Description and Results of the LARS/GE Data Compression Study by David Landgrebe

The purpose of this Information Note is to report the results of an evaluation of the sensitivity of a maximum liklihood pattern classification system to several data compression schemes in the face of noise. The compression schemes were suggested and implemented by the General Electric Company under contract to NASA. 1

At LARS, a data system parameter study has been underway for some time. The purpose of this study is to determine the sensitivity of system performance to such data system parameters as spectral and spatial resolution, signal-to-noise ratio, registration precision, data compression and others.

As a result of these joint interests by LARS and GE, a cooperative study into the effects of the G. E. data compression schemes was initiated. The steps followed in this study were as follows:

1. Suitable flightlines were jointly selected for the study. It was decided initially to pick flightlines which were typical of agricultural scenes, but which also had been well studied in order that anomalies would be understood. The flightlines selected are indicated in Table 1; and all are data collected by the Michigan multispectral scanner system over Purdue flightlines. This data was written onto tape by LARS and transmitted to G.E.

Multispectral Scanner Data Redundancy Study, NASA contract NASS-21151, Project Manager: Mr. Ronald Kern, Room U2450, General Electric Company, Valley Forge Space Center, P. O. Box 8555, Philadelphia, Pa. 19101 Technical Monitor: Mr. Joseph Silverman, NASA Goddard Space Flight Center, Greenbelt, Maryland

The work described in this report was spencored by NASA under Grant No. NGL 15 - 005 - 112.

Flight Line	Run Number	No. of Scan Lines
Cl June 66	66000600	951
C2 June 66	66000800	887
Cl July 66	66007700	1111
C2 July 66	66007900	1144

Table 1. Flight lines of data selected for test

2. It was originally intended that G E. would combine appropriate spectral bands of the 12-channel data so as to simulate the 4-bands of the ERTS scanner. It was later decided, however, that four of the scanner bands were already sufficiently near to the four ERTS channels so as not to require the use of a combination of scanner bands. Table 2 shows a comparison of the ERTS channels with the airborne scanner channels used. The second step thus became the processing of these four bands of data through data compression algorithms and appropriately re-expanding the data as will be described below. This was done by G. E.

ERTS Channels - μm	Airborne Scanner Channel used - μm	Channel Number
.5060	.5255	6
.6070	.6266	9
.7080	.7280	11
.80-1.1	.80-1.0	12

Table 2. Spectral band comparison

3. The re-expanded data was returned to LARS and data classifications were run using the LARSYSAA data classification system. A quantitative evaluation of these classifications using test fields compared against a like classification of data not having been compressed and re-expanded was used to evaluate the effect of the compression schemes on the classification accuracy.

It was later decided to test the compression schemes and classification accuracy in the face of additive noise simulating a decreased signal-to-noise ratio due to detector noise. The details of the noise generation and addition together with a description of the compression algorithms tested will be given next.

Description of Compression Algorithms

Four different compression algorithms were tested in the manner described above. Each of the four was also tested with two different noise levels. The descriptions of these algorithms which are provided here are taken from private correspondence between LARS and G. E. The descriptions are as follows:

Compression Algorithm Number 1 - Sampled Element - Unscaled

The technique here is simply to transmit only every fourth sample as follows:

In each scan line transmit sample 1 of channel 1, sample 2 of channel 2, sample 3 of channel 3, sample 4 of channel 4, sample 5 channel 1, sample 6 channel 2 etc. The reconstruction consists of replacing the missing pixels (samples) with pixels of the same intensity as the last sample transmitted in that particular band. In this case, since only 1/4 of the data is transmitted the resultant bandwidth reduction is 4 to 1.

Compression Algorithm Number 2 - Sampled Element - Scaled

In this scheme, alternate picture elements are sampled in the same fashion as in compression algorithm number 1; thus, only 1/4 of the picture elements have been retained at this point. However, in this case, all four channels are summed prior to sampling to create a luminous channel called the Z or intensity channel. All samples of this channel are also transmitted to the ground; thus, a full bandwidth channel is used for the luminous channel, whereas each of the four sample channels requires a 1/4 bandwidth channel. Therefore, the net amount of data transmitted is equivalent to two full channels, and the net bandwidth compression is 2 to 1.

The following is a description of the ground reconstruction used for this algorithm:

Consider band 1. If this band is sampled in the first, fifth, ninth, etc. pixel, these same pixels will be used directly to fill those pixels in the reconstruction. However, the reconstructed values of pixels 2, 3, and 4 are the values sampled in pixel 1 times the ratio of intensity that existed in pixel 2 divided by that in pixel 1, pixel 3 divided by pixel 1, and pixel 4 divided by pixel 1. Likewise, the intensities used on reconstruction of pixels 6, and 8 is that sampled in pixel 5 scaled by the intensity difference between 5 and 6, 7 and 8.

Compression Algorithm Number 3 - Low passed filtered with mixed highs

In this case, the data is low passed filtered digitally in each band using a filter time constant equivalent to one pixel in width. The low pass filtered version of the data is then subtracted from the original data in each band to obtain a high pass filtered version of that band. Next, in each pixel, the four high pass filtered versions are added and divided by four. This gives a new

final high pass filtered version, which may be considered a high pass filtered version of the luminuous or intensity channel. This final high pass filtered data is then sent to the ground. It requires one full bandwidth.

Simultaneously, the low pass filtered data is sampled in the manner of the compression algorithm number 1; that is, each band is sampled once every four elements. These data are also sent to the ground. The total compression thus achieved by this algorithm is a factor of two. The reconstruction in each band depends upon the last sampled pixel in that band and on the high pass filtered data sent to the ground for the particular pixel in question.

Resolution. In this scheme one band would be sent to the ground uncompressed and the other three bands would be selectively compressed in gray scale and in resolution (by not campling each pixel). The details of this algorithm are described in a memo supplied to LARS by G.E. and attached to this information note as Appendix A.

As previously mentioned these algorithms were to be tested in the face of additive white Gaussian noise. Two different noise levels were used. The noise levels were selected by G. E. in an attempt to simulate noise levels which might be present in "a bright scene" and "a dim scene". The noise levels added to each spectral band in the two cases are given in Table 3. The noise level in this table is specified in terms of the number of bins out of 256 per one standard deviation. The mean value of the noise was adjusted to zero. The noise was to be white Gaussian and uncorrelated from spectral band to spectral band; however, through an error in programming the generation of Noise Level 2, this noise is not uncorrelated between spectral bands.

Channel - um	l o for Noise level l	l σ for Noise level 2
.5258	3.2	10.4 17.9
.6266	3.9	12.8 17,6
.7280	7.1	23.3 20,0
.80-1.0	4.1	43.3

Table 3. Standard deviations of noise used in test

		53 00	IAL TURNS		41	2009401		C.L	4551F1EC-	SEPT 27.	1470	
)AVI	U IFAIRI	MG				
	HUN HUMBER	CELIC.	11851	LINE	i trit (ref.	COLUMN	CLICAN	(d(uph	170	INFURMATIUM	CLASSIFY	CLASS
ı	namouseu	:3-6	63	+ 1	,	44	44	2		SUTHE ANSI	2004 18TH;	SUTHEANS
	********	14-15	211	150		101	141		1	SUTHEANS	SOYES ANS	LUTBEANS
3	600006C0	36-/	14.7	121	1	4.9	18	2		SUTHE ANS 3	SUTREAMS	SOYMEANS
•	66400660	1-21	113	111		1.15	. 74	2	1	SUYBLARSO	CHATTAN	SUTHE AN
•	********	14-4	10/	1//		1.1	"		1	CHRNI	CORM	CORN
	P4000P4CA	16-4		243	1	45	41	2	1	LURNI	CORN	
1	00000000	10-0	119	141	,	21	>1	1	ı	CORN S	CURN	LUMM
		12-9	691	417	4	1.5	, ,	2	1	1, 1)8844	COMM	CUMB
4	******	4-2	165	111	1	145	14.	1)	UATSI	OATS	UATS
U	*********	1-11	4/1	415	- 2	~ 1	in S	1	1	1277AD	0A15	U445
1	*****	7-1	591	544	4	1.15	1 4 4	4	,	LATSI	CAFS	0445
1	0000000	31-12	795	16 0	1	1 10	175	1		WHEAT L	untEAT I	MARK W.
	*****	6-10		***	4	111	101	1	4	WHE A L	SHEAF [umt 4.5
	*******	7-1	"G1	000		101	411	7	•	west 4 5 5	##€41 I	west A ?
•	**********	6-10	. 19	**/		1.54	160	2	6	ALIN CL 1	SED CFAN	HEU LLY
•	0000000	1-1	134	707		1.75	145	2	6	MID CFS	MED CTAN	WED CTA
ı	*********		544	414	,	57	15		6	MEG CL 3	HIE CTAN	**** CT 41
•	44000400	1-24	/11	111	1	124	111	2	6	46 04 1 4 6	ALFALFA	AL 1 AI 9 A
	56U006CU	7-14	144	199			1 6 6	1	6	ALFALFAZ	ALIALFA	ALI ALI A
u	00000CU	7-22	104	347	1	135	1 4 9	1	6	ALFACFA 1	ALFALFA	AL F AL F A
ı	0000000	4-4	241	>64	t	1/1	122	2		44(1	# A 6	RYL
2	6400000	36-L	41	115	t	4.4	4.0	1	5	CH UU -	SW 2017	SW SUIL
1	44000000	14-10	640	44.	- 2	1.7	44	7	19	H6EL14	SHEAT IS	WHE AT

