

PAST AND PRESENT LARGE SOLID ROCKET MOTOR TEST CAPABILITIES

David B. Owen II
The Johns Hopkins University
Chemical Propulsion Information Analysis Center
Columbia, MD

Robert R. Kowalski
National Aeronautics and Space Administration
White Sands Test Facility
Las Cruces, NM

ABSTRACT

A study was performed to identify the current and historical trends in the capability of solid rocket motor testing in the United States. The study focused on test positions capable of testing solid rocket motors of at least 10,000 lb_f thrust. Top-level information was collected for two distinct data points plus/minus a few years: 2000 (Y2K) and 2010 (Present). Data was combined from many sources, but primarily focused on data from the Chemical Propulsion Information Analysis Center's Rocket Propulsion Test Facilities Database, and heritage Chemical Propulsion Information Agency/M8 Solid Rocket Motor Static Test Facilities Manual. Data for the Rocket Propulsion Test Facilities Database and heritage M8 Solid Rocket Motor Static Test Facilities Manual is provided to the Chemical Propulsion Information Analysis Center directly from the test facilities. Information for each test cell for each time period was compiled and plotted to produce a graphical display of the changes for the nation, NASA, Department of Defense, and commercial organizations during the past ten years. Major groups of plots include test facility by geographic location, test cells by status/utilization, and test cells by maximum thrust capability. The results are discussed.

PROJECT OVERVIEW

In 2010, the NASA Rocket Propulsion Test (RPT) Program Office contracted The Johns Hopkins University/Chemical Propulsion Information Analysis Center (JHU/CPIAC) to conduct a rigorous assessment of U.S. liquid rocket engine (LRE) test capabilities that are available at commercial, government, and academic facilities in order to support the development of their RPT Master Plan. CPIAC performed the analysis and assessment of U.S. Test Capability for Liquid Propulsion for 2010, as well as in select historical timeframes. The focus of the assessment was on test cells for liquid rocket engines for boost and axial thrust systems of 1000 lb_f or greater in thrust. 1000 lb_f thrust was selected as the low cutoff because the study was only concerned with test positions that could test engines sizable enough to be placed on a launch vehicle or manned spacecraft. Shortly after, the RPT requested CPIAC do a similar study to provide a graphical display of the changes in the solid rocket motor (SRM) test capabilities across the nation for between 2000 and 2010 in support of an Agency level rocket study. Test facilities of 10,000 lb_f or greater were requested in order to ensure the facilities in the study would be for large motors and not laboratory scale motor tests. The study included top-level data on 111 current and historical test positions in 19 current and historical test facilities for large SRMs. The 19 facilities included 10 U.S. government facilities—7 Department of Defense (DoD) and 3 NASA, 8 commercial facilities, and 1 academic facility. Test ranges and launch facilities were beyond the scope of the project. The specific time frames of 2000 and 2010 were included.

RESEARCH TECHNIQUES

PHASES OF U.S. SOLID ROCKET MOTOR DEVELOPMENT

The analysis included the specific timeframes of 2000 and 2010, with the data reflective of the period within a couple of years of those dates. These data points were selected to demonstrate the changes to the solid motor industry in the past ten years. The reasoning behind these selections is as follows:

- 2000 (Y2K): turn of the century/millennium; and
- 2010 (Present): present day and just after the initial development of emerging small commercial launch vehicle (LV) companies.

It was thought that upon reporting the data for a selected year, all changes to a test facility in the years after a data point would accumulate until the next selected data point year. It was also recognized that data from the year in question may be reported in reports published the following year. Thus, it was assumed that for any facility that was found to be operating for a few years prior to or after one of the selected dates, the facility could be assumed to be operating in the same capacity on that date. This assumption allows for a more complete collection of data by allowing such examples as 1998 through 2001 data to be combined into the year 2000.

SOURCES

Data for the analysis came from a variety of sources, including CPIAC's Current and Legacy Test Facilities Data. These data are provided to CPIAC by the test facilities, either directly, through the National Rocket Propulsion Test Alliance (NRPTA), or through the Rocket Test Group (RTG). CPIAC has historically used these data in the CPIA/M8 Solid Rocket Motor Static Test Facilities Manual (M8 Manual), and now in the Rocket Propulsion Test Facilities Database (RPTF). Other data sources for the project include test program, engine development, test facilities documentation and reports; JANNAF, AIAA, and other journal publications; and U.S. government and contractor reports. Various collections searched include the CPIAC collection, Defense Technical Information Center (DTIC) collection, and the NASA Scientific and Technical Information (STI) collection (now the NASA Aeronautics and Space Database). CPIAC also collected information through the engagement of facilities/organizations and their local reports, collections, and records; greybeards; and historians.

