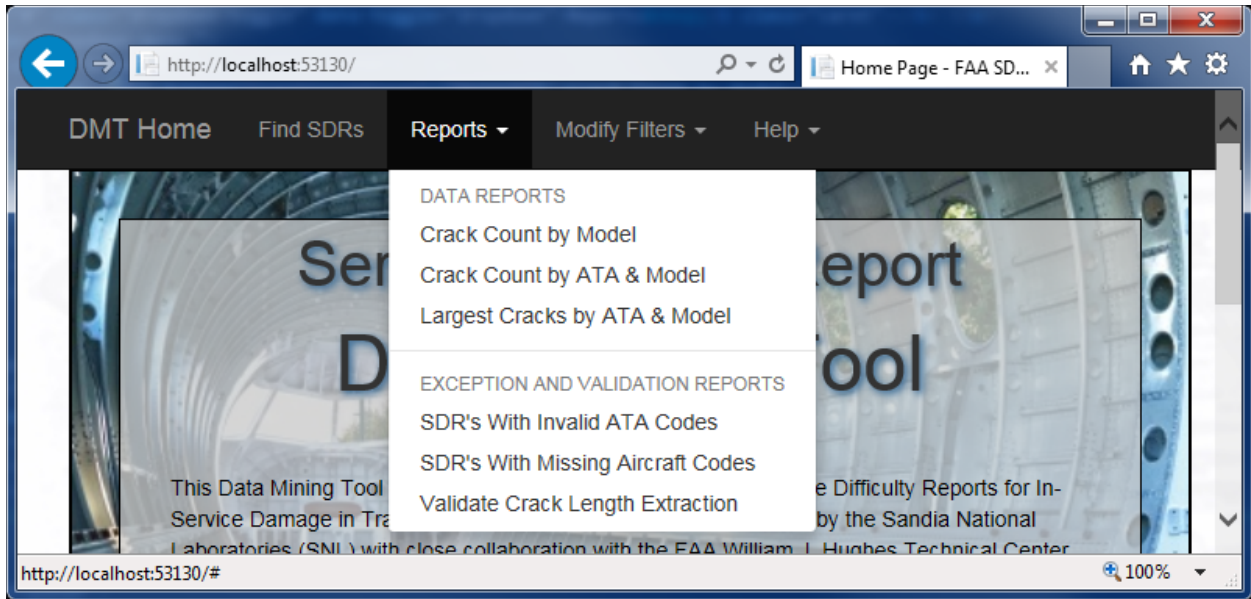
Reports – Crack Count by Model

Specify your search criteria on the initial page and then click "Search" to display the search results in the "Crack Count by Aircraft Model" results page. If you want to save the results in Excel format, click "Export to Excel".
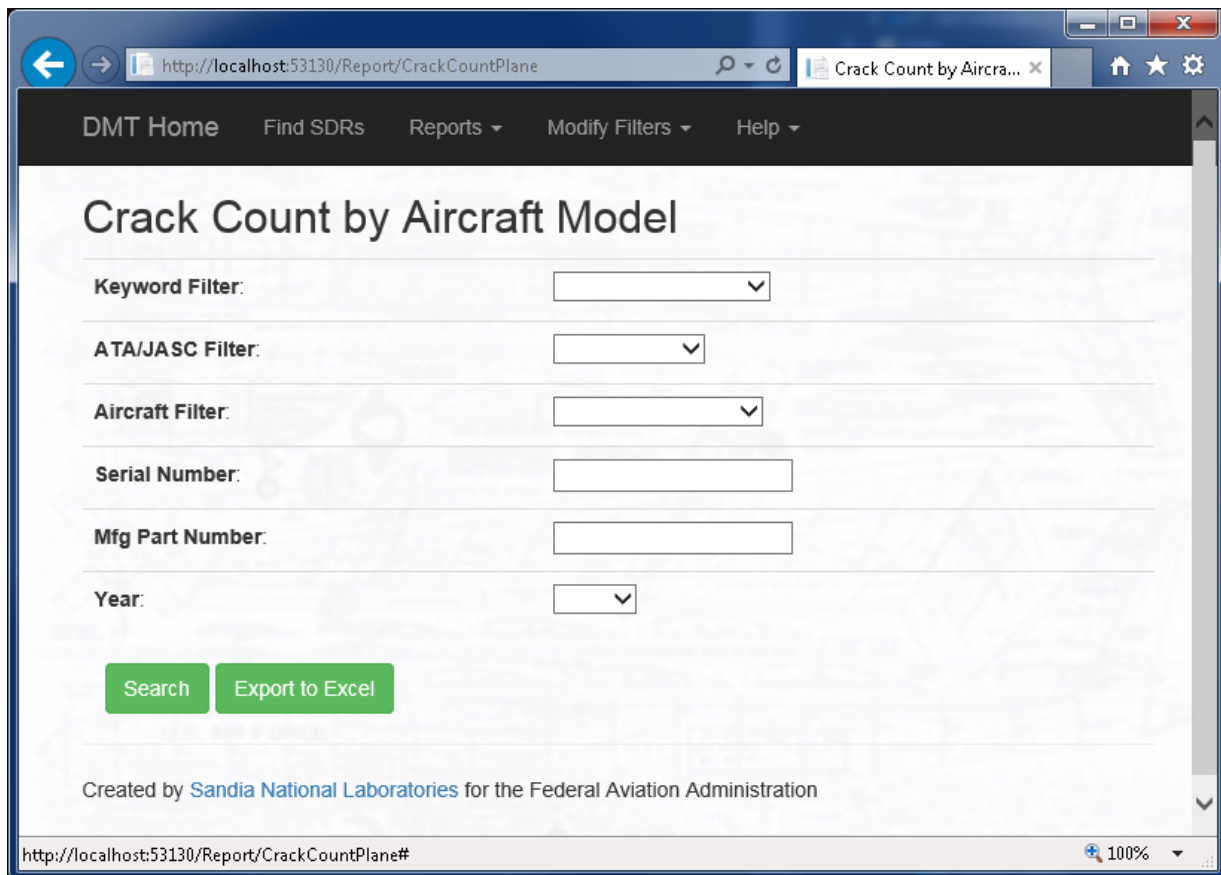
Clicking on a result value in the "Total Crack Records" column will show you the detailed information for those SDR records on the "SDR Search Results" page. Clicking a column heading will sort the data by that value.