Table 4. List of Training Samples

	GE LATA	COMPRES:	.ion Slow	,								
		21 1		n	"	7005401		11	47711 ILO+	SEPT 27,197	n	
							avir 115	1 1 1111 11				
	AUMHER	01316.	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	LASI	141.	i (at.)	CLLUPA	COLUMA INI.	TYPE	INFORMATION	CLASSIFY	CEASS
1	04000000	15-0	>1	8.0		*1	10.5	1		CHA JUVIL	SUYHE ANS	2014444
2	*******	19-4	6.1	14		115	100	1		SUTEN COVERS W	SCYREAMS	2044F WA
1	**000600	11 - 1	43	101		114	1 8 8			ZUARM COALMZ A	SOAM WA?	CON SHEARS
•	66000600	14-4	173	111		41	101			SUPRE ANS	201481 WW?	SUYBEANS
•	44000400	16-1	111	100	4	* 1	.,			SOAREWAS	20181 VM7	SOTHE ANS
•	44000400	31-13	211	211	2	100	201	4		SUYREARS	SOTAL ANS	SUTREAMS
1	66000600	1:-3	149	191	1	6.4	111	, ,		SUVEN E PAT PE	SUYBE ANS	SUYBEANS
•	*******	1-01	241	191		• •	.,,	,		PRIANK AUFONES	POARS WAS	SUTHE ANS
10	660006CU	7-41	484	214	,	125	141			SUABLUS	POANT WAY	STAUL YOR
11	0000000	14-1	691	697		31	141	,		1178F ANS	ZOVRE ANS	SOTHEANS
12	1000000	12-4	441	6/3		41	111			74401 WAZ	JUNE 48 VOZ	SUFBEANS
	66000600	14-5 .	/43	141	;	11		- 2		SUTUR W. PRE P	SUYBE ANS	SCYNE ANS
14	46000eu0	1-43	154	745		121	191	,		SOVEN PLI CINC	SOVAL AND	SOTHEAMS
13	0000000	10-0	157	101		11	101	,		Cush	CURR	Ltime
1.4	*****	30-4	104	245		10	7-0			CHRM	CORN	CUMA
11	+6000000	14-10	221	/25		19	50			LUAN	(Omn	CUMP
1.0	44000400	10-4	201	481	2	1.0	6'			-	CORN	COMA
19	+4060+00	16-4	101	144	4	14	15	4		Cr. at N	CURM	LUAN
20	44000400	6-11	-01	+21		. 111	144	2		Cunn	CURM	COMM
21	46000660	12-0	544	441		•	* *			CORN DEFF VARE	CD#4	CUAN
44	*******	16-66	321	139	1	109	101	,		DATS	DATS	UAIS
43	4 6000000	6-1	103	111		1 14	1 6 6			HATS HITCH & L	UAIS	2140
10	***********	1-11	413	441		• 9	41			UAIS	2740	11415
13	*********	7-1	109	000		171	1.4 6	,		UAIS	DATS	LIAIS
26	Ve000000	11-15	2 = 5	117	Α.	104	144			sere à l	MEAT IL	unt Al
21	renocean	4-1	141	***	2	107	205			with & I	1) 1444m	
10	0000000	4-1	105	141	•	109	503	,		wet 41	II lasme	14 144
24	*********	6-14	***	509		11.1	711	:		wit / VARIETI	WHEAT 11	HAME A I
10	0.000000	1-2	501	084		/01	211			ami &1 / VAR LU	untal II	une of
11	*********	12-10	129	(11		111	179	,		NO CL DIVEL SH	ALO CLYR	460 CTAB
: 1	0000000	1-1	124	149	- 1		4.9	,		HED CE HAY	ALD CEAN	AFII CLIA
10	*************	9-10	211	951	,	111	197			HIU GL HAT	MED IL VII	HE11 LL 04
15	0000000	6-1	521	261	,	10	215			MAD CL PASTURE	REU CLYM	MED LIVE
36	50400044	1-6	124	>64	•	44	109			HED CL PASTURE	4f () 1.1 VM	HEU CLUR
11	44000000	17-0	244	613	,	44	109			MED CL PASTUAF	MAN CEAM	MER CTAN
30	A6000600	7-24	613	419	,	171	181			MU CL DIVERTED	REII CL VH	HED CLAR
19	46,00000	1-20	6/4	011		121	191			HP13 CL +447	HED CLYM	HEN CEAK
40	46000600		012	6.45	,	147	145	/		PID CL	MED CTAN	4F# LL #4
41	666C06G0	1-14	124	111	7	171	1.00			ALLALFA HAY	ALFALFA	A4 + 44 + A
42	66660660	1-1-	745	151	1	121	1.45			ALFALLA HAY	ALFALFA	41 44 6 4
43	******	1-22	144	#15	1	141	175	/		ALFA. HAY GHAS	41 646 64	AL 141 A
44	£6000400	6-4	545	511	,	119	16.5			411	475	MAF
.5	06020600	14-1	111	154	2	15 6	101	2		HARF SUIL	H4 5011	NE SHEE
	4000060	10-1	45	117	1	**	15.4			nant suit	BH SOIL	MM SULL

Table 5. List of Test Samples

Details of Classification Accuracy Tests and Conclusions

Data of flightline C1 June '66 (Run number 66000600) only was used for test due to time limitations. This flightline has been used at LARS for a number of studies and is therefore ideal for this purpose. 1,2 Training samples and test samples for this flightline had previously been selected. The training samples and test samples used are given in Table 4 and 5, respectively. A reference classification was carried out on this flightline using the preferred set of spectral bands as selected by the SSELECT feature selection algorithm. The preferred set of bands turned out to be channels 1, 6, 10, and 12 (.40-.44, .52-.55, .66-.72, and .80-1.00 µm respectively). A printout of this classification is shown as Figure 1. The test class performance for this classification is shown in Table 6. This same list of training samples and test samples was used for each classification in the study. 4

Table 7 shows the list of runs received from G. E. The results of the classification of these runs in terms of test class performance are given in detail in Appendix B and summarized in Table 8. This table shows the overall classification accuracy for each compression algorithm and noise situation. In the case of no noise there appears to be a slight preference for compression algorithm number 3. This preference continues in the Noise Level 1 trials.

[&]quot;Remote Multispectral Sensing in Agriculture" 1968 Report of the Laboratory for Agricultural Remote Sensing, Vol. 3. Purdue University Agricultural Experiment Station, Research Bulletin No. 844, Lafayette, Indiana.

²K. S. Fu, D. A. Landgrebe, and T. L. Phillips, "Information Processing of Remotely Sensed Agricultural Data." Proceedings of the IEEE 57:4, pp. 639-653.

^{3&}quot;Remote Multispectral Sensing in Agriculture." 1970. Report of the Laboratory for Agricultural Remote Sensing, Vol. 4. Purdue University Agricultural Experiment Station, Research Bulletin No. 873, Lafayette, Indiana.

The actual training samples used for classifying a given data set were drawn from that data set, however.

		20	# 141 NUM	ne a	- 472005	100		CLASSIF	166-	SCP1 22.	1910	
						CHA	AMFES CALL					
	LPAK	NFL L	Vetc	INAL NAME	0.40 10	4.44	# LC H (P2 [R		INNAFICM C	me - 1	L0 . V	1.00
		net "		IMAL PAND	0.52 10		PICADAFIER		ISSALION CO			1.00
	4-44	NEL 10		TRAL HAND	0.66 16		*1(*C*(16#		IRRALICA CO		3000 0000	1.00
		NCL 12			0.40 10		F1C#C#8188		104 CI			1.30
							LL 4558 S					
			LLASS	CHIMP	CHMP?	PCI			CLASS	CACUP	1+#(2 PC	. 1
		k.	SUTUE AN					•	ALIALIA	AL FAL FA	0.5	
		4	CUMM	CURN	4.5			1	AAL	MYF.	9.5	
		,	GAIS	LAIS	0.5				un zeit	HR ZOIL	0.5	
		•	pri al I	MANE A !	0.5			-1	11 14 1-1-	HHI AT	0.5	
		,	MED CFA	M HIOLEY	/# U.1							
					!	31 614	SS PERFORP	ANCI				
		NG GF	ec. 1.		MUMBE	COL SA	PPLES CLAS	siine ii	ALC:			
		'AMP'	CHILT	MINE T	THE ANY	LUAN	HATS	meti Ct	ALFALIA MY	A 7 6	AR SULL	CHR SMIL
1	W-1 41	4091	41.6	2578	O	D.	1.1	13	u	***	L3	4
1	PRARTAN	1111		10		110	114			1.40	1.2	4/1
	CURN	. 115	40.4	1	241	. 304		"		u.	Q	7.5
,	UAIS	1950	*1.0	10	21	4	1 555	114	14	14	u	1
		14 16	41.0	•	1.4	* 0	151	1106	. 70	5	£,	2.41
	WAR CLAN		114.0	r	,	0	5.5	**	196	C .	t.	•
	ALPALIA	417	100000 0000									
	5 (50)	912 621	74.8	. 5		4 4		.,	- 6	. 34	11	6)