U.S. TEST CAPABILITY ASSESSMENT AND ANALYSIS APPROACH

The primary approach was to gather top-level information for each test cell for the years in question. The data was gathered in a series of three Excel spreadsheet workbooks (Figure 1); graphs (Figure 2) were produced assessing the nation's solid motor testing capabilities. The spreadsheets tracked the number of geographic locations and test positions in 2000 and 2010, their operational status, and the thrust level for each test position. This approach was similar to the approach used in the previously mentioned LRE Test Facilities report. However the dataset was much smaller, due to the timeframes in question, and easier to manipulate. The downside to the smaller dataset was that it limited traceability if test location or position information was missing or inconsistent. While this abbreviated method was not ideal, it still utilized all of the lessons learned from the LRE Test Facilities research project, drastically reduced the overall workload and cost of the project, and with the exception of no data sheets being produced or final report being immediately written, it produced the same primary results: graphical display of the condition of the United States' SRM Test Facilities. The quality and accuracy of the data remained unchanged.

Status					Test Cell												Key	
					2009						2010							
					O	M	A	N	R	T	O	M	A	N	R	T		
3		D	D		Arnold Engineering Development Center	All	4	0	0	0	4	1	2	0	0	0	3	
4					Altitude		4	0	0	0	4	1	2	0	0	0	3	
5					J-3													Liquid only in 2010
6		DA	DA		J-4													
7					J-5													
8					J-6													
9		D	D		Air Force Research Laboratory	All	7	0	0	0	13	7	1	1	0	0	17	
10					Altitude		7	0	0	0	13	7	1	1	0	0	17	
11		DB	DB		1-32Pa1													
12					1-32Pa2													
13					1-32Pa3													
14					1-32Pa5A													
15					1-32Pa5B													
16					1-32Pa5C													
17					1-36A													
18					1-36B													
19					1-36D													
20		DA	DA		1-42A													
21					1-42D													
22					1-42E													
23					1-52A													
24					1-52B													
25					1-52C													
26					1-52D													
27					1-56													
28					1-125 1C													
29					1-125 30E													
30		LC	LC		Aerojet - Camden	All	3	0	0	0	3	3	0	0	0	0	3	
31					Altitude		3	0	0	0	3	3	0	0	0	0	0	
32		LDB	LDB		Bldg 8													
33					Bldg 45													
34					Bldg 15													
35		LC	LC		Aerojet - Gainesville	All	6	0	0	0	6	0	0	0	0	0	6	
36					Altitude		6	0	0	0	6	0	0	0	0	0	6	
37		LDB	LDB		Cell 1													
38					Cell 2													
39					Cell 3													
40		LCA	LCA		Cell 4													
41					Cell 5													
42		LC	LC		Aerojet - Orange	Bldg 01	0	0	0	2	2	0	0	0	2	0	2	
43					Altitude		0	0	0	2	2	0	0	0	2	0	2	
44		LDB	LDB		Cell 1													
45					Cell 2													
46		LC	LC		Aerojet - Sacramento	All	6	0	0	2	6	0	0	0	2	0	8	
47					Altitude		6	0	0	2	6	0	0	0	2	0	8	
48		LDB	LDB		A-Zone													Analysis data from All Liquid
49					B-Zone													
50					B-7													
51					J-Zone													
52					J-3A													
53		LCA	LCA		L-4													
54					P-Zone													
55					P-2													
56					T-Zone													
57		D			Army Propulsion Lab AMRDEC/WBI	All	0	0	0	0	4	0	0	0	0	0	4	
58					Altitude		0	0	0	0	4	0	0	0	0	0	4	
59		DB			SFC													
60					7N3 Bay 1													
61					7N3 Bay 2													
62					7N3 Bay 3													
63		LC	LC		ATK - Allegany Ballistics Lab	All	2	0	0	0	2	0	0	0	2	0	2	
64					Altitude		2	0	0	0	2	0	0	0	2	0	2	
65		LDB	LDB		Large HC													
66		LC	LC		Large Test Range Bay 3													
67		LC	LC		ATK - Thiokol	All	3	0	0	0	3	0	0	0	0	0	3	
68					Altitude		3	0	0	0	3	0	0	0	0	0	3	

Figure 2. Example spreadsheet.

