Final Report
For
Domestic Reduced Vertical Separation Minimum (DRVSM)
Initial Simulation

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TABLE OF CONTENTS

1. INTRODUCTION

1.1 Background

Reduced Vertical Separation Minimum (RVSM) is an ICAO approved concept that reduces the vertical separation standard from 2000 ft to 1000 ft above flight level (FL) 290 to FL410, inclusive. RVSM adds six flight levels between FL290 and FL410, thereby increasing airspace throughput and allowing more flexibility for controllers to grant user preferred altitudes. RVSM is already implemented in the North Atlantic and Pacific oceanic airspace, and domestic RVSM (DRVSM) is a high priority for the FAA's Operational Evolution Plan (OEP). However, the impact on en route controllers in high-density U.S. domestic airspace needs to be understood.

Under the auspices of the Air Traffic Planning and Procedures Program (ATP-110), a series of human-in-the-loop (HITL) simulations are planned to investigate the operational impacts of implementing DRVSM in the domestic U.S. airspace on en route controllers and airspace users. The first of the series of HITL simulations took place October 24 – 30, 2001, at the Display System Facility (DSF) at the William J. Hughes Technical Center (WJHTC). This initial simulation focused primarily on identifying and understanding the impacts of different DRVSM altitude bands on en route controllers.

1.2 Scope of the Report

The purpose of this Final Report is to provide the results of the initial DRVSM simulation. Different types of data were collected throughout the simulation, including subjective controller ratings (e.g., for workload, complexity, potential for error, and ease of transition), as well as objective data captured via system analysis and recording (SAR) tapes and voice switching and control system (VSCS) training and backup system (VTABS) recordings. The previously published Quick Look Report provided results of the analysis of the subjective data collected during the simulation. This Final Report integrates the results of the analysis of the objective data.

The following section provides an overview of the simulation structure, environment, and conduct. The results of the simulation are provided in Sections 3 through 8.

2. SIMULATION OVERVIEW

2.1 Objectives

The primary objectives for the initial DRVSM simulation were to:

1. Identify the impact of DRVSM on the en route controller, including workload, complexity, and potential for error.
2. Compare the air traffic control (ATC) impacts associated with three alternate DRVSM altitude bands.
3. Identify impacts on DRVSM/non-DRVSM airspace.
4. Identify ATC procedural implications.
5. Gather information to plan and structure follow-on DRVSM simulations.

2.2

Altitude Bands

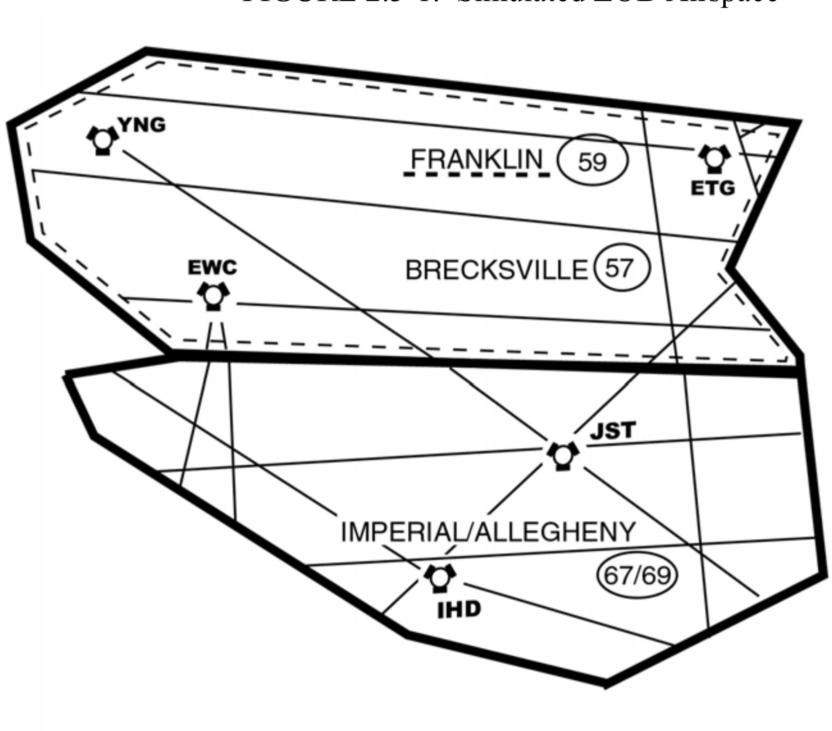
Four distinct vertical separation cases were studied:

1. Conventional vertical separation (CVS) minimum (baseline).
2. DRVSM for FL350 – FL390.
3. DRVSM for FL330 – Fl 390.
4. DRVSM for FL290 – FL410.

2.3 Airspace

This initial DRVSM study was designed as a real-time, high fidelity, HITL, en route simulation. The simulated airspace was based on four adjacent sectors in Cleveland Air Route Traffic Control Center (ZOB). ZOB Sectors 59 (Franklin), 57 (Brecksville), 68 (Allegheny), and 67 (Imperial) had the appropriate characteristics for this study. Sector 59 is a super-high altitude sector (FL330 and above). Sector 57 is directly below sector 59 (FL240-FL310). Sector 68 is a super-high altitude sector (FL350 and above). Sector 67 (FL240-FL330) is below half of sector 68. For this study, sector 67 and half of sector 68 were combined at sector 67 (FL240 and above). Figure 2.3-1 depicts the sectors and their stratifications.

FIGURE 2.3-1. Simulated ZOB Airspace



•Brecksville: FL240 – FL310 (FL320 during DRVSM FL290 – FL410 runs)
•Franklin: FL330 and above
•Imperial/Allegheny: FL240 and above

2.4 Scenarios

The traffic scenarios were realistic and provided a demand and level of complexity that engaged both the Radar (R) and Radar Associate (RA) controllers. Two baseline scenarios with CVS were developed from flight plans extracted from data analysis and reduction tool (DART) runs of ZOB SAR tapes. These are referred to as Baseline A and Baseline B. The data allowed for the realistic representation of sector boundaries, jet routes, and fixes for the chosen and adjacent sectors. ZOB personnel and ATC subject matter experts assisted in developing and validating the scenarios, and in ensuring that the traffic levels represented realistic peak conditions. For each of the three DRVSM altitude bands, the scenario development team used the two CVS baseline scenarios to generate two corresponding DRVSM scenarios, one using the traffic characteristics of Baseline A, the other using the traffic characteristics of Baseline B. A total of eight scenarios were developed, fully tested, and used for this initial DRVSM simulation. Since each baseline was used to create three additional scenarios, aircraft identities were changed to minimize the learning affect.

2.5 Scenario Conditions

Scripted events were added to all scenarios in a manner that allowed a direct comparison of the three DRVSM altitude bands with each other and with the CVS baseline. The scripted events included:

- Weather.
- Pilot requests.
- Transitioning aircraft (both DRVSM-approved and non-DRVSM-approved aircraft).
- Accommodation of non-DRVSM-approved military aircraft.

Each baseline and its three associated DRVSM scenarios maintained the same percentage of military and civilian non-DRVSM-approved aircraft, so as to permit the best possible comparison of workload implications for the three DRVSM altitude bands. Table 2.5-1 provides the number and percentage of non-DRVSM-approved aircraft within each baseline and its three associated DRVSM scenarios.

TABLE 2.5-1. Numbers of Non-DRVSM Approved Aircraft

	Baseline A		**Baseline B**	
	Number	**Percentage**	**Number**	**Percentage**
Non-DRVSM-approved military aircraft	4	1.3%	4	1.8%
Non-DRVSM-approved civilian aircraft	22	12.6%	26	16.6%
Total non-DRVSM-approved aircraft	26	13.9%	30	18.4%

2.6 Participants

Six certified professional controllers (CPC's) from ZOB who regularly work the sectors that were simulated staffed the R and RA positions. The participating controllers interacted with individuals functioning as pilots (simulation pilots) and ghost controllers. The simulation pilots manipulated computer-generated targets in response to controller instructions. Ghost controllers performed the automation entries and voice communications associated with the airspace surrounding the sectors that were simulated.

2.7

2.7 Measures

Table 2.7-1 depicts the subjective and objective data collected during the simulation.