Table 6. Test Sample Performance for Preferred Channels

Run Number	Tape Number	Description
66000620	907	Reference Data - No Noise
66000621	909	Reference Data - Noise Level 1
66000622	910	Reference Data - Noise Level 2
66000623	907	Sampled Element - Unscaled - No Noise
66000624	909	Sampled Element - Unscaled - Noise Level 1
66000625	910	Sampled Element - Unscaled - Noise Level 2
66000626	908	Sampled Element - Scaled - No Noise
66000627	909	Sampled Element - Scaled - Noise Level 1
66000628	910	Sampled Element - Scaled - Noise Level 2
66000629	908	Low-Phas Filtered with Mixed Highs - No Noise
66000630	909	Low-Pass Filtered with Mixed Highs - Noise Level 1
66000631	910	Low-Pass Filtered with Mixed Highs - Noise Level 2
66000632	908	Intensity Channel
66000635	911	3 Band Compress. of Gray Scale & Resolution - No Noise
66000636	911	3 Band Compress. of Gray Scale & Resolution - Noise Level 1
66000637	911	3 Band Compress. of Gray Scale & Resolution - Noise Level 2

Table 7. List of Runs Received from General Electric

Due to the previously described error resulting in correlation between channels in the Noise Level 2 case, it is inappropriate to draw conclusions in this situation.

The slight preference for Compression Algorithm Number 3 tends to be observed in each class as well as the overall results. Tables 9 and 10 show the best class

performance for two individual classes. Table 9 gives the performance for soybeans, a relatively difficult class to identify. Table 10 shows the same results for the class wheat, a much simpler classification task. It is interesting to note that with Noise Level 1, several of the results from the compressed data are higher than the accuracies obtained on the uncompressed reference data.

Overall Test Sample Classification-Accuracy in Per Cent

Compressio Algorithm	n Data Description	No Noise	Noise Level 1	Noise Level 2	Compression Ratio
	Reference Data (ERTS-Simulated Channels)	79.7	63.6	78.1	
1	Sampled Element - Unscaled	76.5	62.8	31.8	4
2	Sampled Element - Scaled	76.5	64.5	51.4	2
3	Low Pass Filtered with Mixed Highs	78.5	68.8	43.8	2
4	Three Band Compression of Gray Scale & Resolution	75.3	61.8	46.2	Variable

Table 8. Overall Performance on Test Samples

Overall Test Sample Classification Accuracy in Per Cent

Compression Algorithm	n Data Description	No Noise	Noise Level 1	Noise Level 2	Compression Ratio
	Reference Data (ERTS-Simulated Channels)	71.0	50.2	73.1	
1	Sampled Element - Unscaled	67.3	48.6	16.7	4
2	Sampled Element - Scaled	69.7	53.9	48.8	2
3	Low Pass Filtered with Mixed Highs	70.7	56.5	31.7	2
4	Three Band Compression of Gray Scale & Resolution	66.2	50.1	40.9	Variable

Table 9. Test Class Performance for Soybeans

Overall Test Sample Classification Accuracy in Per Cent

Compression Algorithm	Data Description	No Noise	Noise Level 1	Noise Compression Level 2 Ratio
	Reference Data (ERTS-Simulated Channels)	97.8	88.7	95.3
1	Sampled Element - Unscaled	96.0	86.2	48.0
2	Sampled Element - Scaled	96.5	85.2	41.9
3	Low Pass Filtered with Mixed Highs	96.6	91.5	59.4
4	Three Band Compression of Gray Scale & Resolution	96.5	80.8	93.7

Table 10. Test Class Performance for Wheat

While the differences in accuracies indicated in these three tables is, in general, not great as a function of the compression algorithm used, the preference of the classifier for Classification Algorithm Number 3 does seem to be fairly consistent throughout the results. Care must be used, however, in the extrapolation of these results to other situations. There are several reasons for this.

First, the flightline selected for tests was chosen because of the variety of agricultural classes present in this relatively small area. However, it must be kept in mind that the area covered by this flightline (approximately 4 sq. miles) is relatively very small. Further, it does not contain classes typical of other times of the growing season nor of many of the important non-agricultural classes of data.

Second, as a procedural matter test fields are selected from within the agricultural field in such a way as to guarantee that the boundaries of the agricultural field are not included. Since the algorithms themselves are in the main attempting to utilize spatial redundancy to achieve compression, the algorithms may be expected to cause greater degradation of the data in the vicinity of agricultural field boundaries. Thus, one might reasonably expect greater overall degradation than is indicated by these accuracy figures.

Two additional points can be made as a result of the availability of these results. These two points are somewhat tangential to the matter of data compression but are, nevertheless, of considerable interest to the design of future space and aircraft systems. They are as follows:

1. The error in generating the random noise data for noise level 2 does provide an opportunity to illustrate the manner in which correlation between channels affects classification accuracy. Figure 2 shows a printout of channel 12 of the reference data for the No Noise, Noise Level 1, and Noise Level 2 cases. Recall from Table 8 that the accuracies in classification were 79.7, 63.6 and 78.1 respectively. First, it is clear from these results that one cannot predict from a casual glance at imagery or a casual knowledge of the data signal-to-noise ratio, what accuracy will be achievable by machine-processing algorithms capable of taking correlation between channels into account. Second these results illustrate the fact that when degrading effects occur in the data system, the type of degradation is as important as its size.

The reason the very noisy data was more accurately classified than the Noise Level 1 data was that the noise added was highly correlated between channels. Visualize the data in four-dimensional space; it is known that data of this type generally lies along lines which are somewhat radial to the origin. Thus, adding

noise which is highly correlated between channels lengthens the distribution of data along these radial lines, but does not materially contribute to increased overlap of data from different classes.

2. The second point raised by these results has to do with the relative importance of a band selection capability. Notice from Table 6 that the overall classification performance for the preferred set of spectral bands was 90.1 percent. This is more than 10 percent higher than the same performance figure for the reference data (ERTS simulated channels). Thus, one may say from the data analysist's view point that being required to give up the capability to tailor the band selection to the particular classification to be carried out is a more serious effect than accepting degrading effects in the data due to a data compression algorithm. This can be seen more clearly as follows:

The feature selection algorithm implemented in the LARSYSAA programming system computes the relative separability of each class pair for each possible four-tuple of spectral bands. Table 11 shows the results of applying this algorithm to this classification task. The numbers on the right of Table 11 are the numbers indicating the relative separability of the class pairs. Classes are indicated by a single symbol: "S" for soybeans, "C" for corn, "W" for wheat, "A" for alfalfa, etc. The four-tuple of features (spectral bands) are then rank-ordered based upon the average of these interclass separability measures. Thus, it is seen that bands 1, 9, 11 and 12 were selected as the best feature sets and bands numbered 6, 9, 11 and 12 which are the ones most nearly matching the ERTS channels are second. 1

In the case of an actual satellite, however, channel I would probably not be as useful as it appears to be here since it is well into the blue portion of the spectrum and from space there would be considerable blue scattering. These results tend to bear out the choice that the ERTS spectral bands are generally a good set.

However, it is possible to further tailor the band selection to the classification task by using additional options available with the feature selection algorithm. Note that in Table 11 some of the interclass pair separabilities are very large indicating very obvious separability; on the other hand, other interclass separability measures are quite small. It would be desirable to pick feature sets based on the possibility of increasing the separability of the more difficult interclass pairs at the expense of the classes with more obvious separability. In order to do this, the feature selection algorithm has been provided with an option permitting the imposing of a maximum interclass separability measure which will be considered for the purpose of rank ordering the four-tuples. Table 12 shows the results of using a maximum of 200. Note that the preferred feature set now becomes 1, 6, 10 and 12 and that the ERTS simulated channels 6,

This validity of this re-ranking is borne out in the difference in overall accuracy ultimately obtained in the two classifications, 90.1 percent for channels 1, 6, 10 and 12 as compared to 79.7 percent for the ERTS channels 6, 9, 11 and 12.

Thus, by being forced to a suboptimum choice of spectral bands an overall 10% accuracy loss occurred, and the increased loss in accuracy due to data compression was only an additional 1.2 percent in the case of algorithm #3 or 3.2 percent for algorithm one. Figure 3 shows a performance comparison for the preferred bands, the ERTS bands and the ERTS bands with compression number 1.