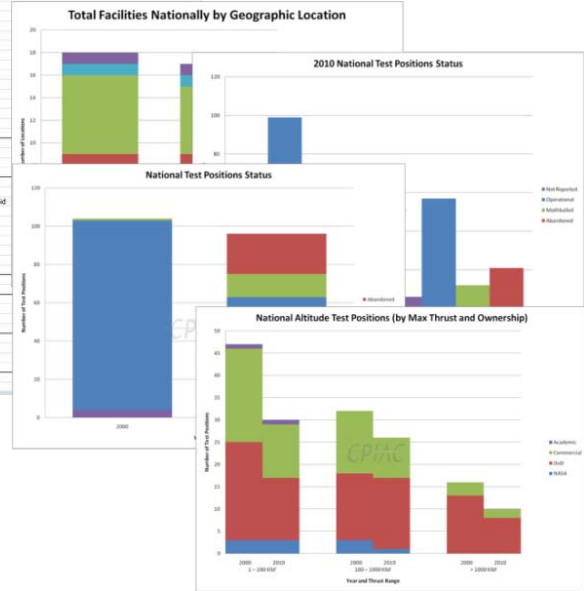


Figure 1. Example graphs.

DATA ARRANGEMENT

Data for the plots was divided into the following groupings of organizations: Academic, Emerging commercial, Legacy commercial, and Government. The only organization falling into the Academic category was the Princeton Combustion Research Lab.

The only organization falling into the Emerging category was the Mojave Test Area (MTA). The MTA has been around as an amateur test facility since the 1940s, but is counted here as an Emerging facility. This is because much more recently small emerging propulsion companies—and some universities—have been using that facility for their rocket tests instead of building their own. Since most new launch vehicle companies are using liquid engines instead of solid motors, the solid motor aspect of the industry has not had an influx of new organizations constructing large SRM test facilities.

The Legacy sector of the industry includes Aerojet (Camden, Gainesville, Orange, and Sacramento), ATK (Allegany Ballistics Lab and the former Thiokol location in Utah), and Pratt and Whitney Space (Chemical Space Division). The combination of the Legacy and Emerging organizations make up the rocket propulsion commercial sector as a whole.

The Government category is a combination of both military and civilian government test facilities. Military test facilities are grouped under the label DoD. NASA is the only civilian government organization with test facilities, so naturally all civilian government organizations are grouped as NASA. The DoD organizations included in this study are the Arnold Engineering Development Center, Air Force Research Laboratory (Edwards), Army Propulsion Lab Aviation and Missile Research Development and Engineering Center (AMRDEC) Weapons Development and Integration Directorate (WDI), Naval Air Warfare Center Weapons Division (China Lake, NAWC-WPNS), Naval Surface Warfare (Indian Head), Redstone Test Center, and White Sands Missile Range.

The NASA facilities are made up of the Marshall Space Flight Center, Stennis Space Center, and White Sands Test Facility.

All of the organizations are combined in the following chart to display the nation's test facilities, their locations, and the years of operation relevant to this study where each facility has had large SRM test capabilities.

Table 1. Solid Rocket Motor Test Facilities Geographic Overview.

Organization	Location	Years of Operation	
		2000	2010
Arnold Engineering Development Center	Arnold Air Force Base, Manchester, TN	X	X
Aerojet	Camden, AK	X	X
Aerojet	Gainesville, VA	X	X
Aerojet	Orange, VA	X	X
Aerojet	Sacramento, CA	X	X
Air Force Research Laboratory	Edwards Air Force Base, Edwards, CA	X	X
Army Propulsion Lab AMRDEC-WDI	Redstone Arsenal, Huntsville, AL	N/A	X
ATK (Allegany Ballistics Lab)	Rocket Center, West Virginia	X	X
ATK (formerly Thiokol)	Clearfield, UT	X	X
Mojave Test Area	Ridgecrest, CA	X	X
NASA Marshall Space Flight Center	Huntsville, AL	X	X
NASA Stennis Space Center	Stennis Space Center, MS	X	N/A
NASA White Sands Test Facility	Las Cruces, NM	X	X
Naval Air Weapons (NAWC-WPNS)	China Lake, CA	X	X
Naval Surface Warfare	Indian Head, MD	X	X
Pratt and Whitney Space (Chemical Space Div.)	San Jose, CA	X	N/A
Princeton Combustion Research Lab	Princeton, NJ	X	X
Redstone Test Center	Redstone Arsenal, Huntsville, AL	X	X
White Sands Missile Range	Las Cruces, NM	X	X

INTERESTING RESULTS

This section discusses some of the results of plotting selected general information, capabilities, and features over time. Each subsection will focus on a different capability.