TABLE 2.7-1. Measures

Objective	Measure	Data type

1. Identify impact of DRVSM on the controller and airspace	1.1 Workload	• Subjective controller ratings
		• Objective data
		  o Frequency and duration of A/G and G/G communications
		  o Number of pointouts, unaccepted handoffs, pilot requests denied
		• Assess how this changes as experience grows
		• Assess how this compares with other DRVSM strata

	1.2 Complexity	• Subjective controller ratings • Objective data o Number of non-DRVSM-approved aircraft transitioning through exclusionary airspace, conflict alert warnings, altitudes used, and aircraft per altitude • Assess how this changes as experience grows • Assess how this compares with other DRVSM strata
	1.3 Potential for errors	• Subjective controller ratings • Objective data o *Number of hear-back errors*, separation errors • Assess how this changes as experience grows • Assess how this compares with other DRVSM strata
	1.4 Ease of transition from CVS to DRVSM (e.g., altitude direction reassignments)	• Subjective controller ratings • Assess how this changes as experience grows • Assess how this compares with other DRVSM strata
	1.5 Training implications	• Written and verbal controller input

2. Identify controller procedural implications (local, national, if any)	2.1 Procedural implications	• List of national and local procedural implications, issues and questions, developed via
		  o Written and verbal controller input
		  o Debrief discussions

3. Gather information to plan and structure follow-on simulations	3.1 Operational issues requiring further simulation	• Initial list of operational issues requiring further simulation, including relative priority for each issue, developed via
		  o Controller and human factors (HF) input
		  o Debrief discussions

	3.2 Future simulation requirements	• Per issue, list of simulation parameters, characteristics and requirements needed to assess or resolve priority issues, developed via
		  o Controller and HF input
		  o Debrief discussions

4. Identify impacts on DRVSM airspace and below.	4.1 Comparison of aircraft distributions in relevant altitude strata	• Number of aircraft moved from “baseline” requested altitude due to DRVSM • Altitude distribution of aircraft
5. Compare impacts between implementation approaches	5.1 Analytic comparison of measures	• Comparison of measures associated with Objectives 1 – 4 for each implementation approach.
	5.2 Subjective Comparison	• Subjective controller rating and ranking of approaches, based on cumulative controller impact.

***The objective data highlighted in italics was not available from the data collection and analysis process. See Appendix A for details.*

2.8 Simulation Environment

The simulation was performed in the Display System Facility (DSF) at the WJHTC. The display system replacement (DSR), host computer system (HCS), and VTABS displays were, with very few minor differences, configured identically to ZOB's systems. Flight progress strips were used at each of the simulated sectors in a manner consistent with today's ZOB operations. The Target Generation Facility (TGF) provided high fidelity target generation and flight path movement.

Two modifications were made to the DSR/HCS environment for the DRVSM simulation runs.

1. A symbol in the data block was used during the DRVSM scenario runs to indicate that an aircraft was not DRVSM-approved. Since it is expected that significantly more aircraft will be approved than not, coding the non-approved aircraft reduces clutter on the controller's situation display. The indicator was a "+" located in the first line of the data block prior to the aircraft identifier. This was a temporary design, used for the purposes of the simulation only. DRVSM program personnel will work with the AT DSR Evolution Team (ATDET) to achieve a permanent and more readily discriminated indicator.
2. The conflict alert logic used by the HCS was updated to accurately reflect the revised vertical separation standards for each DRVSM altitude band, and to dynamically apply the correct vertical separation standard for the DRVSM-approval status of each aircraft pair.

2.9 Data Collection

The same data was recorded, collected and analyzed for each of the four altitude bands, including the CVS baseline. This approach allowed the impacts of each DRVSM altitude band to be assessed and compared to the CVS baseline (which is representative of today's operations). It also allowed the impacts of each DRVSM altitude band to be understood relative to the others.

The subjective data collected included questionnaire ratings on workload, complexity, potential for error, and ease of transition, completed after each run. Additionally, the workload assessment keypad (WAK) was used during the conduct of each scenario run. The WAK allows a workload rating to be entered electronically at regular intervals. The WAK was programmed to beep at 5-minute intervals, prompting the controller to enter their "instantaneous" ratings of combined cognitive and physical workload. They recorded their responses on a 7-point scale, where a rating of 1 was very low, 4 was moderate, and 7 was very high. After all eight runs were completed, the participants filled out a final questionnaire asking for their views of DRVSM.

The objective data collected includes SAR data, VTABS voice recordings, and TGF recordings.

3. RESULTS

The results of the initial DRVSM simulation are presented in several sections. Section 3 provides a *qualitative* overview of key results. Section 4 presents the *quantitative* results that allow a comparison of the operational impacts, in terms of workload, complexity, potential for error, and the ease of transition, for the four vertical separation altitude bands evaluated. Section 5 identifies the impacts on DRVSM/non-DRVSM airspace, while Section 6 discusses procedural implications for DRVSM. Areas requiring further investigation in subsequent DRVSM simulations are provided in Section 7. Lastly, Section 8 provides conclusions.

3.1 Correlation of Simulation Objectives to Results

Table 3-1 provides the correlation between these various sections and the five simulation objectives listed in Section 2.1.

TABLE 3-1. Correlation of Objectives to Results

Initial DRVSM Simulation Objectives	Results
1. Identify the impact of DRVSM on the en route controller, including workload, complexity, and potential for error.	Sections 3, 4, and 8
2. Compare the ATC impacts associated with three alternate DRVSM altitude bands.	Sections 3, 4, and 8
3. Identify impacts on DRVSM/non-DRVSM airspace.	Section 5
4. Identify ATC procedural implications.	Section 6
5. Gather information to plan and structure follow-on DRVSM simulations.	Section 7

3.2 Key Findings

In terms of identifying and comparing the ATC impacts associated with the three alternate DRVSM altitude bands, there are three key findings that result from a detailed analysis of all the subjective and objective data collected. These are:

1. The impact and benefit of DRVSM on the sector controller team varies based on the altitude stratification of the sector. Based on the results of this simulation, the impact of DRVSM is more beneficial for super-high altitude sectors than for high altitude sectors. Throughout the detailed results, the impacts of DRVSM on Sector 59 (Franklin, a super-high altitude sector) differ, sometimes substantially, from the impacts of DRVSM on Sector 57 (Brecksville, a high altitude sector).
2. Of the three DRVSM altitude bands, only FL290-FL410 clearly benefits all three of the sectors simulated. The "mixed" vertical separation standards represented by the FL350-FL390 and FL330-FL390 altitude bands tend to have greater negative impacts on some of the sectors. Section 8 provides a summary of the benefits and impacts for each of the three sectors.
3. All six controller participants strongly preferred the FL290 – FL410 altitude band. Of the three DRVSM altitude bands, it produced the largest decrease in workload, complexity, potential for error, and the greatest ease of transition for both high and super-high altitude sectors. Further, it eliminated the additional scanning and cognitive workload associated with applying multiple vertical separation standards within a sector, as well as the potential for applying the wrong separation standard. The fact that the FL290 – FL410 altitude band maintains today's alternating direction of flight for consecutive altitudes was also a simplifying factor for the controllers. In their written recommendations, five of six controllers suggested an "all or nothing" approach to adding additional altitudes, that is, to introduce the full envelope of DRVSM from FL290 to FL410, rather than taking an incremental, phased approach.

4. QUANTITATIVE ANALYSIS RESULTS

Section 4 presents the *quantitative* results that allow a comparison of the operational impacts, in terms of workload, complexity, potential for error, and the ease of transition for the four vertical separation altitude bands evaluated. The analysis presented below encompasses both the subjective and objective data collected during the simulation. Constraints for data collection are provided in Appendix A.

4.1 Workload

The controller workload results are based on the analysis of the following data collected during the initial DRVSM simulation:

- Subjective workload ratings.
- Numbers of Ground-to-Air (G/A) calls.
- Numbers of Ground-to-Ground (G/G) calls.
- Number of pointouts.
- Number of unaccepted handoffs.
- Number of denied pilot requests.
- Subjective Impact Assessment for Non-Approved Aircraft in DRVSM Airspace.

4.1.1 Subjective Workload Ratings

Participants were asked to rate workload subjectively in two distinct ways. During each run, controllers were prompted every five minutes to enter a rating of 1 to 7 to describe their "instantaneous" workload via the WAK. Secondly, the controllers completed a questionnaire following each run in which they rated their overall workload, also on a scale of 1 to 7. In both cases, a rating of 1 represented very low workload, 4 a moderate workload, and 7 a very high workload. Table 4.1.1-1 provides the workload ratings for the WAK, the questionnaires, and the average of the two, by sector. The data is averaged over the A and B runs for each altitude band. The raw WAK data, from which the averages presented in the table were derived, are included in Appendix B.

Table 4.1.1-1 shows that of the three DRVSM altitude bands, only FL290-FL410 resulted in a *lower* subjective workload rating for all three sectors. Each of the DRVSM altitude bands resulted in a net increase in Sector 57's volume of traffic (see Section 5 for details) when compared to the CVS baseline. However, only FL290-FL410 resulted in Sector 57 gaining any additional altitudes (FL300 and FL320), hence the increase in workload for the other two DRVSM altitude bands.