¹From these results one might tend to conclude that the ERTS channels, which are undoubtedly the best possible set of bands in general, may be considerably sub-optimum in specific cases.

As a matter of speculation, there is some reason to believe that the use of sub-optimum features in this test may well be compressing the range over which the performance figures for the various data compression algorithms distributed themselves. It would be a desirable experiment to repeat the tests used in this study with the optimum set of features so as to get a clear view of the effects of data compression alone.

-17-

Class Separability Measure (No Maximum)

Rank	Spectral Bands	Average <u>Separability</u>	SC SC	ndividual <u>SW</u>	Class <u>SA</u>	Sepa:		•	•
1	1, 9, 11, 12	444	25	190	188	620	58		
-ERTS- 2	6, 9, 11, 12	428	26	177	229	630	208		
3	2, 9, 11, 12	423	24	151	182	619	58		
4 -	5, 9, 11, 12	420							
5	8, 9, 11, 12			•					
	•								

Table 11.

Class Separability Measure (Maximum = 200)

Rank	Spectral Bands	Average Separability	In SC	dividual <u>SW</u>	Class SA	Separ <u>WR</u>	ability <u>WY</u>
1	1, 6, 10, 12	155	34	200	196	200	180
2	1, 6, 10, 11	154	34	200	192	200	183
3	1, 6, 9, 12	153	26	200	193	200	200
4	1, 6, 9, 11	153	27	200	190	200	200
				•			
	•						
-ERTS 55	6, 9, 11, 12	145	26	177	200	200	200
	•						



Figure 1. Classification Results of Test Flight Line Using Preferred Channels

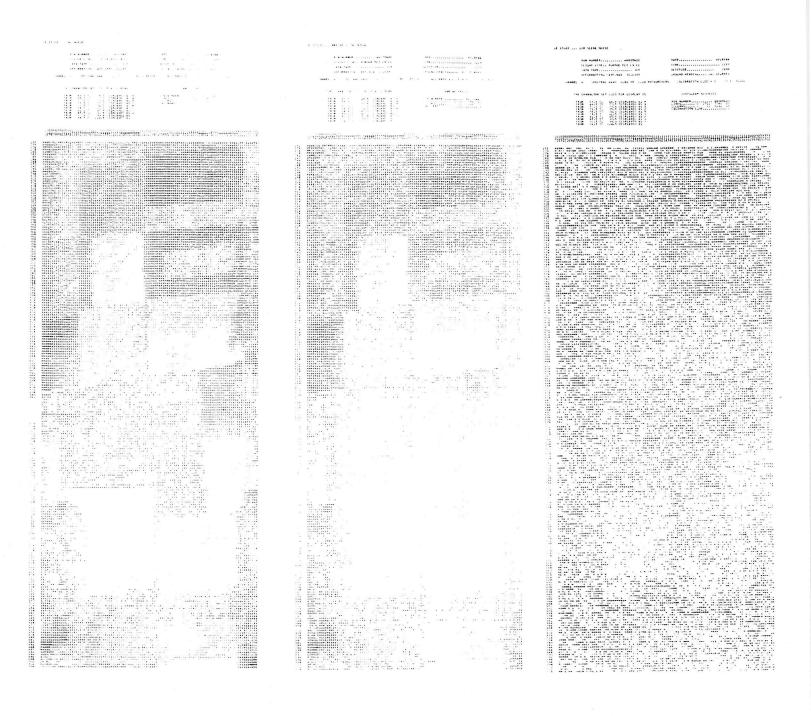


Figure 2. Pictorial Printouts of Reference Data (0.8-1.0 Omm Channel) with No Noise, Noise Level 1 and Noise Level 2

GE/LARS Data Compression Study June 1966 CI Test Results

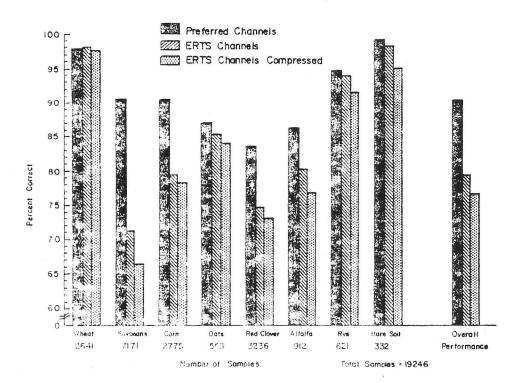


Figure 3. Performance Comparison of Preferred Channels, ERTS Channels and ERTS Channels with Compression #1.

- 1. Read into temporary store the first 18 pixel signal levels for each of bands 1,2,3,4 as follows:
 - a. Band 1: (1) Actual signal levels for pixels 1,4,7,10,13, 16
 - (2) For pixels 2,3 same level as for pixel 1
 - (3) For pixels 5,6 same level as for pixel 4
 - (4) etc. for pixels 8,9; 11,12: 14,15; 17,18
 - b. Band 2: Actual signal levels for all 18 pixels
 - c. Band 3: Same procedure as for step la. (Band 1)
 - d. Band 4: Same procedure as for step la. (Band 1)
- 2. For the stored signals, measure the difference between the maximum and minimum signal levels in each band. Label these differences D_1 , D_2 , D_3 , and D_4 for bands 1,2,3,4 respectively.
- 3. Do either or both D_1 or D_2 exceed 32? If "yes" go to step 4. If "no" go to step 5.
- 4. Modify the stored pixel signal levels for <u>Band 1</u> by adding <u>17*</u> to the level of every third pixel stored for <u>Band 2</u> (i.e. pixels 1,4,7,10,13,16), and place the result for each of these six pixels in the appropriate storage cell for <u>Band 1</u>. Then modify the other pixel signals in <u>Band 1</u> so that pixels 2,3 have same level as pixel 1, pixels 5,6 same as pixel 4, etc. Do <u>not</u> modify the signal levels stored for <u>Band 2</u>.
- 5. Do either or both D_3 or D_4 exceed 32? If "yes", go to step 6. If "no", go to step 7.

^{*} Note: These modifications pertain only to Mission File No. 66000600.

Other modifications, derived from the flight data, will be used in other missions.

- 6. Modify the stored pixel signal levels for <u>Band 4</u> as follows: Find the value of each pixel signal level stored in <u>Band 3</u>. For each of these 18 values, multiply by (2/3) and add 12.* Place the result for each pixel in the appropriate storage cell for <u>Band 4</u>. Round off to nearest integer. Do <u>not</u> modify the signal levels stored for Band 3.
- 7. Printout for the new data tape for Purdue the pixel signal levels now stored for pixels 1 to 18 in each of the four bands.
- 8. Repeat steps 1 to 7 for the next 18 pixel signals in each of the four bands.
- 9. Continue step 8 until 11 segments of 18 pixel signals in each band have been processed. Then repeat steps 1 to 7 for the last 24 pixel signals in each band. (That is, the last segment in the line will contain 24 pixels rather than 18). The procedure of step 1 will have to be extended to 24 pixels for the last segment, of course.
- 10. Proceed to line 2 and repeat steps 1 to 9, except that step 1 is modified as follows (and step 4 is adjusted to correspond to it):
 - a. Band 1: (1) Actual signal levels for pixels 2,5,8,11,14,17
 - (2) For pixels 1,3 same level as for pixel 2
 - (3) For pixels 4,6 same level as for pixel 5
 - (4) etc. for pixels 7,9; 10,12; 13,15; 16,18
 - (5) Extend the procedure to 24 pixels for the last segment.
 - b. Band 2: Actual signal levels for all 18 or 24 pixels.
 - c. Band 3: Same procedure as for step 10a (Band 1).
 - d. Band 4: Same procedure for step 10a (Band 1).
- 11. Proceed to line 3 and repeat steps 1 to 9, except that step 1 is modified as follows (and step 4 is adjusted to correspond to it):
 - a. Band 1: (1) Actual signal levels for pixels 3,6,9,12,15,18
 - (2) For pixels 1,2 same level as for pixel 3
 - (3) For pixels 4,5 same level as for pixel 6
 - (4) etc. for pixels 7,8; 10,11; :3,14; 16, 17
 - (5) Extend the procedure to 24 pixels for the last segment.
 - b. Band 2: Actual signal levels for all 18 or 24 pixels.
 - c. Band 3: Same procedure as for step 11a (Band 1).
 - d. Band 4: Same procedure as for step 11a (Band 1).

- 12. Proceed to line 4 and repeat steps 1 to 9 (same procedure as for line 1).
- 13. Proceed to line 5 and do the same as in step 10 (same procedure as for line 2).
- 14. Proceed to line 6 and do the same as in step 11 (same procedure as for line 3).
- 15. Continue the cyclic procedure to the end of the flight run:

```
Line 7,10,13,16---- same procedure as for line 1
Line 8,11,14,17---- same procedure as for line 2
Line 9,12,15,18---- same procedure as for line 3
```

This completes the processing for compression - reconstruction and should result in a tape which can be sent to Purdue.