GEOGRAPHIC LOCATIONS

In this section, the number of geographic locations across the nation where any organization has a test position is discussed. Each geographic location is a test facility that consists of at least one test position. The number of test positions located within the nation will be discussed in a future section of this report and is not represented here. If multiple organizations are geographically located in the same region, Army Redstone and NASA MSFC for example, each is counted as a separate location.

Figure 3 displays the differences between the nation's large SRM test facilities between 2000 and 2010. It can be seen that the total number of locations has decreased, within which the numbers of NASA and Legacy commercial test facilities have decreased while the number of DoD facilities has increased. The Academic and Emerging organizations have remained constant.

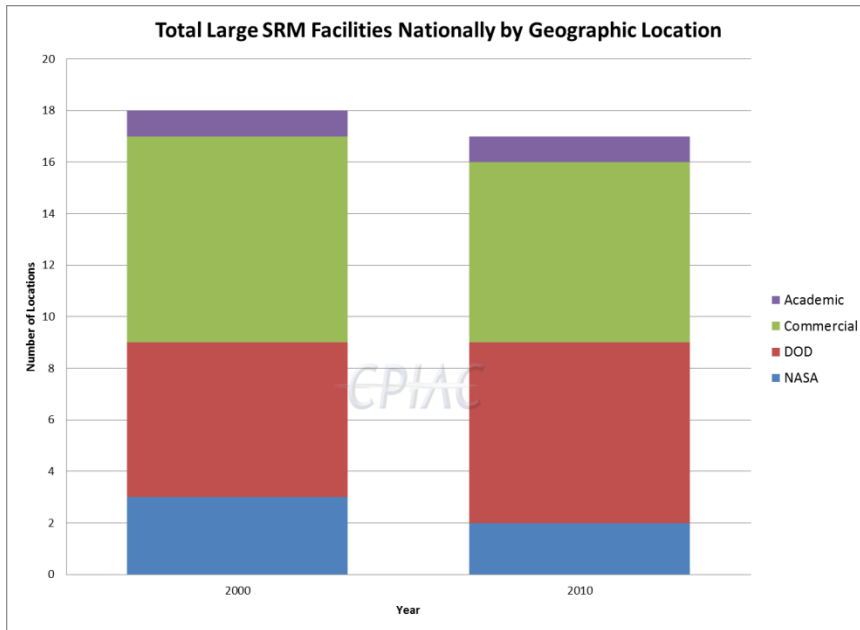


Figure 3. Total Facilities Nationally by Geographic Location.