TABLE 4.1.1-1. Average Workload Subjective Ratings

Sector	Vertical Separation	WAK Ratings	Questionnaire Ratings	Average Rating	Percentage Change in Average Workload from CVS
57- Brecksville High Altitude FL240-FL310/320	CVS	3.9	3.8	3.81	--
	FL350-FL390	4.00	4.7	4.35	+14%
	FL330-FL390	3.7	4.5	4.09	+7%
	FL290-FL410	2.9	3.9	3.4	-11%
59- Franklin Super-High Altitude FL330 and above	CVS	3.5	5.0	4.27	--
	FL350-FL390	3.7	4.8	4.2	-2%
	FL330-FL390	3.4	4.8	4.09	-4.2%
	FL290-FL410	2.3	3.2	2.71	-37%
67/68 Imperial* FL240 and above	CVS	3.9	5.4	4.65	--
	FL350-FL390	3.7	4.8	4.23	-9%
	FL330-FL390	3.5	4.1	3.84	-17%
	FL290-FL410	2.8	3.4	3.09	-34%

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

4.1.2 Number of Ground-to-Air (G/A) Calls

The number of radio calls made by controllers to pilots is a direct measure of sector workload. Ground-to-air communications represent a significant portion of the workload performed by the R controller. Moreover, the RA controller monitors communications with pilots when he/she is not performing G/G coordination.

Table 4.1.2-1 provides a summary of the G/A communications workload, per sector. The numbers were derived by listening to VTABS audiotapes and manually flagging each G/A call. The data in the table is the number of calls from controllers to pilots, averaged over the A and B runs for each altitude band.

As seen in Table 4.1.2-1, the number of G/A calls summed across all three sectors was smallest for FL290-FL410. In fact, FL290-FL410 resulted in a 7.6 percent decrease in G/A communication workload when compared to the CVS baseline. The minimal 1 percent decrease realized for FL330-FL390 was a substantially smaller decrease than for either of the other DRVSM altitude bands. This was largely driven by Sector 57 results. In this DRVSM altitude band, the number of G/A calls from Sector 57 actually *increased* by 4.6 percent over the CVS baseline. FL330-FL390 resulted in pushing more aircraft into the upper altitudes of Sector 57's airspace than FL350-FL390. Also, Sector 57 gained no additional altitudes for the FL330-FL390 altitude band, and therefore had to rely more heavily on speed, heading, and altitude clearances to maintain separation at the affected altitudes.

A similar phenomenon can be seen in Sector 67. The G/A communications workload increased for FL330-FL390 when compared to FL350-FL390. Although Sector 67 gained the use of additional altitudes in both cases, more non-DRVSM-approved aircraft would have been pushed into the altitudes between FL240 and FL310 for the FL330-FL390 altitude band than in the FL350-FL390 altitude band, thereby requiring additional clearances on the part of Sector 67 to maintain separation.

Appendix C provides the raw data used in the above analysis, broken into the individual A and B runs for each vertical separation altitude band. Additionally, the number of A/G calls, the combined number of A/G and G/A calls, and the durations of A/G and G/A calls are provided in the appendix.

TABLE 4.1.2-1. Number of G/A Calls

Vertical Separation	57-Brecksville		59-Franklin		67-Imperial*		Total Across Sectors	Total Percentage Change from CVS
	High Altitude FL240-FL310/320		Super-High Altitude FL330 and above		High/Super-High Altitude FL240 and above			
	Avg. Number	% Change from CVS	Avg. Number	% Change from CVS	Avg. Number	% Change from CVS		
Baseline CVS	214	--	193	--	302.5	--	709.5	--
FL350-FL390	193	-9.8%	195.5	+1%	277	-8.2%	665.5	-6.2%
FL330-FL390	224	+4.6%	178	-7.8%	301	No change	703	-1%
FL290-FL410	213	No change	166	-14%	276.5	-8.6%	655.5	-7.6%

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

4.1.3 Number of Ground-to-Ground (G/G) Calls

The number of G/G calls made per sector is one element of sector workload. Table 4.1.3 -1 provides the number of G/G calls initiated or received by each sector per altitude band. The numbers were derived by listening to VTABS audiotapes and flagging each G/G call. The numbers represent the number of G/G calls placed or received by either the R or RA controller for each sector. Except as noted, the numbers were averaged across the runs of the A and B scenarios for each vertical separation altitude band. Appendix D provides the same data broken out by the individual A and B runs, per sector.

TABLE 4.1.3-1 Number of G/G Calls

Vertical Separation	57-Brecksville	59-Franklin	67-Imperial*
	High Altitude FL240-FL310/320	Super-High Altitude FL330 and above	High/Super-High Altitude FL240 and above
Baseline CVS	21.5	8	14.5
FL350-FL390	14.5	16	15
FL330-FL390	15.5	8	11
FL290-FL410	18.5	4.5	11.5

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

The data presented above show that workload associated with G/G communications for FL290-FL410 decreased from the CVS baseline for all three sectors. The analysis of the impact of the other two DRVSM altitude bands on G/G communications workload was affected by a VTABS malfunction that occurred during the FL330-FL390 and FL350-FL390 altitude bands. See Appendix D for additional information.

4.1.4 Number of Pointouts

A pointout is an action taken by a controller to transfer radar identification of an aircraft to another controller if the aircraft will or may enter the airspace or protected airspace of another controller and radio communications will not be transferred. The controller initiating the pointout must coordinate with the affected sector to gain approval. Consequently, the performance of pointouts represents one element of controller workload. Table 4.1.4 -1 provides the number of pointouts performed, averaged across the A and B runs for each vertical separation altitude band. The numbers were derived by listening to VTABS audiotapes and flagging each ground-to-ground call made to coordinate a pointout.

While the results varied on a sector-by-sector basis, the *total* number of pointouts performed by all three sectors increased for FL350-FL390 and FL330-FL390, but decreased for FL290-FL410, when compared to the CVS baseline. Due to a VTABS malfunction that occurred during one FL330-FL390 run and one FL350-FL390 run, the number of pointouts for these two altitude bands may be artificially low. See Appendix D for further information.

TABLE 4.1.4-1 Numbers of Pointouts

Vertical Separation	57-Brecksville	59-Franklin	67-Imperial*	Total
	High Altitude Only FL240-FL310/320	Super-High Altitude Only FL330 and above	High and Super-High Altitude FL240 and above	
Baseline CVS	8	1	3	12
FL350-FL390	3	4	12	19
FL330-FL390	6	3	4	13
FL290-FL410	2	4	3	9

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

4.1.5 Number of Unaccepted Handoffs

No instances of an unaccepted handoff occurred during any of the runs for any of the altitude bands.

4.1.6 Number of Denied Pilot Requests

Two cases of denied pilot requests occurred at Sector 67 during one of the F290-FL410 runs. Analysis of the voice tapes indicated that both of the requests were scripted pilot requests to deviate around weather, and the controller was unable to grant the clearances due to traffic. As soon as the aircraft were cleared of traffic, the requests were granted.

4.1.7 Subjective Impact Assessment for Non-Approved Aircraft in DRVSM Airspace

During debrief discussions controller participants indicated that the workload impact of non-DRVSM-approved aircraft flying in DRVSM airspace is significant. As depicted in Table 2.5-1, each run contained four non-approved DOD aircraft that were accommodated in DRVSM airspace. Table 4.2.3-1 provides the number of non-DRVSM-approved civilian aircraft that transitioned through DRVSM airspace during the simulation runs. While no objective measures of workload for individual flights were collected in this initial simulation, the controllers' subjective input was that a non-approved aircraft that is to be accommodated in DRVSM airspace has a greater impact on workload than a non-approved aircraft that is transitioning through DRVSM airspace. The impacts of non-approved aircraft to be accommodated (DOD and humanitarian flights), as well as non-approved aircraft transitioning through DRVSM airspace, will be studied in greater depth during the second DRVSM simulation.

4.1.8 Workload Summary

For the workload measures discussed above, the results are consistent across both subjective and objective data, and demonstrate that FL290-FL410 was the only DRVSM altitude band that was beneficial to sector workload across the sectors that were simulated. Several of the measures for complexity are also equally meaningful as measures of workload, since complexity relates directly to cognitive controller workload. The complexity results in Section 4.2 also validate the above statement.

4.2 Complexity

The complexity measure results are based on the analysis of the following data collected during the initial DRVSM simulation:

- Subjective complexity ratings.
- Number of conflict alert warnings.
- Number of non-approved aircraft transitioning through DRVSM airspace.
- Number of altitudes used and the numbers of aircraft per altitude.

4.2.1 Subjective Complexity Ratings

Participants were asked to complete a questionnaire following each run in which they subjectively rated the complexity of traffic patterns, flows, and volume in the run. Participants used a 7-point scale in which 1 represented not complex at all, 4 was moderate, and 7 was extremely complex. Table 4.2.1-1 provides the complexity ratings by sector, averaged across the runs of the A and B scenarios, per altitude band.

TABLE 4.2.1-1. Subjective Complexity Ratings

Vertical Separation	57-Brecksville		59-Franklin		67-Imperial*	
	High Altitude FL240-FL310/320		Super-High Altitude FL330 and above		High/Super-High Altitude FL240 and above	
	Average	% Change from CVS	Average	% Change from CVS	Average	% Change from CVS
Baseline CVS	4.75	--	5.75	--	5.75	--
FL350-FL390	5.25	+11%	5	-13%	5	-13%
FL330-FL390	5.5	16%	4.5	-22%	3	-48%
FL290-FL410	5	5%	3.75	-38%	3.75	-38%

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

All three DRVSM altitude bands were rated as increasing Brecksville's complexity when compared to CVS, although the rating spread for all four altitude bands was quite small (.75 out of a 7 point scale). Nevertheless, the Brecksville complexity rating for the FL290 – FL410 altitude band was lower than the other two DRVSM altitude bands simulated.