- 16. As a separate processing output (not to go to Purdue), provide three totals for the entire flight run as follows:
 - a. The number of occasions (line segments) where either or both D_1 or D_2 exceed 32. (If both exceed 32, that is only one occasion, and should not be counted as two).
 - b. The number of occasions (line segments) where either or both D_3 or D_4 exceed 32. (If both exceed 32, that is only one occasion and should not be counted as two).
 - c. The total number of segments in the entire flight run (This is 12 segments x number of lines).

APPENDIX B: CLASSIFICATION RESULTS IN TERMS OF TEST CLASS PERFORMANCE

	i.k	HIAL HUN	*#! #	- 10/Ad	05404		1.1.45511	ILC-	OCT 26	. 1910	
					1,1-4	ANELS IN	C.				
(, t-Ah		- 210	TRAI :	mp 6.52	10 0.55	HII HEMITE	AS CAL	IRRATION L	1 • 100	10 . 1	1.00
CHAN	MII .	SPEC	IKAI BA	110	1. 0.06	P16.46 P116	HL LAL	TERMITON C	nof - 1	ro - 1	1.20
+ 1"AN	MI L	Sett	IRAL PA	MD 0.77	10 0.00	NIS ACRE IL	45 CAL	IRRATION D	OD€ • 1	5.6 × 1	1.00
	W1 F -		INAL OA	Nº 0.40	11 1.46	F14 41 #3 11	H'. (AL	INPATTON C	006 - 1	(r: • (1.00
						(1455)5					
		CLASS	·/ H 1	ce teer	S PC1			11455	GROUP	TIMES PE	e i
	1	COTHEAN	On the con-	LANS L	-5		4	ALIALIA	ALFALIA	6.5	5.0
		L. HN	ULINA		. 5		,	6.91	RYI	0.5	
	.1	CATS	1.445	1.	. 5			WH VILLE	es SDIL	4.5	
	•	art Al 1	beri A	T to			:9.			10.00	
							- 4	MERAL II	me t A f	6.5	
	1	MEG CLV			. 5	S. of Billion		FLAC 11			
		*/ *		ctyn "	IPSE ELA	51 PFB641H.	PANCI		ni tat		
LATUP	NO OF	egy[]		ctyn "	.5 - 1851 CLA - 188 OF SA		PANCE.		HYE	54 SON	THR SHOL
41	40 0F 74HP7 2641	esset.	H H [[;	CL VA	.5 - 1851 C.LA - 188 CE SA	PPC1 , 11 A	PANCE.	N1 G		,	TH#SHOL
AMEAT	40 OF 14MMS 2641	coll ore	NO 810 1	HUPE SCHEEN A SERVE	TEST DEA NEW DE SA NS LORA	PP(1, 114	MANGE SSEFER E	MTC VA INCALFA	***	59 SON	100000000000000000000000000000000000000
MITTELANS COMM	AG OF 1200 CONT. 2001	conti	Ant Al 2564	NOME 50 TO EAST A SECTOR AS SECTOR A	IFSE CEA SEA OF SA SE CORA 219 219 219	#P(1) (() 615 15	MANGE SSEFTED E MED CL	NIG VA BLEALFA	***	58 50 11	4
MITTERNS COMM LAIS	NG OF SAMPS 2641 7171 2175 1558	70.1 10.2 10.8	Ant Al 2584	HUPE SCHEEN A SERVE	IFAT CLA MERICE SA MS CORA 219 219 7108 74	PP(1), 1(4) 615 (*) 657	PANCI SSTELED I HER CL C	NIG VA BLEALFA G	**E	ne 1014 L	2
MINIME AND CLUMN CATS HEE CLUMN	%() GF (AMP), 2641 7171 2775 1958 1236	77.6 17.6 17.6 17.6 17.6	on Alta (NOME 50 TOTAL A STATE 198	18 AT CEA MEA CE SA NS CORA 219 219 2106 72 CS1	PPLIS CLA - 618 - 527 - 67 - 619 - 619	###GI #### GE #### GE #### #### #############	NIC VA ALFALFA L 2 11	11 11 146	88 50M L L 2	2
MITTAL AND LEGAN LATE LEGAN LEGAL LE	2041 7171 2175 1958 1236 912	70.1 10.2 10.8 10.6 10.6	H HEG 1	HUMM SCHOLAR SCHOLAR A SETT 198	SEA OF SANS CORA	#PCLS CLA - ALS 	###GI #### TE ### TE ##	MEC VM ALFALFA L 5 13 'DF 721	### 11 176 2 21 4	88 50M 1 1 2 0	4 2 6
MITTAL ANS LUMN LAIS HED CLYM ALFALFA KYE	2001 7171 2175 1958 1236 912 621	2011 -1.6 -1.7 -10.8 -10.6 -10.6 -10.7	MITAL 2588 - 111 -	MOMESTERA STOREA A STORE CA FORE TO	IPAL CEA MEM CE SA MS CORA 72 72 84 74 151 1-	#PCL CCA ALS A	###GI #10 / / / / / / / / / / / / / / / / / / /	NTC VA ALLALIA 5 6 7 13 764 721	#YE 11 1126 7 21 1	88 5048 L 1 2 0 0	4 2 6 0
MITTAL AND LEGAN LATE LEGAN LEGAL LE	2041 7171 2175 1958 1236 912	70.1 10.2 10.8 10.6 10.6	H HEG 1	HUMM SCHOLAR SCHOLAR A SETT 198	SEA OF SANS CORA	#PCLS CLA - ALS 	###GI #### TE ### TE ##	MEC VM ALFALFA L 5 13 'DF 721	### 11 176 2 21 4	88 2011 1 1 2 0 6	2 8 11

Table B-1. Test Class Performance - Reference Data, No Noise

		ALEL NO	F613.	, 1/2							
				and white			· CASTE	1+:	. 1 7	.1976	
						4/(5)	٠.				
· F.A.	A11			INC COL	11	*10*(*(),	- II	CHARLES L			
C AP			CIPAL	erer out	11			Institute t			11.66
1.45		, 141	Cast na	MI 0.17	11	*1. H. *1 1-		PRATTICA C			1.00
t . 44	NI:		(1×4) na	ran er	1.00	M11 1 1 1 1 1 1 1		PRATECH L			1.00
						CLASSES					
		era mada-									
		1455	1,04	5.00	5 49 1			CLACS	HEUD	THRE! P	
		SUYBEAR			. ,		^	21 1 At 1 A	ALPALFA	0.5	
	4	COMA	LUNK		. •		2	× * f	A TE	5.5	
			. A I .		. 5			34 ST 11	ne sch	ri . •	
		MED ITS	70.000		. `		- 9	-ME AT 11	BPI AT	6.5	
			# #FD		. 5						
				100	TENE CLA	SS PERKER	ANI.I				
	NC ()	er r.		. (#)	CERTLE SA	MPC+1 LGA	ATELIG IN	16.			
CHCLE	VAPES	COME !	-MEAF		S CLAN				× 74	ne Still	
PHI AT	2001	26.0	25.45	1.1	10			•	4.5	4	1 24 18 5 2-4 1
SUAME TH?	11.71	21.1	555	***	212	110	7		tici		1.1
CHA	1114	10.1		116	vil to	144	7.60		3		
						190 11	200		1 2	× .	-2
0.47%	1 ** 4	1	2.1	- E.C	11.2		7.0	3.85			19
HAT'S HEC CEYN	12.16	73.1	3.6	· ·	146	100	. 117	51"			
HEC CEYN ALPALEA	32 16 21 2							414	1		ed.
 HAC CLYM ALPALFA MYP	3236 212 621	73.1		w	1 46		. 177		7		2.
HAR TERM ALPADEA MYR BM SCIL	3236 212 771 771 772	73.1			146		.117	41. enc	1 0 568	in An	2.
HAR TERM ALPADEA MYR BM SCIL	3236 212 621 532	/1.1 /5.9 91.5			146	•	. 117	41. 100	7		2.