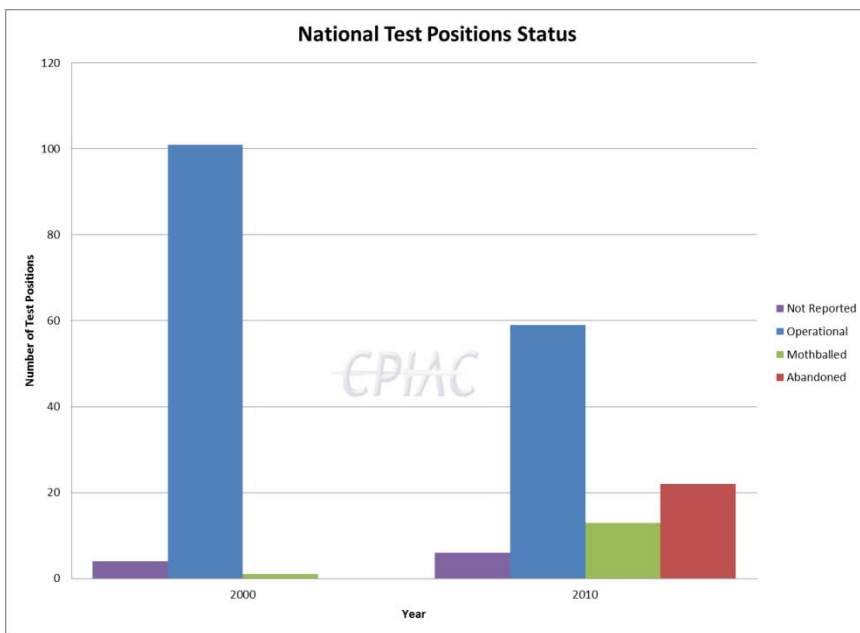


Figure 4. Status of Large SRM Test Positions Nationwide in 2000 and 2010.

for the years 2000 and 2010 divided into the three categories of 10–100 Klb_f, 100–1000 Klb_f, and >1000 Klb_f, from here on referred to as low, medium, and high, respectively. The charts are also color coded to display the number of test positions owned by each ownership group: Academic, Commercial, DoD, and NASA. The Commercial category is the combination of all Emerging and Legacy organizations. The abandoned test positions have been removed from the results thereby showing what capabilities the nation has without a massive investment required to reactivate or rebuild abandoned test positions.

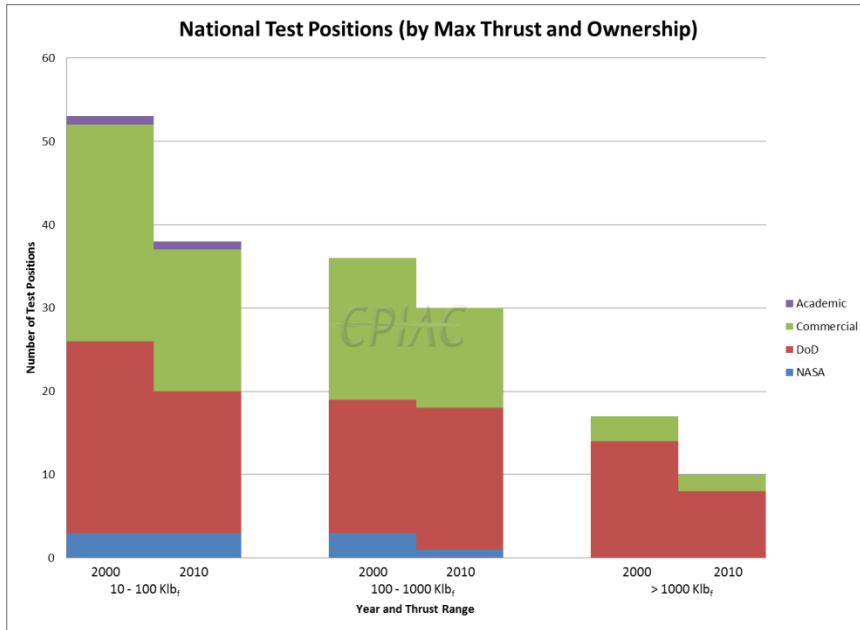
If the capabilities for Abandoned positions are removed from the data, as shown in Figure 5, then there has been a reduction of the number of test positions in all thrust ranges. The largest decrease is in the low thrust range. While NASA and the Academic positions show no change, the DoD positions decreased with the loss of 6 positions and the Commercial positions have decreased by 9 positions. For medium thrust test positions, NASA decreased by 2 positions, the Commercial positions decreased by 5

TEST POSITION STATUS

As can be seen in Figure 4, the total number of operational test positions for SRMs of 10 Klb_f thrust or larger has decreased between 2000 and 2010, dramatically from 101 operational positions in the year 2000, down to 59 in 2010; a decrease of just over 41.5 %. This coincides with an increase of Mothballed and Abandoned test positions. The number of Mothballed positions increased from 1 to 13, and the number of Abandoned positions increased from 0 to 22. The total number of positions reported in 2010 was 6 fewer than in 2000. The DoD added 4 positions with the new facility, but 10 government test positions were demolished, converted to non-rocket testing, or were liquid engine and solid motor positions that only tested liquid engines by 2010.