4.2.2 Conflict Alert Data

Table 4.2.2-1 provides the frequency with which conflict alerts occurred at each sector. The numbers represent the average of the number of conflict alerts that occurred during the A and B runs for each vertical separation altitude band. The numbers have been corrected for two environment-induced separation errors (and their corresponding conflict alerts) that occurred during the simulation runs. More detailed information on the environment-induced conflictions is provided in Appendix H.

A reduction in complexity, as measured by the reduction in conflict alerts, is easily seen in the super-high altitude strata, which is represented by Franklin. As is consistent with the subjective results, FL290-FL410 resulted in the largest reduction in conflict alerts when compared to CVS, dropping from 4.5 to 1, a 78 percent decrease.

Table 4.2.2-1. Frequency of Conflict Alerts

Vertical Separation	57-Brecksville	59-Franklin	67/68 Imperial*
	High Altitude FL240-FL310/320	Super-High Altitude FL330 and above	High/Super-High Altitude FL240 and above
Baseline CVS	1.5	4.5	4.5
FL350-FL390	2.5	2	1.5
FL330-FL390	3	2	5.5
FL290-FL410	1	1	4.5

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

Also consistent with the subjective results, Brecksville's complexity, as measured by conflict alerts, increased from the CVS baseline for both the FL350-FL390 and the FL330-FL390 cases. Since Brecksville's airspace is from FL240 to FL310, it gained no additional altitudes in either of these cases, but did gain non-DRVSM flights that were pushed out of Franklin's airspace. Only FL290-FL410 resulted in a lower number of conflict alerts at Brecksville.

For Imperial (combined with part of Allegheny), the conflict alert data is more difficult to interpret. No patterns emerged in the detailed analysis, even when the runs of the A and B scenarios, per altitude band, were analyzed separately. It is interesting to note, however, that Imperial is the only sector of the simulation that, regardless of the DRVSM altitude band, always received both positive impacts (i.e., always gained additional altitudes) and negative impacts (i.e., a higher density of traffic below the lower DRVSM threshold) due to non-approved aircraft being pushed down into non-DRVSM altitudes.

The conflict alert data for runs A and B per vertical separation altitude band is provided in Appendix E.

4.2.3 Number of Non-Approved Aircraft Transitioning Through DRVSM Airspace

Each non-DRVSM-approved aircraft transitioning through DRVSM airspace represents a substantive complexity and workload factor for the accommodating sector(s) since the controller team must provide that aircraft with 2000-foot vertical separation for the duration of the time the aircraft is in DRVSM airspace. Table 4.2.3-1 provides the number of non-DRVSM-approved aircraft that transitioned through the DRVSM airspace. Again, the data represents the average of the A and B runs, per altitude band. Appendix F provides the data broken out by the individual A and B runs, per altitude band.

Table 4.2.3-1. Number of Non-Approved Aircraft Transitioning Through DRVSM Airspace

Vertical Separation	57-Brecksville High Altitude FL240-FL310/320	59-Franklin Super-High Altitude FL330 and above	67/69 Imperial* High/Super-High Altitude FL240 and above	Total non-approved aircraft transitioning through DRVSM airspace
Baseline CVS	N/A	N/A	N/A	N/A
FL350-FL390	1	2	3.5	5.5
FL330-FL390	1.5	2.5	3	5.5
FL290-FL410	1.5	2.5	2.5	4.5

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

Traffic was duplicated across all four vertical separation altitude bands to allow meaningful comparison. The lower level of traffic for the FL290-FL410 altitude band, compared with the other two DRVSM altitude bands can be explained by one of two factors. The first possibility is that an affected aircraft flew at FL410 (during the FL330-FL390 and FL350-FL390 runs), but was not capable of flying at FL430 or higher (during the FL290-FL410 altitude band). The other possibility is that the controller team was unable to accommodate the aircraft in the FL290-FL410 altitude band, but was able to do so in the other two altitude bands.

The next DRVSM simulation will study in greater detail the workload and complexity attributable to transitioning non-approved aircraft through DRVSM airspace and accommodating Department of Defense (DOD) or humanitarian flights.

4.2.4 Altitudes Used and the Numbers of Aircraft per Altitude

The number of aircraft at a given altitude within a sector is a measure of sector complexity since aircraft that are at the same altitude must be separated vertically (via an altitude clearance), laterally, or longitudinally (via route, heading and/or speed clearances). Where heading and speed clearances are used for separation, the controller must monitor the effectiveness of the clearance and, once the aircraft is cleared of the potential confliction, a second clearance often must be given to resume the prior speed or heading. Although this measure was included to address sector complexity, it applies equally to sector workload.

Tables 4.2.4-1, -2 and -3 present summary data, per sector, for the numbers of aircraft at each altitude for each of the four vertical separation altitude bands. In post-run analysis, the number of aircraft at a given altitude, per sector, was captured and subtotaled once every 10 minutes for each of the eight 60-minute runs. This raw data is presented in Appendix G. The summary statistics presented in this section were derived from the raw data by summing across the six 10-minute subtotals for each run, and then averaging across the A and B runs for each vertical separation altitude band. Note that the data may exceed the total number of aircraft that passed through the sector in an hour, since any aircraft that remained in the sector more than 10 minutes may be counted more than once. Nevertheless, this measure provides a meaningful way to compare the *relative* complexity of one altitude band to another.

In the sector-specific tables below, the additional altitudes available to that sector in each DRVSM altitude band clearly allowed more aircraft to be separated via altitude separation, thereby reducing the frequency with which the controller would need to give clearances (and monitor their effectiveness) to avoid a loss of separation among aircraft at the same altitude. The beneficial impact of DRVSM on sector complexity is illustrated in Table 4.2.4-4, using Sector 59 results.

As seen from the table, the average number of aircraft per altitude is smaller as more altitudes are added. Much more important, however, is how the distribution of numbers across the altitudes becomes more even (and closer to the average) as the number of altitudes added increases.

Table 4.2.4-1. Sector 57 Numbers of Aircraft per Altitude

ALTITUDE	CVS BASELINE	FL350-FL390	FL330-FL390	FL290-FL410
240	3.5	4	3.5	2
250	3	3	5.5	4.5
260	3.5	3	3.5	2.5
270	9.5	8	11.5	15.5
280	15.5	17	15.5	18.5
290	22.5	23	24.5	14.5
300	.5	1	1	8
310	21.5	28.5	26	7.5
320	0	0	1	10
330	.5	0	.5	0
340	0	0	0	1

Table 4.2.4-2. Sector 59 Number Aircraft per Altitude

ALTITUDE	CVS BASELINE	FL350-FL390	FL330-FL390	FL290-FL410
280	0	.5	0	1
290	0	0	0	0
300	0	0	0	0
310	2	2.5	1	0
320	.5	1	.5	.5
330	18	14	10.5	9
340	.5	.5	10.5	14.5
350	26.5	5	5.5	9
360	0	34.5	29.5	23.5
370	19	10	12	8
380	0	16.5	12.5	12
390	16.5	6	6	7
400	0	0	0	8
410	6.5	7	7.5	4.5
430	2	1	1	2
450 & up	0	0	.5	0

Data within brackets is used in Table 4.2.4-4 to illustrate the positive impact of DRVSM on sector complexity.

Table 4.2.4-3. Sector 67/68 Numbers of Aircraft per Altitude

ALTITUDE	CVS BASELINE	FL350-FL390	FL330-FL390	FL290-FL410
240	2	2.5	3	2
250	4	4	5.5	4.5
260	2.5	2	1	1.5
270	4	4	5.5	17
280	1	2	3.5	3.5
290	14	12.5	20	5
300	.5	0	.5	2
310	12.5	16	16.5	9
320	0	0	0	8
330	30.5	28	16	13.5
340	0	.5	7.5	10
350	20.5	8.5	6.5	9.5
360	0	17.5	11	14
370	16.5	11	12.5	8.5
380	0	8	7.5	6
390	7.5	4	4	4
400	.5	0	0	3.5
410	1.5	2	1.5	1
430	3	3	3	3.5
450 & up	0	0	0	0

TABLE 4.2.4-4. Distribution of Aircraft Across Altitude for Sector 59

ALTITUDE	CVS BASELINE	FL350-FL390	FL330-FL390	FL290-FL410
330	18	14	10.5	9
340	.5	.5	10.5	14.5
350	26.5	5	5.5	9
360	0	34.5	29.5	23.5
370	19	10	12	8
380	0	16.5	12.5	12
390	16.5	6	6	7
400	0	0	0	8
Count Totals	80.5	86.5	86.5	91
No. of Altitudes	4	6	7	8
Average Count per Altitude	20.1	14.4	12.4	11.3

4.2.5 Complexity Summary

While each of the DRVSM altitude bands resulted in the reduction of some complexity measures for Sectors 59 and 67, the data show that each of the DRVSM altitude bands actually increased Sector 57's complexity (see Table 4.2.4-1). Nevertheless, of the three DRVSM altitude bands, FL290-FL410 had both the *largest positive* impact on Sectors 59 and 67's complexity and the *smallest negative* impact on Sector 57.