Table B-2. Test Class Performance - Compression #1, No Noise

							Crazzt.	111-	DEC	7-1410	
					Li	ARRES LSEL					
CHAR	NEL I	2010	TRAL PA	vn c.52	TC 0.55	PICACPRIFAS	CAL	INDATICA CO	DDF - 1	CO - 1	1.00
(- A A	NEL .		1941 BAL	10	16 0.66	PILHEPETERS		IBRATICH CO		CC = 3	
CHAR	htt 3	SPEC	. THAL HA!	WC (1.77	10 0.40	PILACPETERS		ISPATION CI		CC = 3	
LHAR	MEC 4	2860	LIRAL MAI	d. 6.00	10 1.00	PICKLPETERS		IDRATICS CO		66 - 3	
					-	CLASSES					
		CLASS	LACI	IP IHME	5 061			CLASS	GROUP	THRES PE	
	1	SLYBEAR	SE THE	ANS G	.5		6	ALPALFA	AL FALF		•••
	2	CCRN	LLHN	U	. 5		,	PY1	HAE	0.5	
	1	LAIS	LAIS	0	. 3			te SCIL	88 SOL		
		SPEAT 1	AME AT	L L	. 5		7	11 TA344	MHEAT	G. 5	
	5	wer cra	M 44C C	.t.v= 0	. 5					***	
					test cu	ASS PERFERPA	NCI				
	No ct	PCT.		nu#		ASS PERFORMA		RTC			
GREUP	NU CA	cE\$Ei	net & t				1511U 1	RTC VA ALFALFA	AVE	## 2011	Inashu
	1691	CEACI	nmE B 1		*** OF 54	APPIIS CLASS	1511U 1		RVE	## 701F	THRSMUS
SUTRE ANS	7691 7691	(4.1 (4.1		PRAME	NEW OF ST	APPIIS CLASS	IFIIU I	VA ALFALFA			
SHEAT SHYREANS CURN	2004 2013 2115	(4.1 (6.4	1599	PRAME	HER OF ST	APPLIS CLASS LAIS	IFIIC II REC CL	O STALFA	**	1	
SUYREANS CURN UAIN	/ t71 / t73 / 175 1958	(4.) (4.) (6.)	1369 195 5 76	11 20aul	05 CURA 11 256	APPLIS CLASS	15110 11 REC CL 3	C C	1051	t c	4
SUPREANS CURN LAIS RED CLYR	7691 7673 2775 1358 3236	76.7 (6.7 (6.7 (6.7	399 393 3 74 11	18 5+0 6441 11	HEM DE SI NS CUNA 11 256 2135	APPLIS CLASS LAIS 14 415 107	REC CL	C C b	1051	1 C U	8 4 10
SUTREAMS CURN UAI' RED CLYR ALFALFA	7691 7173 2775 1358 3236	76.3 64.1 76.3 86.1 67.0	1369 195 5 76	18 4441 18 70486 W	49 OF ST NS CURA 11 256 2135 112	APPLES CLASS LAIS 14 415 187 1810	REC CL	O C b	1051	t c u	8 4 10 3
SUPREANS CURN LAIS RED CLYR	7691 7673 2775 1358 3236	76.7 (6.7 (6.7 (6.7	399 393 3 74 11	18 5+0 6441 11	NS COM 11 256 2135 112 704	APPLIS CLASS 1 A15 14 415 107 1310 82	REC CL 3 1 1 Ab 59 21 on	O C b v	1051	1 0 0	8 10 3

Table B-3. Test Class Performance - Compression #2, No Noise

		21	PIM NU	*****	170100	1466		CLASSIA	1160-	CLC	2.1970	
						Ç.	A58015 USED					
		461 1	1946		1440 S.32 I	C 0.55	P1CHC#111#	(AL	LAMALIGN CO.	or - 1	(0 .)	1.00
	CHAR	NEC .	5810	-	AND CALL	U 11.66	PECALPETER		CHRATTEN COL	. 1		1.00
	(F &R	~L+	100		AND 0.12 F	£ 0.0C	PICALPHILA	CAL	INASTILN CO	Dt - 1	co - 1	1.00
	LHAN	A16 5	SPEL		440 0.80 1		**********	CAL	IRRAFIGN CUI	1		1.00
							CLASSES					
				6,34	COP THEE	PCT			CLASS	GACUP	IHRES P	CI
		i	LYDEAN	N 55 9	HEAMS 0.	,			ALFALFA	ALPALF	4 0.5	
			CCKM	CLA	N G.	5		1	H.Y.6	RYE	0.5	
		1	LATS	t'A I	1 0.	5		¥	OR SCIL	8H 5G1	L C.5	
		•	APEAL I	m+12	Al L.	5			SPEAT II	MIEAT	0.5	
		4	HOD CLU	# ALU	CLAS C.	5						
					•••		PPELS CLASS		N.C.			
	LHCUP	SAPPS	CHET	WH! A!	SEVELAN		UATS		V8 42 F 44 F 4	RVE	88 5014	THRSHULL
	ert o i	2091	14.4	1996	10	14	1.1		G	41	0	13
•	CTHEARS	1111	10.1		1004	142	447	U	c	789	0	2
	CAN	. 115	74.4	6	200	21.40	119	231	3	ti	0	14
3	AIS	1558	**.*	12	0	14	1110		ı	15	c	,
0		1236	11.9	1.1	3	105	4.0	4340	57C	a	۵	34
0	EL CLAM	414	15.1	1	1	1.3	44	121	640	G	U	34
	IEL CEAN		11.1	10		U		Q.	u	7/0	٥	o
		041						9	c	1	110	q
) ()		114	43.4	20	0	u						****

Table B-4. Test Class Performance - Compression #3, No Noise

Table B-5. Test Class Performance - Compression #4, No Noise

		24	-	# f H	13040	05467		142211	ttL-	fit. A	. 1976	
							44ALLS 1510					
	LMAN	NIL I	SPEC		MD52	16. 9.55	FICHUMI CEN	S CAL	INMATTEN CO	nor • 1	(1.00
	LFAA	MIL .	SPEC		ND 4.67	11 11.66	F1CH1#111#	LAL	LHP411. 5 1.0	n	f. c	
	HAR	KIL I	PEC	IRAL MAI	40 0.72	16 7.80	#1CHI #111 #	S CAL		DF - 1	60 · 1	1.00
	Cran	MIL .	SPEC	THEL HAI	W() 0.80	1. 1.66	P1(#(P()(#		189411UN 1.	CF - 1	1	
						-	CLASSES					
			(1455	1.44.1	J# 1MHE	134 2			CLASS	CHLUP	[HH15 PF	
		A.	PEARLAN	2010	ANY	. 11		6	ALFALFA		4.5	
		1	CUMP	C(,#M	L	- 5		1	**1	**	0.5	
		1	LAIS	CAIS	U.	. 5		4	4H 7C11	net '.011	0.5	
		•	m+ A 1	ant At		. 5			SPIAL II	BHIF A I	2	
						031.14	NIS PERFORM	ACI.				
		NO 1.1	CERCI				CAMILL CLASS	11110 11	itt			
		SAMP'		ant At	PEARL OF	AMIL C	1 41 5	wit (FA	A	< Y1	HM 2118 E	unez unt
	LAULP		t /	1141	5.4	la.	25	4.	C	104	115	
	ni-t A I	20.01						1		11119	29.3	1
	NEAT	1111	50.2	115		313	521		•			
,	MEEAT OLTPEANS JURN	.115			*10	1441	216	174	ř	٠.	-	Q.
	MEAT SCTPCANS SCRM SALS	1171	****	•	110	1441	274	119			1	
	NEAT SCTPCANS SCRN SATS SECULIVE	1111 1115 115a 1136	66.1	•	110	710 707	274 1011 158	779 77 1761	12			
	NEEAT SCTPEANS JURN JATS PLE SLVR NEFALFA	1111 1125 1236 247	66.1 66.1 60.4		110	710 767 71	276 1011 15m 5e	119	e 12	1	ī	60
	MEEAT SCTPCANS SCRN SATS SCECULUM SCFALFA	1111 115 155a 1736 117 671	66.1 66.1 66.2 73.2 64.4		110 110 12 6	710 769 71	274 1011 15m 5e	100 1001 101 101	e 12 845 640	1	i c u	6. 2
	NEEAT SCTPEANS JURN JATS PLE SLVR NEFALFA	1111 1125 1236 247	66.1 66.1 60.4		110	710 767 71	276 1011 15m 5e	179 1361 1361	12 875 840	1	E	6. 1