At the bottom of the results page, you can see the total count of records found (e.g., 533) and navigation buttons to page through the results.

<u>Reports – Crack Count by Aircraft Model and ATA Code</u>

Specify your search criteria on the initial page and then click "Search" to display the search results in the "Crack Count by Aircraft Model and ATA Code" results page. If you want to save the results in Excel format, click "Export to Excel."

The report results page will display the total number of SDRs found for each make/model/code combination. Clicking a column heading will sort the data for that make by that heading value. Clicking on a result value in the "Total Crack Records" column will show you the detailed information for those SDR records on the "SDR Search Results" page.

Reports - Largest Crack by ATA Code and Aircraft Model

Specify your search criteria on the initial page and then click "Search" to display the search results in the "Largest Cracks by ATA Code and Aircraft Model" results page. If you want to save the results in Excel format, click "Export to Excel."

The "Max Number of Cracks to Return" field is defaulted to return the five largest cracks found for each make/model/ata code combination, but the user can change that value to return a different number of results. If the search returns fewer crack-length records for a given make/model/ata code combination than is specified by the "Max Number of Cracks to Return" field, then it will display all of the crack-length results available for that code.

The report results page will display the total number of SDRs found for each make/model/code combination. Clicking a column heading will sort the data for that make by that heading value. Clicking on a result value in the "Total Crack Records" column will show you the detailed information for those SDR records on the "SDR Search Results" page. Crack-length values specified as "Invalid" in the "Validate Crack Length Extraction" report will not be shown in the results for this report.

EXCEPTION AND VALIDATION REPORTS

Reports – SDRs with Invalid ATA Codes

This report will automatically launch Excel and display a list of SDRs, which have either a blank value in the "c40_ata_code" column or a code that does not match one of the valid ATA lookup values, making them unavailable when using any ATA/JASC filter. It is intended to meet the deliverable specified on page 12 of the DWP, Figure 2 Box 4 "Report 'A – insufficient' SDR entries with insufficient content to filter."

When you click on the link for the report, you will see a window in your browser asking if you want to open or save the file. Click "Open."
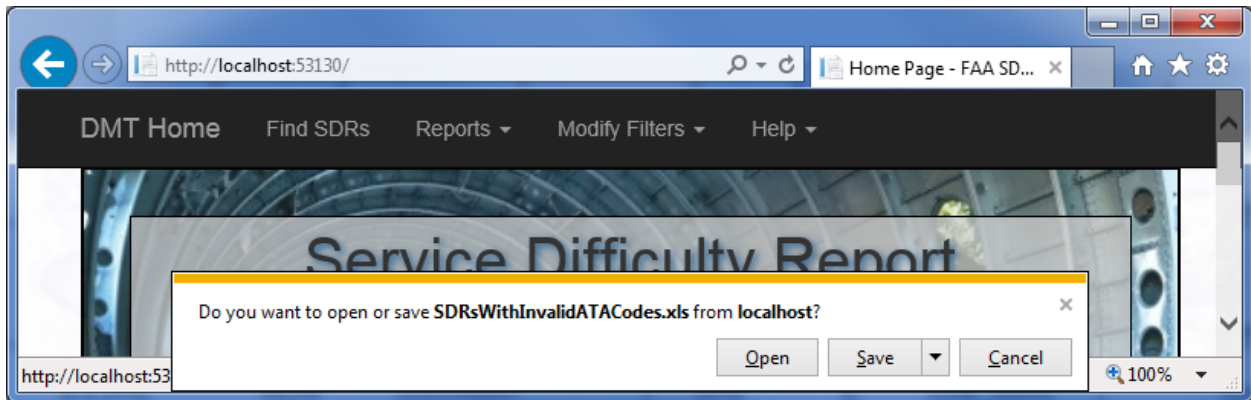
You will likely receive an error message about the file extension. Click "Yes."
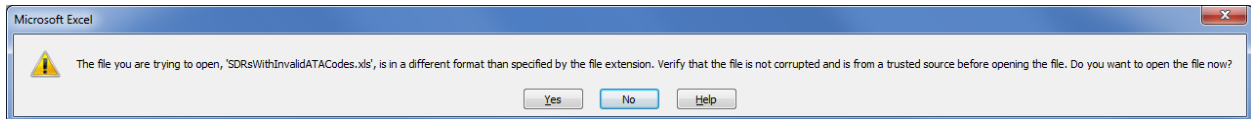
In the Excel report, you can see that the values in the "c40_ata_code" field are blank or non-numeric.