TEST POSITIONS BY MAXIMUM THRUST CAPABILITY

This section discusses the nation's test positions in terms of the maximum thrust-level range the SRM test positions are capable of testing, with regards to ownership. Figure 5 displays the maximum thrust



positions, and the DoD had an increase of 1 position. For the high thrust range, the Commercial test positions decreased by 1 and the DoD decreased its inventory by 5 positions. This data correlates with the data for Figure 3 from the “Geographic Locations” section above. As expected, the reduction of a Commercial and NASA facility have resulted in a reduction of test positions. It is interesting to note that an increase in the number of DoD facilities still showed a decrease in number of DoD test positions.

Figure 5. National Test Positions by Maximum Thrust and Ownership.

TEST POSITIONS BY ALTITUDE CAPABILITY

This section discusses the altitude capabilities for large SRM test positions. As with the previous section, these graphs divide the cells by the low, medium, and high thrust levels, and are color coded by ownership. The same definitions as before apply for low, medium, and high thrust range test positions. Figure 6 displays the Nation’s ambient test positions, and figure 7 displays the Nation’s altitude test positions for large SRMs. To portray an accurate view of the Nation’s capabilities at the two selected years, without a hypothetical massive investment into a position to bring it up to a status capable of testing a SRM, the capabilities of abandoned test positions have been removed from these results.

The number of ambient U.S. test positions for SRMs has decreased in all ranges, but most drastically in the low thrust range. Here the NASA and Academic positions remain constant at 2 and 1, respectively, but the DoD and Commercial positions are respectively reduced by 5 and 4. The number of capable DoD positions went from 20 to 15, and the Commercial positions dropped from 18 to 14. In the medium thrust range, the number of test positions decreased by a total of 6. NASA lost two positions ending with one ambient test position, and the Commercial organizations lost a combined total of 5, bringing down to 12 positions. Even with reductions at some DoD facilities, the DoD had a net gain of 1 to total 15 available test positions in the year 2010. For the high thrust range test positions, the DoD

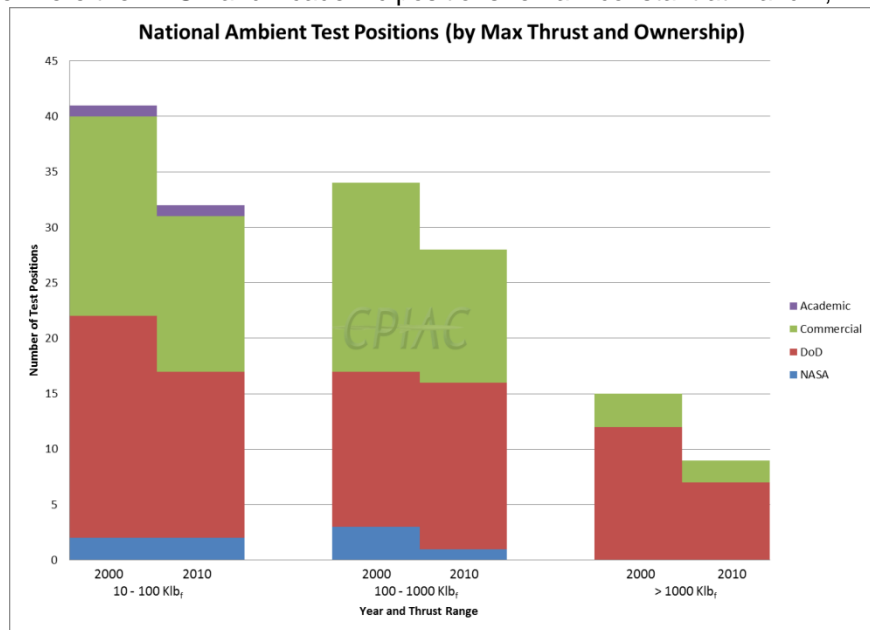


Figure 6. U.S. Ambient Test Positions by Maximum Thrust and Ownership.

had a reduction of 6 positions and the Commercial organizations experienced a reduction of 1 position. That leaves the nation with only 9 SRM test positions—7 DoD and 2 Commercial—in the high thrust range.

The number of U.S. altitude test positions for SRMs has also decreased. The nation lost 6 low thrust range altitude positions and 1 high thrust range position. The DoD dropped from 3 to 2 low thrust range positions, while the Commercial organizations experienced a much larger reduction from 8 to 3. The number of altitude simulation capable positions in the medium thrust range remained constant with the DoD holding onto the Nation’s only 2 medium thrust range SRM test positions. In the high SRM thrust range, the DoD was reduced from 2 to 1 altitude test position.