Table B-6. Test Class Performance - Reference Data, Noise Level 1

	,	PREME NO	MK! #	14	0 /00:54	08		CLASSIC	IEC-	CIC	4.1910	
						(F	ALMILS L.FF					
LMAR	N(L	I SPE	CINAL H	AND P.	. 10	0.55	* C C C 1 0	CAL	IRRATILA C	006 - 1	60 · 1	1.00
LHAR	MEL		CIRAL H.	Lio	11 11	1.60	#11 =1 =+ 11 A		-		CC -)	
LHAN	MEL	t SPE	CINAL m	490 C.	11 15	4.80	* 15 x (P# 1 (# 1		INPATION L		LC . 1	
CHAN	MIL		CIHAL III	auti .	11 OF	1.60	PICHIPFIFE	CAL	INPATION C	1 • 100	cc • 3	
							C1 4555 \					
		LLASS					••••					
	1	i Int A		1 4NS	4.5				ELIASS	CHOUP	THRES P	. 1
		CLAN			2.2			1	HTF	MYE		
	,	LATS	LAC								0.5	
		wrt & f			6.5			d	MR SCIE	HM 4.011		
	,	486 CL		C E VM	0.5			4	wr(41	PHET	0.5	
							155 PERCEPA					
	NG C1	PC1,					APPLES CLASS		AIC			
CHEUP	NG ()	CONCL	uri A f	71 44	1 455			12116 11	NTC VH ALPBLFA	476	AR SOIL	THRSHO
-	104	. cosci	2716	71 44	1 ANS	LURN	SPPLES (LASS UATS	#16 GL1		47F	AR SOLL	THR SMOI
20486 WP?	164		129	51 YY 44 3445	1 455	17U	SPPLES CLASS UATS EU /28	15116 H	WH ALPBLFA		/////	
SUVEE ANS	1111	. CDAC!	129	50 YY 2405 412	I ANS	170 170 1777	SPPLES CLASS UATS LB ICB ICB	19110 31 #16 6L1	VR ALPALFA C L J	152	113	2
SUVERANS CORN CATS	/64 / /// /// ///	. CD4C1 1 56.2 1 44.0 2 44.8 1 61.1	2716 129 2 57)+d5	I ANS	197 197	SPPLES CLASS LAFS LU 728 129 LC46	IPHIO HI RIC CLI A 1	VM ALPALFA C L J	152	113	0
SUPPLANS COM CAIS HEU CLYM	7641 7177 2775 1556 1216	. CD4C1 56.2 44.0 64.8 61.1	2216 129 51 6) 41.2) 41.2) 41.2	IANS	190 190 191 191	SPPLES CLASS LAFS LU /28 129 LC46 156	1F110 10 #10 Ct1 ** 1 218 #5 2C27	VN ALPALFA C L 7 4	152	115	0
HEEL CLYH ALI ALPA	7640 7670 2775 1556 1216 917	. CIMC! 1 56.2 1 44.0 1 44.0 1 61.1 1 62.5 1 10.8	2716 129 57 6	51 YY 2443 417 110	IANS	1797 . c7	10 (145) 10 (145) 10 (146) 10 (146) 10 (146)	15 (10)) #16 Ct1	VH ALPALPA C L 7 4	152	0 115	0 0
HEAT SUTBLANS CORM CATS HEU CLYH ALTALPA HEE	7646 7676 7175 1556 1256 417 621	. CIMCI 1 56.2 1 48.0 2 67.1 3 67.1 7 70.2	2216 129 51 6	St VV	I ANS	1797 . C7 . C7	APPLES CLASS UATS LU 728 129 1048 138 42	19110 11 #16 Ct1 	VM ALPALFA C L 7 4 11. **A6	152	0 0	0
HELAT SUVEENNS COMM CATS HELD CE VIN ALT ALPA ALT ALPA HEE HEE NOTE	7651 7171 7175 1556 1216 117	1 56.2 1 48.0 5 64.8 6 61.1 6 62.5 10.8 19.4	2716 129 57 6 	St VV	I ANS	1/9/ .c/ /6/	APPLES CLASS UM 15 10 104 104 104 104 105 107 107 107 107 107 107 107 107 107 107	19110 14 #16 Ct1 4 1 218 #5 2022 161	VM ALPALFA C L 7 4 11. 146 C	152	0 0	0
HEAT SUTBLANS CORM CATS HEU CLYH ALTALPA HEE	7641 717 1554 1554 117 117	1 56.2 1 48.0 5 64.8 6 61.1 6 62.5 10.8 19.4	2776 129 57 6	51 VV	I ANS	1/9/ .c/	IPPLES CLASS UATS LB /CB 129 ICAB 158 47	19110 31 #16 Cts 1 218 #5 2022	VR ALPALFA C L 7 115 146 C	152	0 0 0	0 0 0

Table B-7. Test Class Performance - Compression #1, Noise Level 1

	51	WIAL AU			171000	54(4		CE#2218	116-	CFC	0.1910	
							ARMILS USIE					
1 148	NE ()	. ***		BANU	1.52 1	c 0.55	#1CH(#111#	CAL	188411/M (C	06 • 1	(C = 1	1.00
(+ AA	MII .	581	IMAL	****	62 1	1	PICALMITE	. CAL	INDATICA CO	ot - 1		1.60
CHAN		.210	IMAL	PAND	5.12 1	1	# 1 C H C P + 1 E #	. CAL	INHALICA CO	DE - 1	(0 .)	1.00
CPAR	MLI Y	251.0		P456	0.60 1	1.00	* 1 CH(*1 1+R	CAR	1 M # 8 1 1 1 40 CC	Df • 1	Lu - 3	1.00
							((45/15					
		11 ASS	1	ACLE	(1001.5	PET			CLASS	GROUP	IMMES PO	1.
		St. THE AM		4 8 8 8 8 Y	6.	1			ALFALFA	ALFALF	G. 5	
		LE 44				5		1	476	**6	C.5	
	3	CATS	1. 4	15	See.)		8	50 54.12	an 1011	0.5	
	•	n+ + & f	-1	+ 41	u.	5		7	SPEAT IL	-	C.5	
	5	HEL CLY		C (FA	0.	•						
						11.11 (4)	135 PERFLAPE	INC t				
							•••••••					
	NC CF	2011					PPERS CLASS					
unt Al	SAMPS		WP-6 4		LYMIAN		C 14.5		TH ALFALFA	144	84 2011	THESHOL
SUVBEANS	71.71	34.9	///		5.1	i.	17	1	G	144	143	2
LUNN	2115	0.00	114		467	***	191		c	1007	110	
LAIS		04.6	1		14.8	1405	14/	144	23	5	0	C
KEE CEAN	1558	16.9	44		114	231	10-1	4.1	6	1 5	C	G
ALFALFA	3236	6/.0			,	140	163	1415	451	2	9	
***	0/1				1	16		711	011	G	0	6
DH 5611	132	10.0	10.1		4.3	i.	•	**	4	-01	•	u
		47.8									308	
TLIAL	14740		1100	•	404	. 494	1114	1116	1401	2410	571	14

Table B-8. Test Class Performance - Compression #2, Noise Level 1

5016 11/ VA.; 10 1
107AL 197AB 2073 4502

CYFRALL PERFORMANCE: 11/50/ 197ABJ - AR.S

AVERAGE PERFORMANCE BY CLASSE ALLA/ 81 - 20.7

Table B-9. Test Class Performance - Compression #3, Noise Level 1

		. 6	RIAL NU	M(1) H	121000	1416		CLASSI	FIEC-	14A 6	.1371	
i ç							ARRELS USEL					
		441 1	5.740		of e.52 to	0.55	#16 #G#6 F£#	5 (40	TORALLON C	GCI • 1		1.60
		ALL J	251.0		C C.A2 0	0.00	MICROMETER		IRRATION C			1.01
	1 14 44	MIL I	SP+		C 4.17 1	0.80	MICRIMETER		TURALIEN C			1.10
		MEL 4	. 216	Irac san	C	1.00	PECACHETER		INRATICS C			
							CEASSES					
			PLASS	SHEE	P (HR15	Pt. 1			LLAS	UNCLP	1141	
		1	SCYNEAR		4N5 C.			4.	ALFALFA	ALFALIA		
		1	GEAR	SCAN				,	***	HYF		
		1	GATS	LAIS	0.0				78.5011	PR 50 41	6.8	
		5	wet 41 1	-	44.			19	MEAT (1	HILL AT	15.0	
		5	sen ct v		LVR C.							
					!	F51 (14	SS PERFCHA	NCE				
		HO 04	261		AUPAF	R CE SA	IMPLES LLASS	SIFIEC 1	NTC .			
	CHOLP	SAPPS	ceaci	MEAT	SCYREAMS	LCHN	CATS	REG (L		***	PH 1131	THROME
ı	MME AT	2641	80.0	21.14	2.6	G	23	5	c	201	111	2
2	SETBEAKS	1111	50.1	120	1590	Sel	654	6	100	1781	16.4	
	COAN	2175	66.0	6	151	1832	166	140	20		7	i
	LAIS	1220	54.8	17	1 * 1	114	1616	100	140	4.1	1	
,	MED CLAM	1/16	01.1	6	19	100	127	1985	140	2		
,		912	44.5	· ·	k.	74	51	120		0	7	
	AL FALFA		11.5	110	1.0	o	ű.	3		400	Æ	- 1
	476	451										
		112	14.4			(4	:	5		, ,		14