Reports - SDRs with Missing Aircraft Codes

This report will automatically launch Excel and display a list of SDRs with a blank value in any of the "c130_aircraft_mfg," "c140_aircraft_group," or "c150_aircraft_model" columns, which makes those records unavailable when using an aircraft filter. It is also intended to meet the deliverable specified on page 12 of the DWP, Figure 2 Box 4 "Report 'A – insufficient' SDR entries with insufficient content to filter." This report will open the same way as "SDRs with Invalid ATA Codes" with the same warning message.

Reports - Validate Crack Length Extraction

The purpose of this report is to allow the user to suppress invalid crack-length values from appearing in the "Largest Crack by ATA Code and Aircraft Model" report. The natural language processing algorithm uses abstract rule sets to determine crack-length information from the very unstructured "c510_remarks" text field. As a result, it is likely that the NLP program will sometimes extract numerical information that is not related to crack length so this page allows a user to manually review the information and tag it as either "Valid" or "Invalid."

Text in the "Remarks" field matching the crack-length value is highlighted to make going through this page easier. As the user goes through the report and selects either "Valid" or "Invalid," the selected status is displayed in the "Status" column. Values marked as "Invalid" will not appear in the "Largest Crack by ATA Code and Aircraft Model" report. "Valid" data are not currently treated any differently than data that have not been reviewed, but that selection may be used to calculate metrics in future versions of the application. Marking a value as "Valid" also makes it easier to quickly scan the page to find values that still need to be reviewed. If you mark a value incorrectly, you can reload the page to have the buttons reappear for all rows.

HELP

General

The help screens will display some of the key documentation for this project, including the DWP, the System Setup & Configuration guide used to install the DWP application on a new computer, and this User Guide.
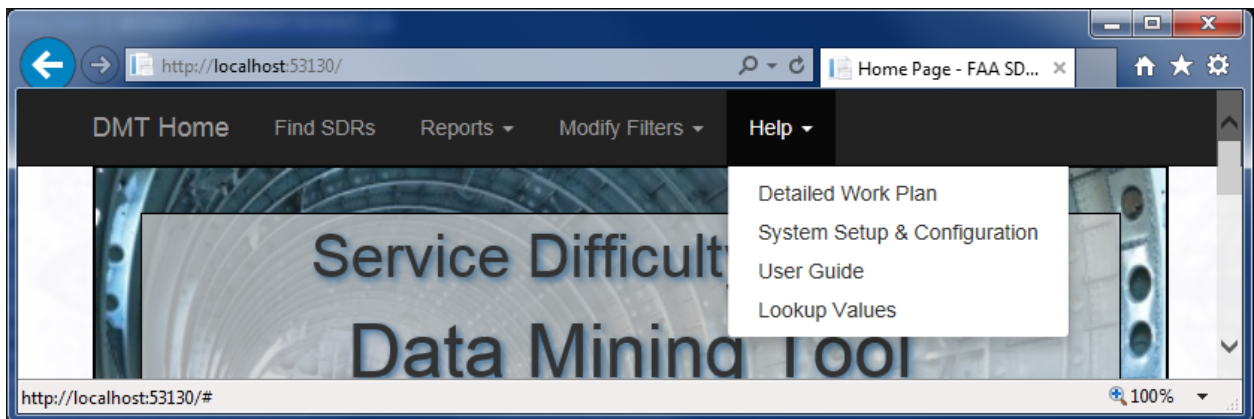
Application Lookup Values

The "Application Lookup Values" screen displays the lookup table information stored in the database. There is no need to modify any of the information on this screen. Any data changes will not be reflected in the SDR data displayed in the application because the historical SDR data have already been loaded into the application and pre-populated with the long description text.