4.3 Potential for Error

The results for potential for error are based on the analysis of the following data collected during the initial DRVSM simulation:

- Potential for error subjective ratings.
- Separation violations.

4.3.1 Potential for Error Subjective Ratings

After each run, the participants subjectively rated the potential for error during the run. Again, the 7-point scale ranged from 1, very low, to 7, extremely high, with 4 representing a moderate potential for error. Table 4.3.1-1 provides the potential for error ratings by sector, averaged across the A and B runs per vertical separation altitude band.

The FL290-FL410 altitude band produced the greatest reduction in the ratings for potential for error consistently across each of the three sectors. As can be seen from the table, the perception of the controller participants is that the FL290-FL410 altitude band will significantly reduce the potential for error.

TABLE 4.3.1-1. Ratings of Potential for Error

Vertical Separation	57-Brecksville	59-Franklin	67/69 Imperial*
	High Altitude FL240-FL310/320	Super-High Altitude FL330 and above	High/Super-High Altitude FL240 and above
Baseline CVS	4.25	5	6
FL350-FL390	4.5	4	4.5
FL330-FL390	4	2.75	3.25
FL290-FL410	2.75	2	2.75

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

4.3.2 Separation Violations

Two separation violations[1] occurred during the eight runs conducted for the initial DRVSM simulation. One was due to a pilot deviation that occurred during the CVS Baseline A run. The other was caused by the overly subtle indication used to distinguish non-DRVSM-approved flights from DRVSM-approved flights on the situation display (a "+" sign preceding the call sign in the full data block). The latter error occurred during the first DRVSM simulation run. The controller team had 1200 feet vertical separation between a pair of aircraft. They believed this was adequate because they were unaware that only one of the aircraft was DRVSM-approved. (Note: this error was directly observed by a study observer who was asked by the controller team, in real-time, why they were getting a conflict alert between two aircraft that were adequately separated.) Neither of these errors is considered to be meaningful for understanding the operational impacts of the DRVSM altitude bands simulated. (Note: the "+" sign was selected to indicate the non-DRVSM-approved status of a flight only for the purposes of the initial simulation, since it was considered the best choice available using HCS display capabilities. The actual non-DRVSM indicator is being designed by the ATDET, using the enhanced graphics capability available in DSR to ensure the non-DRVSM indicator is readily visible to the controller team.) Appendix H provides the details on the separation violations that occurred during the initial DRVSM simulation.

4.3.3 Summary of Potential for Error

There was general agreement on two points. First, FL290-FL410 reduced the potential for error significantly over the CVS baseline, as well as over the other two DRVSM altitude bands. Second, an effective design to easily distinguish non-DRVSM-approved aircraft from approved aircraft is critical to the successful deployment of DRVSM.

4.4 Ease of Transition

The ease of transition results are based on the analysis of the subjective ratings of the participants. Participants were asked to complete a questionnaire following each run in which they subjectively rated two aspects of transition to DRVSM. The first was the ease of transition and the second was the ease of using the correct altitude for direction of flight. The 7-point scale used was defined by 1 - very easy, 4 - moderate, and 7 - extremely difficult. Table 4.4-1 provides the average ease of transition ratings by sector, while Table 4.4-2 provides the average ratings for ease of using the correct altitude for direction of flight.

[1] This number has been corrected to eliminate two separation violations determined to be directly caused by the simulation environment. Appendix H provides a description of all separation violations and their cause.

TABLE 4.4-1. Ease of Transition Ratings

Vertical Separation	57-Brecksville	59-Franklin	67/69 Imperial*
	High Altitude FL240-FL310/320	Super-High Altitude FL330 and above	High/Super-High Altitude FL240 and above
Baseline CVS	N/A	N/A	N/A
FL350-FL390	N/A	3.5	3
FL330-FL390	N/A	3.25	3.5
FL290-FL410	2.25	1.5	1.5

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

TABLE 4.4-2. Ease of Using the Correct Altitude for Direction of Flight.

Vertical Separation	57-Brecksville	59-Franklin	67/69 Imperial*
	High Altitude FL240-FL310/320	Super-High Altitude FL330 and above	High/Super-High Altitude FL240 and above
Baseline CVS	N/A	N/A	N/A
FL350-FL390	N/A	3.5	3
FL330-FL390	N/A	2.25	3.5
FL290-FL410	2.5	1.5	1.25

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

5. IMPACTS ON DRVSM/NON-DRVSM AIRSPACE

The primary purpose of looking at impacts to airspace was to understand how many non-DRVSM-approved aircraft were pushed to a lower altitude stratum for each of the three DRVSM altitude bands. Table 5-1 provides this information for Baseline A, Baseline B, and the average of the two. The data *exclude* non-approved aircraft that can fly high enough to get above the upper DRVSM limit since these aircraft will transition through DRVSM airspace, traffic permitting. These numbers also exclude non-approved military aircraft, which are to be accommodated in DRVSM airspace.

TABLE 5-1. Number of non-DRVSM-Approved Aircraft Pushed to Lower Altitude in DRVSM Runs

Vertical Separation	Number of non-DRVSM-Approved Aircraft Pushed to Lower Altitude in Corresponding DRVSM Runs		
	Baseline A	Baseline B	Averaged over A and B runs
Baseline CVS	N/A	N/A	N/A
FL350-FL390	12	5	8.5
FL330-FL390	17	15	16
FL290-FL410	30	19	24.5

6.

PROCEDURAL IMPLICATIONS

The team identified two procedural issues that will need to be addressed prior to implementing DRVSM. They are: (1) management of non-DRVSM-approved aircraft in exclusionary DRVSM airspace; and (2) coordination between sectors. Further identification of procedural issues will be a primary focus of the second DRVSM simulation planned for June 2002.

7. INFORMATION FOR FOLLOW-ON DRVSM SIMULATIONS

One of the objectives of the initial DRVSM simulation was to obtain insight into areas that need to be assessed in future simulations. Discussions with the controller participants resulted in the following recommendations:

1. Continue to assess heavy traffic situations for sectors of various stratifications.
2. Include situations in which there is a higher percentage of non-DRVSM aircraft.
3. Further investigate the impacts of non-DRVSM-approved aircraft in exclusionary DRVSM airspace. Specifically, include scenarios in which there are conflicts with non-DRVSM-approved military aircraft flying in DRVSM airspace.
4. Suspend DRVSM for a single aircraft (e.g., to simulate an equipment outage).
5. Continue to identify procedural implications.
6. Evaluate tactical use of additional altitudes prior to DRVSM implementation.
7. Evaluate alternate designs for the non-DRVSM-approved indicator.
8. Assess transition to non-DRVSM airspace.

Current plans for the second DRVSM simulation include assessing each of the first six items in the above list. The last two items will likely be assessed during the third DRVSM simulation tentatively planned for October 2002.

8. CONCLUSIONS

The six controller participants were very enthusiastic about DRVSM. The controllers stressed that DRVSM is a win-win situation for controllers and airspace users. The participants cited significant potential for benefits to the controller workforce. Participants also indicated that DRVSM has the potential to increase sector throughput, reduce fuel costs, and increase their ability to grant pilot requests. In general, the controllers found it easy to transition to the use of DRVSM standards.

Of the three DRVSM altitude bands, FL290-FL410 produced the largest benefits in terms of workload reduction, complexity, potential for error, and the greatest ease of transition for both high and super-high altitude sectors. The primary sources of decreased workload in DRVSM airspace are reduced vectoring for separation and associated communications, reduced frequency of wrong altitude for direction of flight and associated coordination, and significantly reduced numbers of confliction points. Further, it eliminated the additional scanning and cognitive workload associated with applying multiple vertical separation standards within a sector, as well as the potential for applying an inappropriate separation standard. The fact that the FL290 – FL410 altitude band maintains today's alternating direction of flight for consecutive altitudes was also a simplifying factor for the controllers.

For the FL350 – FL390 and FL330 – FL390 cases, controllers found the multiple vertical separation standards inherent in these schemes more difficult to work than FL290-FL410. For example, controllers at the super-high altitude sectors experienced additional cognitive workload in these two altitude bands, caused by the need to verify that a given altitude was or was not a DRVSM altitude before issuing an altitude clearance. During very busy times, this additional cognitive workload caused some controllers to fall back to conventional separation standards, thereby affecting the potential benefit to the airspace users.

All six controllers strongly preferred FL290-FL410 to the other DRVSM alternatives and today's conventional vertical separation standards. In their written recommendations, five of six controllers suggested an "all or nothing" approach to adding additional altitudes, that is, to introduce the full envelope of DRVSM from FL290 to FL410, rather than taking an incremental, phased approach.