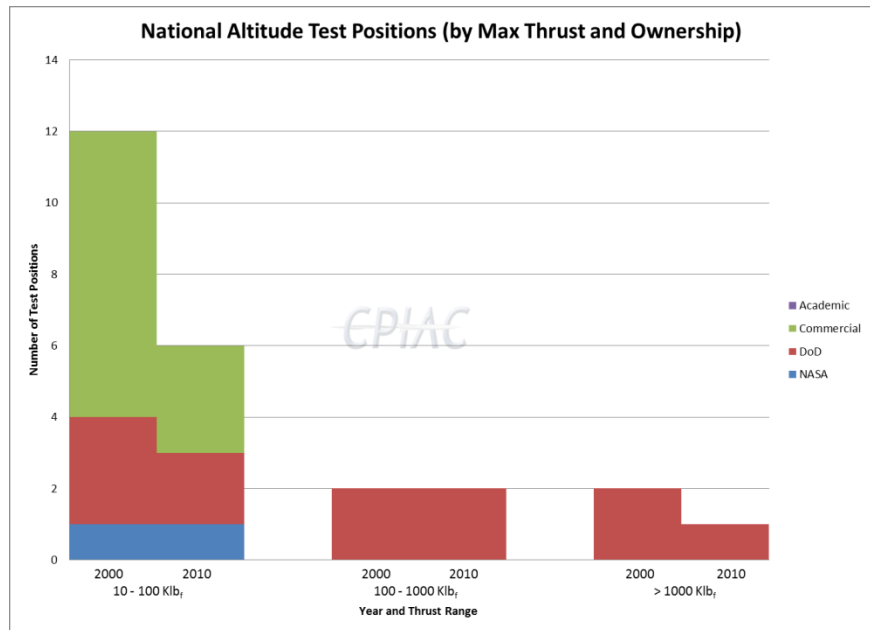


Figure 7. U.S. Altitude Test Positions by Maximum Thrust and Ownership.

LESSONS LEARNED

SUGGESTED IMPROVEMENTS

There were two suggested improvements on how the data in the original study was handled within the spreadsheets to create the graphs. Color coding the test positions’ capabilities by the positions’ operational status would be a minor visual tool that would allow the capabilities to be more easily grouped by operational status, and to include or exclude particular stands’ capabilities based on the operational status of that year. The most useful application of this would be to remove the capability data of Abandoned test positions from the totals, thereby allowing the totals to display only Operational and Mothballed positions. That set of graphs would then show only those positions that were able to test an SRM with minimal additional funds having been necessary to bring the stand up to an operational condition. It is suspected that those graphs would more accurately portray the nation’s immediate test capabilities at any one time, and may more accurately follow overall trends seen in the history of rocket test programs. After having completed the initial set of spreadsheet and graphs, these suggestions were implemented, and those results were used for the writing of this paper.

FACILITY RESEARCH DATABASE

The RPTF is maintained by CPIAC for NRPTA member organizations. These organizations are NASA Stennis Space Center, NASA Plum Brook Station, NASA Marshall Space Flight Center, NASA White Sands Test Facility, Arnold Engineering Development Center, Air Force Research Laboratory, Redstone Test Center, and the Naval Air Warfare Center. The RPTF consists of test position data for both solid and liquid rocket test positions, and includes downloadable PDFs of the datasheets from the heritage CPIA/M7 Liquid Rocket Engine Static Test Facilities Manual and M8 Manual. Data for RPTF are provided from the facilities either directly through NRPTA, or through RTG. RTG is an entirely volunteer

organization of rocket test facility operators that consists of members of NRPTA and the commercial and academic community.

The database can be accessed from CPIAC's homepage, www.cpiac.jhu.edu, through the Chemical Propulsion Information Network (CPIN), along with CPIAC's other databases. The RPTF is one of many tools and resources provided to the researcher by CPIAC. Facility operators and managers, program managers, and other engineers use RPTF for finding information on test positions within the U.S. It is recommended that that the spreadsheets produced in this project eventually become a downloadable attachment in RPTF. Access to CPIN is limited to qualified U.S. citizens, and RPTF data is at the Distribution Statement C level (U.S. Government agencies and their U.S. contractors). Access to RPTF and CPIAC's other CPIN databases can be purchased online through the "Sign up here" link from the CPIN log-in page on CPIAC's website.