APPENDIX A - DATA REDUCTION AND ANALYSIS CONSTRAINTS

As noted in Section 4, some of the objective data planned to be collected were not available. This was due to unavoidable constraints in the lab environment and in the off-line, post-simulation data reduction capability.

- One constraint occurred in the analysis of voice communications. Conflicts with the VSCS program's critical test schedule precluded the use of VSCS during the simulations. Hence, VTABS had to be used instead. While this had no impact on the actual running of the simulations (VTABS and VSCS look and act exactly alike to controllers), VTABS does not provide the sophisticated off-line data reduction and analysis capabilities that are available in VSCS. Consequently all voice communications data had to be manually processed to determine numbers and durations of voice communications. While the audio quality of the voice recordings provided an accurate means for collecting the number of verbal communications (communications between controllers and pilots, as well as communications between controllers), the audio quality did not always allow a reliable rendering of the actual *content* of each voice communication.

It is important to note that it is not at all unusual for simulations using extensive data recording and data reduction capabilities to be unable to capture all of the desired data. In this case, the most critical and meaningful measures of workload, complexity, potential for error, and ease of transition were, in fact, fully available and reliable: the data reduction constraints in no way hampered meeting any of the objectives of this simulation.

APPENDIX B - WAK DATA

TABLE B-1. R-Controller WAK Ratings, Averaged Across A and B Runs

Time	Baseline CVS	FL350-FL390	FL330-FL390	FL290-FL410
57-Brecksville Sector/R-side				
5 min	2.5	2.5	2.5	1.5
10 min	3	3.5	3.5	2
15 min	4.5	4	5	3
20 min	4.5	4	4.5	3.5
25 min	5	4.5	5	3
30 min	4.5	4.5	5.5	3.5
35 min	5	4.5	5.5	3
40 min	4.5	4.5	5	3.5
45 min	5.5	5.5	6	3
50 min	5.5	5.5	6	3.5
55 min	4.5	5	5	3.5
59-Franklin Sector/R-side				
5 min	2	2.5	2	1.5
10 min	3	3	2	2
15 min	2.5	3.5	2.5	1.5
20 min	3.5	3	4.5	2
25 min	4	3.5	4.5	3
30 min	5	4.5	5.5	3.5
35 min	5	5	5.5	3.5
40 min	6	5	6	3.5
45 min	5.5	4	5	3.5
50 min	5	4.5	4.5	3
55 min	5	4	5	3
67/69 Imperial with Allegheny Sector/R-side				
5 min	2.5	2.5	2.5	1.5
10 min	3	2.5	2.5	2
15 min	3.5	4	3.5	2
20 min	4	4	4	2.5
25 min	4	4	4	2.5
30 min	4.5	3.5	3.5	2.5
35 min	4.5	4.5	4	3.5
40 min	4.5	5	3.5	4
45 min	5	5	4.5	3.5
50 min	5	4	3	3.5
55 min	4	3	3	2.5

TABLE B-2. RA Controller WAK Ratings, Averaged Across A and B Runs

Time	Baseline CVS	FL350-FL390	FL330-FL390	FL290-FL410
57-Brecksville Sector/RA controller				
5 min	2	2	2	1.5
10 min	3	3	2.5	2.5
15 min	4	3	2	2.5
20 min	4	4	2.5	3.5
25 min	3.5	3.5	3	3.5
30 min	2.5	3	2	3
35 min	3	3.5	2.5	2.5
40 min	3.5	4	3	3.5
45 min	3.5	4.5	3	2
50 min	3.5	5	2.5	3
55 min	3.5	5	2.5	2.5
59-Franklin Sector/RA controller				
5 min	1	2.5	1.5	1.5
10 min	2	2.5	1.5	1.5
15 min	1.5	3	2	1
20 min	2	3	3	1.5
25 min	3	3.5	2.5	2
30 min	2.5	3	3	2
35 min	3.5	4.5	2.5	1.5
40 min	4.5	4	3	2.5
45 min	3.5	3.5	2.5	2
50 min	3.5	4	2.5	2
55 min	3	2	3	1.5
67/69 Imperial with Allegheny Sector/RA controller				
5 min	2	2.5	1.5	2.5
10 min	2.5	2.5	2.5	2.5
15 min	3	3	3.5	2.5
20 min	4	4	4	2.5
25 min	3	3	4	2.5
30 min	4	3.5	4.5	2.5
35 min	4.5	4.5	3.5	3
40 min	5	4	4	3.5
45 min	5	4.5	4	4
50 min	4.5	3.5	4	3.5
55 min	4.5	4	4.5	2.5

APPENDIX C - G/A AND A/G VOICE COMMUNICATIONS

TABLE C-1. Ground-To-Air Communications

Vertical Separation	Run	57-Brecksville High Altitude FL240-FL310/320		59-Franklin Super-High Altitude FL330 and above		67-Imperial (1) High/Super-High Altitude FL240 and above	
		Number	Total Duration (2)	Number	Total Duration(1)	Number	Total Duration(1)
CVS Baseline	A	220	704	189	563	307	710
	B	208	522	197	522	298	883
FL350-FL390	A	152	468	168	461	249	573
	B	234	730	223	595	305	1054
FL330-FL390	A	223	704	187	644	294	784
	B	225	587	169	469	308	1039
FL290-FL410	A	221	628	160	464	267	632
	B	205	572	172	487	286	947

Notes:
1. Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.
2. Durations are shown in total number of seconds. Average durations are shown in Table C-4.

TABLE C-2. Air-To-Ground Communications

Vertical Separation	Run	57-Brecksville High Altitude FL240-FL310/320		59-Franklin Super-High Altitude FL330 and above		67-Imperial (1) High/Super-High Altitude FL240 and above	
		Number	Duration (2)	Number	Duration(1)	Number	Duration(1)
CVS Baseline	A	220	634	206	633	297	799
	B	228	713	192	514	297	799
FL350-FL390	A	162	445	177	430	255	579
	B	243	777	217	617	315	869
FL330-FL390	A	212	601	186	549	292	801
	B	245	729	186	618	318	918
FL290-FL410	A	236	551	165	391	275	618
	B	228	787	180	513	305	906

Notes:
1. Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.
2. Durations are shown in total number of seconds. Average durations are shown in Table C-4.

TABLE C-3. Combined A/G and G/A Communications

Vertical Separation	Run	57-Brecksville High Altitude FL240-FL310/320		59-Franklin Super-High Altitude FL330 and above		67-Imperial [(1)] High/Super-High Altitude FL240 and above	
		Number	Duration [(2)]	Number	Duration[(1)]	Number	Duration[(1)]
CVS Baseline	A	440	1338	395	1196	604	1509
	B	436	1235	389	1036	595	1682
FL350-FL390	A	314	913	345	891	504	1152
	B	477	1507	440	1212	520	1923
FL330-FL390	A	435	1305	373	1193	586	1585
	B	470	1316	355	1087	626	1957
FL290-FL410	A	457	1179	325	855	542	1250
	B	433	1359	352	1000	591	1853

Notes:
1. Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.
2. Durations are shown in total number of seconds. Average durations are shown in Table C-4.

TABLE C-4. Average A/G and G/A Durations (in seconds)

Vertical Separation	Run	57-Brecksville High Altitude FL240-FL310/320		59-Franklin Super-High Altitude FL330 and above		67-Imperial [(1)] High/Super-High Altitude FL240 and above	
		A/G	G/A	A/G	G/A	A/G	G/A
CVS Baseline	A	2.9	3.2	3.1	3.0	2.7	2.3
	B	3.1	2.5	2.7	2.6	2.7	2.8
FL350-FL390	A	2.7	3.1	2.4	2.7	2.3	2.3
	B	3.2	3.1	2.8	2.7	2.8	3.5
FL330-FL390	A	2.8	3.2	3.0	3.4	2.7	2.7
	B	3.0	2.6	3.3	2.8	2.9	3.4
FL290-FL410	A	2.3	2.8	2.4	2.9	2.2	2.4
	B	3.5	2.8	2.9	2.8	3.0	3.3

Note:
1. Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

APPENDIX D - G/G VOICE COMMUNICATIONS

The numbers of G/G calls placed or received by each sector during each of the eight runs are provided below. As noted in the table, the data for two of the eight runs are incomplete due to the two VTABS malfunctions that occurred at Sector 59. The first malfunction occurred during the A run for FL350-FL390, and the second during the B run for FL330-FL390. The Sector 59 R-position received an erroneous and unexplained push-to-talk (PTT) lockout condition that prohibited the R-side from transmitting on the A/G frequencies to the simulation pilots. In order to continue the simulation runs, the R-side unplugged from the VTABS at the R-position, and plugged into the VTABS at Sector 59's RA position. This is exactly the same action that occurs in live operations whenever there is an R-side malfunction that prohibits communications with pilots. This action eliminated, for the duration of the malfunction, the ability of Sector 59's RA controller to place G/G calls. Therefore, the number of G/G calls for Sector 59 for the two affected runs (footnoted in the table below) represents the number of G/G calls before and/or after the VTABS outage. Because Sector 59's ability to use G/G communications was impaired for a portion of these two runs, the numbers of G/G calls for Sectors 57 and 67 are artificially low, since they do not include G/G coordination that would have otherwise occurred between Sectors 59 and 57 and between Sectors 59 and 67.

Vertical Separation	Run	57-Brecksville High Altitude FL240-FL310/320	59-Franklin Super-High Altitude FL330 and above	67-Imperial(1) High/Super-High Altitude FL240 and above
CVS Baseline	A	17	9	17
	B	26	7	12
FL350-FL390	A	18(4)	2(2)	15(4)
	B	11	16	15
FL330-FL390	A	12	8	9
	B	19(4)	3(3)	13(4)
FL290-FL410	A	23	5	18
	B	14	4	5

Notes:

1. Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.
2. A VTABS malfunction at R59 resulted in a loss of ability to place G/G calls from Sector 59 during the A run for FL350-FL390. Thus, this entry represents the total number of G/G calls for Sector 59 during the B run only.
3. A VTABS malfunction at R59 resulted in a loss of ability to place G/G calls from Sector 59 during the B run for FL330-FL390. Thus, this entry represents the total number of G/G calls for Sector 59 during the A run only.
4. It is likely that these numbers are lower than they would have been had the VTABS malfunction not occurred at R59.

APPENDIX E - NUMBERS OF CONFLICT ALERTS PER SECTOR

Sector	Vertical Separation	Number of CA's with both aircraft in the sector	Number of CA's with only one of the aircraft in the sector	Total Number of CA's
57- Brecksville High Altitude FL240-FL310/320	CVS	2	1	3
	FL350-FL390	3	2	5
	FL330-FL390	2	4	6
	FL290-FL410	1	1	2
59- Franklin Super-High Altitude FL330 and above	CVS	7	2	9
	FL350-FL390	2	2	4
	FL330-FL390	1	3	4
	FL290-FL410	2	0	2
67/69 Imperial* FL240 and above	CVS	8	1	9
	FL350-FL390	3	0	3
	FL330-FL390	10	1	11
	FL290-FL410	8	1	9

*Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.

APPENDIX F - NUMBER OF NON-DRVSM-APPROVED AIRCRAFT TRANSITIONING THROUGH DRVSM AIRSPACE

Vertical Separation	RUN	57-Brecksville	59-Franklin	67/69 Imperial(1)	Total non-approved aircraft transitioning through DRVSM airspace (2)
		High Altitude FL240-FL310/320	Super-High Altitude FL330 and above	High/Super-High Altitude FL240 and above	
Baseline CVS	A	N/A	N/A	N/A	N/A
	B	N/A	N/A	N/A	N/A
FL350-FL390	A	1 (3)	2	4	6
	B	1 (3)	2	3	5
FL330-FL390	A	1 (3)	2	3	5
	B	2 (3)	3	3	6
FL290-FL410	A	1	2	3	4
	B	2	3	2	5

Notes:

1. Part of Sector 68, Allegheny, was combined at Sector 67, Imperial.
2. In the FL330-FL390 and FL350-FL390 altitude bands, Brecksville does not own any DRVSM altitudes. The numbers presented for Brecksville in these cases represent the number of non-approved aircraft requesting altitudes above DRVSM airspace.
3. This is the total number of non-DRVSM-approved flights that transitioned above or down from the top of the DRVSM airspace, i.e., above FL410 in the case of the two FL290-FL410 runs and above FL390 in the other four DRVSM runs. This number is not equal to the sum of the numbers per sector since some aircraft traversed more than one of the simulated sectors.

APPENDIX G – NUMBER OF AIRCRAFT PER ALTITUDE

Sector 57		Baseline						FL290-FL410					
Altitude	Run	00-10	10-20	20-30	30-40	40-50	50-60	00-10	10-20	20-30	30-40	40-50	50-60
240	A	0	2	0	1	0	0	0	0	0	1	0	1
	B	0	2	0	0	1	1	0	1	1	0	0	0
250	A	0	0	1	0	0	0	0	2	0	1	1	2
	B	1	0	1	0	1	2	0	0	0	0	1	2
260	A	1	0	0	1	1	2	0	0	0	2	0	1
	B	0	0	1	0	0	1	0	0	1	0	0	1
270	A	1	2	1	2	1	2	2	3	1	3	6	3
	B	0	1	2	2	3	2	3	2	2	3	2	1
280	A	1	0	0	1	2	5	2	0	2	4	5	5
	B	0	2	3	7	9	1	0	3	4	8	4	0
290	A	2	5	3	5	5	3	2	6	3	2	1	2
	B	3	4	3	5	3	4	2	1	2	4	1	3
300	A	0	0	1	0	0	0	1	0	1	0	2	2
	B	0	0	0	0	0	0	1	1	2	1	3	2
310	A	2	2	1	2	5	5	1	1	0	2	2	3
	B	2	7	6	3	5	3	0	1	2	2	0	1
320	A	0	0	0	0	0	0	1	1	1	1	1	2
	B	0	0	0	0	0	0	1	4	2	2	3	1
330	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	1	0	0	0	0	0	0	0	0	0	0
340	A	0	0	0	0	0	0	0	0	0	1	1	0
	B	0	0	0	0	0	0	0	0	0	0	0	0

Sector 57		FL330-FL390						FL350-FL390					
Altitude	Run	00-10	10-20	20-30	30-40	40-50	50-60	00-10	10-20	20-30	30-40	40-50	50-60
240	A	0	2	0	1	0	0	0	1	1	2	0	0
	B	0	2	1	0	1	0	0	1	1	0	1	1
250	A	0	2	2	0	0	1	0	0	2	0	0	1
	B	0	2	0	0	2	2	0	0	0	0	1	2
260	A	0	1	0	1	0	1	0	0	0	1	1	2
	B	0	0	1	0	1	2	0	0	1	0	0	1
270	A	1	2	1	2	2	2	1	1	0	2	3	1
	B	0	1	4	3	3	2	0	1	2	3	1	1
280	A	0	0	0	2	5	2	0	1	0	2	3	4
	B	0	2	3	6	9	2	0	1	2	6	10	5
290	A	3	4	4	4	5	3	3	6	3	5	4	5
	B	5	3	3	6	4	5	2	4	3	5	3	3
300	A	1	0	1	0	0	0	0	0	1	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	1
310	A	2	1	1	3	6	5	2	2	1	4	6	6
	B	3	7	9	5	6	4	2	9	8	5	7	5
320	A	0	0	1	0	0	0	0	0	0	0	0	0
	B	0	1	0	0	0	0	0	0	0	0	0	0
330	A	0	0	0	0	0	1	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0
340	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0

Sector 59		Baseline						FL290-FL410					
Altitude	Run	00-10	10-20	20-30	30-40	40-50	50-60	00-10	10-20	20-30	30-40	40-50	50-60
280	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	1	1
290	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0
300	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0
310	A	0	0	0	2	0	0	0	0	0	0	0	0
	B	0	0	0	1	0	1	0	0	0	0	0	0
320	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	1	0	0	0	0	0	1	0	0
330	A	3	1	1	5	2	1	0	0	1	2	2	1
	B	6	4	4	1	3	5	3	2	2	1	1	3
340	A	0	0	0	0	0	0	2	1	0	2	4	4
	B	0	0	1	0	0	0	1	2	5	3	2	2
350	A	6	5	8	10	10	10	1	1	2	1	2	2
	B	4	7	11	9	8	5	1	3	2	0	2	1
360	A	0	0	0	0	0	0	3	2	7	5	5	2
	B	0	0	0	0	0	0	2	4	4	7	4	2
370	A	2	3	4	6	5	4	1	1	1	1	0	0
	B	2	1	1	3	4	3	2	1	1	1	4	3
380	A	0	0	0	0	0	0	0	3	3	1	1	3
	B	0	0	0	0	0	0	1	1	2	3	2	4
390	A	1	0	5	4	3	5	0	1	2	1	2	3
	B	1	2	2	4	3	3	1	1	0	2	1	0
400	A	0	0	0	0	0	0	1	0	4	3	3	2
	B	0	0	0	0	0	0	0	0	1	1	0	1
410	A	0	1	1	1	1	1	0	1	1	1	0	0
	B	2	2	3	1	0	0	1	3	2	0	0	0
430	A	0	1	2	0	0	0	0	2	1	0	0	0
	B	0	1	0	0	0	0	0	1	0	0	0	0
450 and above	A	0	0	0	0	0	0	0	0	0	0	0	0
	B		0	0	0	0	0	0	0	0	0	0	0

Sector 59		FL330-FL390						FL350-FL390					
Altitude	Run	00-10	10-20	20-30	30-40	40-50	50-60	00-10	10-20	20-30	30-40	40-50	50-60
280	A	0	0	0	0	0	0	0	0	0	1	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0
290	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0
300	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0
310	A	1	0	1	0	0	0	0	0	1	1	0	0
	B	0	0	1	1	0	0	0	0	1	1	1	0
320	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	1	0	0	0	0	0	1	0	1
330	A	0	0	0	3	1	2	1	2	1	4	2	1
	B	3	4	3	1	1	3	4	3	4	2	2	2
340	A	2	0	1	0	2	4	0	0	1	0	0	0
	B	1	2	3	3	1	2	0	0	0	0	0	0
350	A	1	0	0	2	1	0	0	0	0	0	1	0
	B	1	2	1	1	0	2	1	2	2	2	1	1
360	A	3	6	8	6	6	5	5	5	7	7	8	6
	B	2	4	5	5	5	4	3	5	7	6	6	4
370	A	1	2	2	2	3	3	1	2	1	1	2	2
	B	2	1	1	2	4	1	2	1	2	2	4	0
380	A	1	0	5	3	2	2	1	0	5	3	2	3
	B	1	1	2	3	2	3	2	3	2	4	3	5
390	A	0	1	2	2	1	3	0	1	2	3	1	2
	B	0	0	0	0	1	2	0	0	0	0	1	2
400	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0
410	A	0	2	1	1	1	2	0	2	1	1	1	1
	B	1	3	3	1	0	0	2	2	3	1	0	0
430	A	0	1	0	0	0	0	0	1	0	0	0	0
	B	0	1	0	0	0	0	0	1	0	0	0	0
450 and above	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	1	0	0	0	0	0	0	0	0	0

Sector 67		Baseline						FL290-FL410					
Altitude	Run	00-10	10-20	20-30	30-40	40-50	50-60	00-10	10-20	20-30	30-40	40-50	50-60
240	A	1	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	1	1	1	0	0	0	0	2	2	0
250	A	0	0	0	0	0	1	0	2	1	1	2	1
	B	0	0	2	2	3	0	0	0	0	0	2	0
260	A	1	0	0	0	0	0	1	0	0	0	0	0
	B	0	0	1	2	1	0	0	0	1	1	0	0
270	A	0	2	0	1	0	0	3	2	3	5	3	1
	B	1	2	0	1	0	1	1	2	2	2	5	5
280	A	1	0	0	0	0	1	2	1	1	0	1	2
	B	0	0	0	0	0	0	0	0	0	0	0	0
290	A	2	2	2	3	1	2	1	0	0	0	0	1
	B	4	5	2	2	1	2	2	2	1	1	1	1
300	A	0	0	0	1	0	0	1	0	0	1	1	1
	B	0	0	0	0	0	0	0	0	0	0	0	0
310	A	1	1	1	0	1	3	0	1	1	0	1	2
	B	5	5	3	2	2	1	2	4	4	2	1	0
320	A	0	0	0	0	0	0	1	0	1	0	1	3
	B	0	0	0	0	0	0	3	3	1	1	1	1
330	A	1	6	4	4	5	4	0	1	2	4	1	1
	B	2	8	7	5	9	6	1	3	4	3	3	4
340	A	0	0	0	0	0	0	1	2	2	2	2	0
	B	0	0	0	0	0	0	2	2	1	3	2	1
350	A	1	3	5	5	3	6	1	2	0	1	2	1
	B	4	4	3	4	3	0	3	3	2	3	1	0
360	A	0	0	0	0	0	0	1	2	3	2	2	3
	B	0	0	0	0	0	0	3	3	3	2	3	1
370	A	5	2	5	2	4	3	3	1	3	2	1	1
	B	3	1	0	2	4	2	1	0	0	0	3	2
380	A	0	0	0	0	0	0	0	2	0	2	2	1
	B	0	0	0	0	0	0	1	1	0	1	2	0
390	A	0	4	0	0	0	2	1	2	1	0	2	2
	B	1	1	3	3	1	0	0	0	0	0	0	0
400	A	0	0	0	0	0	1	0	1	0	0	0	0
	B	0	0	0	0	0	0	1	1	1	3	0	0
410	A	0	0	0	1	1	0	0	0	0	1	1	0
	B	0	0	1	0	0	0	0	0	0	0	0	0
430	A	0	0	0	1	1	1	0	0	1	1	1	1
	B	1	1	1	0	0	0	1	1	1	0	0	0
450 and above	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0

Sector 67		FL330-FL390						FL350-FL390					
Altitude	Run	00-10	10-20	20-30	30-40	40-50	50-60	00-10	10-20	20-30	30-40	40-50	50-60
240	A	1	0	0	0	1	0	0	1	0	0	0	0
	B	0	0	0	1	2	1	0	0	0	2	2	0
250	A	0	0	0	0	2	2	0	0	0	0	0	1
	B	0	0	2	2	3	0	0	0	2	2	3	0
260	A	0	0	0	0	0	0	1	0	0	0	0	0
	B	0	0	1	1	0	0	0	0	1	1	1	0
270	A	0	2	0	2	1	0	0	2	0	1	1	0
	B	0	2	1	2	0	1	1	1	0	1	0	1
280	A	1	1	0	1	0	1	1	1	0	0	0	1
	B	0	0	2	0	1	0	1	0	0	0	0	0
290	A	2	0	3	4	2	3	1	2	1	2	1	2
	B	5	7	4	2	5	3	5	5	2	1	1	2
300	A	0	0	0	0	1	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0
310	A	4	1	2	1	1	4	3	2	2	1	1	3
	B	5	5	2	4	3	1	5	6	2	2	4	1
320	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0
330	A	0	2	3	2	2	2	1	3	5	4	5	3
	B	1	4	5	2	4	5	1	7	6	5	8	8
340	A	1	2	1	2	1	2	0	1	0	0	0	0
	B	0	1	2	1	2	0	0	0	0	0	0	0
350	A	2	2	1	0	1	2	2	1	1	1	1	1
	B	1	2	1	0	1	0	1	2	3	2	2	0
360	A	0	1	4	2	1	1	2	4	5	3	2	3
	B	4	3	1	2	2	1	4	4	3	2	3	0
370	A	2	3	3	1	4	3	2	2	3	1	4	2
	B	2	2	1	1	2	1	2	1	0	1	2	2
380	A	0	2	0	1	1	1	0	3	0	1	1	2
	B	1	1	3	3	2	0	1	1	1	3	3	0
390	A	1	0	0	1	0	0	1	1	0	0	0	0
	B	1	0	1	1	2	1	1	0	1	1	2	1
400	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0
410	A	0	0	0	1	1	0	0	0	0	1	1	2
	B	1	0	0	0	0	0	0	0	0	0	0	0
430	A	0	0	0	1	1	1	0	0	0	1	1	1
	B	1	1	1	0	0	0	1	1	1	0	0	0
450 and above	A	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX H - SEPARATION VIOLATIONS

	Vertical Separation	Scenario Run	ACID	Sector	ALT	Current Separation	X-Coord	Y-Coord	Comments
1	FL290-FL410	A	DAL29	67	280	V[2]=0	609.843	155.75	Simulation-environment induced anomaly. Two aircraft came into the first sector with no separation.
			+ASH9476	67	280	L[3]=0	609.843	155.75	
2	FL290-FL410	A	COA3418	67	380	V=12	563.062	156.125	Caused by inadequate indication (+) in data block when an aircraft is non-DRVSM-approved
			+USC571[1]	67	392	L=1.906	563.531	154.281	
3	Baseline CVS	A	N29B	67	350	V=10	560.937	155.937	Error caused by pilot deviation from controller clearance.
			NWA290	67	340	L=3.093	557.906	156.531	
4	FL350-FL390	A	NWA25	67	323	V=13	467.312	182.75	Simulation-environment-induced. Second aircraft was in a ghost sector, not staffed by controllers.
			+MEP168[1]	98	310	L=3.968	470.5	180.375	

Notes:

1. The "+" in front of the call sign indicates that aircraft was non-DRVSM-approved.
2. V= Vertical Separation in 100's of feet.
3. L=Lateral Separation in miles.

APPENDIX I - ACRONYM LIST

A/G	Air-to-Ground
AT	Air Traffic
ATC	Air Traffic Control
ATDET	AT DSR Evolution Team
ATP	Air Traffic Planning and Procedures Program
CPC	Certified Professional Controller
CVS	Conventional Vertical Separation
DART	Data Analysis and Reduction Tool
DOD	Department of Defense
DRVSM	Domestic Reduced Vertical Separation Minimum
DSF	Display System Facility
DSR	Display System Replacement
FL	Flight Level
G/A	Ground-to-Air
G/G	Ground-to-Ground
HCS	Host Computer System
HF	Human Factors
HITL	Human-in-the-Loop
OEP	Operational Evolution Plan
PTT	Push-To-Talk
R	Radar controller
RA	Radar Associate controller
RVSM	Reduced Vertical Separation Minima
SAR	System Analysis and Recording
TGF	Target Generation Facility
VSCS	Voice Switching and Control System
VTABS	VSCS Training and Back-up System
WAFDOF	Wrong Altitude for Direction of Flight
WAK	Workload Assessment Keypad
WJHTC	William J. Hughes Technical Center
ZOB	Cleveland Air Route Traffic Control Center