Table B-10. Test Class Performance - Compression #4, Noise Level 1

AVERAGE PERFORMANCE BY CLASSE 659.97 81 . 82.5

Table B-11. Test Class Performance - Reference Data, Noise Level 2

	74.1	1141 NUP	8 t A	- (51100)	912		CL455111	f G -	DEC 10.	1410	
						ANNELY USEC					
UPAN	Mti t		THAL DANK	. 0.52.10	0.55	PICHEPETERS	CALI	UHAFICN CO	10t - I	CO . 11	.00
CHAN	NEL Z	SPIC		1 1.67 6	0.66	PICALPITERS	CALL	MRATICH CO	1 - 10	CU - 31	.00
1. F A&	HFL 5	5,811	THAL SANT	1 1.72 3		PICHEPFILES	CALL	MATTER LO	101 - 1	11	.00
LEAN		PFC	-	0.00 1	1.16	PICALPFIERS	CALI	BARTICH CO	DE - 1	CC . 31	.00
					121	CLASSES					
		CLASS	C#4(/#	THRES	PLI			CLASS	CHOUP	THRES PC	1
	1	SCYNE AN	STATE	NA 0.*	i.		6	ALFALFA	ALFALFA	0.5	
	¥.	L Carre	CLUN	u.*	6		1	ATE	446	0.5	
	3	LA15	LATS	d.			8	SA SCIL	6# 201L	0.5	
	5	BPIAL I	MIAT		i.		4	WHEAT IS	MHEAT	0.5	
	5	MED CLA	4 41 G 64	VR 0.5	Ç.						
					est cr	ASS PERFUMPA	MCI				
	NO UF	Pt. 1 .		MUMME	a of S	APPLES CLASS	IFIEL IN	rc			
CRUDP	SAMPS	CHILL	WHF & I	SCYPE ANS	CORN	CATS	MED CFA	ALPALTA	RVE	BR SOIL	THRSHUL
WHE AT	2641		1268	760	44	Los	1.8	2	293	515	a
	/1/1	14.1	1033	1197	1046	451	196	121	1799	0 5 6	o
PRABETY					1921	750	121	149	1 56	43	0
CUAN	2115	14.4	1 10	*15	1021						
	2775 1558	14.0	196	152	121	383	1.43	12	171	12	û
CLAN							141	15	171	12	9
GATS	1558	14.0	196	152	121	383		0.000000			
CLAN GATS REG. CLYR	1558	14.0	196	152	171	383	1 160	940	44	14	9
CLAN GATS REG CLVA ALIACPA	155H 1236 417	74.6 42.0 10.1	17	152 92 1	153	383 214	1 160 246	162	16	1.4	o c

Table B-12. Test Class Performance - Compression #1, Noise Level 2

2230

- CVERALL PERFORMANCE (YEAR) 192461 + 51.4 AVERAGE PERFORMANCE BY CLASSI 419.47 81 + 52.0

10

0 BE SOIL 132 74-4 TOTAL 19746

Table B-13. Test Class Performance - Compression #2, Noise Level 2

2176

1033

		5.8	STAL NO	unt a	151100	****		1.1.455.1	1166-	CEC 19.	1976	
						6.4	ARRES CSEC				0	
	CHAR	NEL I	SPC	IRAL BAN	n 0.52 10	. 0.55	PICHEPETER	(a)	LISHATION C	1 * 100	LC . 1	1.00
	CHAR	MEL /	1441	TABL BAN	10 0.64 10	U.66	PICHEPTIER		IBPATION C	:Cf - 1	16 . 11	1.00
	CHAR	NEL 1	SPEC	IRAL GAR	0 0.72 10	0.40	PICACRFIER	1.4	INHAFTIIN CO	04 - 1	.0 - 1	1.00
	LHAR	MEL "	vett	INAL DAN	n c.au i	1.00	PICHLPETER	. (4)	I BHAILCH I.	icre - 1	LC - 1	
							CLASSES					
			CLASS	G M C. C.	P THRES	FLI			(1455	CHOUP	INNES PO	1
		1	SLYREAP	S SCHIE	4N5 0.5	\$		6			0.5	
		1	CORN	CLAN	0.5	•		1	476	***	U.5	
		,	LATS	4415	0.5	•		ű		PR 5011	6.5	
		•	H-1 44 1	het al	u. ·	į.		14	MF141 11	MATE & I	0.5	
		3	HED CLY	A REC	4 WM 0.1							
						431 CL	ASS PERFORM	4C1				
			000		MUMBE	W OF 5	APPLES LLASS		NIC			
	CHUUP	SAMP'S	CONCI	uest & I	SCYRLANS	CURM	LAIS	*** **		ATE	34 5011	THE SHUL
	ME A I	1691	34.4	1204	100	15	120		4	291	> 16	i
2	LYSE ANS	1111	11.7	661	2271	1021	1091	1.4	•.	10 (0)	111	ı
	URN	2119	51.4	15	4/6	1476	147		54	40	۵	o o
	415	1:54	17.6	174	104	111	544	144	16	1 15	11	U
	IC CLVR	3236	50.5	H	4.1	408	254	1617	114			Q.
	L) ALFA	215	51.6	3		44	19	144	463	-2	u	o
	YL	441	. 1 . 1	141	4.3	11	5.1	1	C)	.44	47	Ü
11	A SUIL	112			1.7		:		5		104	
	ICTAL	14740		2611	1101	1514	. 500	/40m	1457	1901	1201	

Table B-14. Test Class Performance - Compression #3, Noise Level 2

AVERAGE PENPERMANCE BY CLASSE 355.77 41 + 44.5

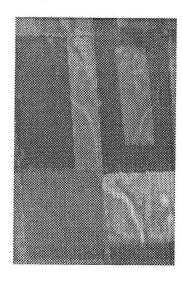
Table B-15. Test Class Performance - Compression #4, Noise Level 2

	,,	HIAL NU	P6(K-	1	07406540	1.5		CL#551	1110-	UG1 24	. 1410	
							AMPLS USE					
CHAP	shes s	SPE	CIRAL	8440 0	.57 10	0.55	*1C#1 #115					
LHAN		5 46	CIRAL				*16×6*111		INRAFION C			1.00
LHAN	MEL I	501	LIAAL				PICHEMITER	930	INPALLEN C			1.00
CHAR	MEL S	500	CINAL	DAND			FICALMITE		. IHRATION C . IBBAILON G		(0 - 1	
							(LASSES					
		CLASS	1.	RLUP	THRES PE				CLASS	CALLER	THRES P	
	1	LYSTA	NS 56	786 445	6.5				ALFALFA	ALFALFA	G.5	LI
	2	LUAN	C.L.	**	0.5			,	341	444	U.5	
	3	LATS	CA	ts.	0.5				84 5016	38 7017	0.5	
	•	HET AT	i hir		0.5				WHEAT II	west a f	0.5	
	•	REG CEN	M ME	C CTAN	0.5						9.9	
	NU_(1	26.1.	71 - 4040-000-00		NUMBER O	المرد لر	55 PERCURP		NIC			
GACUP	SAMAS	LUNCI	unf a l	l Ser	NUMBER O	المرد لر		 	NIC VM ALPALFA	MYE	sa soti	THRSHOL
	24442	41.8	4669	l Ser	NUMBER O	المرد لر	PPLIS CLAS	 		AYE	en satt	
MEE AT	594A2 5918 27370	41.8 71.6		l Ser	MURHER C	J SAI	PPLES CLAS	5.1 F 1 E D 1.	WH ALFALFA	200000		THRSHOU
SUYBEANS COAN	1915 27170 24445	/1.6 /1.6	4649 2618 14	l Ver	MURHER C	J SAI	PPERS CLASS	SIFEED I	VH ALFALFA C	131	1.4	6
SUYBEANS COAN GAIS*	27370 10515 5864	71.6 71.6 74.5	4669 2618	l (67 1941	MURHER C (I) ANS (1) (1) 7	35 3AI 38N - J	PPCFS CLASS GATS 55 1911	SIFEED II. HED CL	VM ALPALPA G 2	131	1 4	6 13 31
MEEAT SUYBEANS COAN OATS*	12147	/1.8 /1.6 /4.5 /4.5	4649 2018 11 49 12	1 - Sér 1943 70	MURHER OF THE PROPERTY OF THE	35 3 AI 38 N 3 U	PPEFS CLAS FAES 55 1911 126	SIFTED II HED CL U H	C	131 3174 16	1 d 3	1.3 31 5
METAL SUPPEANS COMM GAIS* HEL CLUM ALPALFA	5864 12147 1315	71.6 71.6 74.5	1669 2018 11	l Ver 1944 70 7	MURHE () () () () () () () () () (1 5 M	PPCFS CLAS (AFS 35 1913 326 5006	11FEED 1. WED CL U WED CL U	VM ALPALPA C 2 11	131 3174 16 19	1 d 3 0 0	31 31 31
HEEAT SUYBEANS COAN GAIS* HEE CLYR ACFALFA HYE	5485 5948 27370 10515 5864 12147 1375 2385	/1.8 /1.6 /4.5 /4.5	4649 2018 11 49 12	1 - Sér 1243 70 7	MURHE () () () () () () () () () (14 C E E E E E E E E E E E E E E E E E E	PPLES CLASS 1.415 55 1911 126 5006 209	SIFEED II WED CL U W TUMB TIV	C 2 11 40 2168	131 3174 10 29	1 d 3 0 0	13 31 37 13
METAL SUPPEANS COMM GAIS* HEL CLUM ALPALFA	5864 12147 1315	11.6 11.6 14.5 45.4 14.4	14 69 12 0	1 Sér 1243 75 7	MURRE 4 0 0 0 1 1 7 1 1 1 1 1 1 1 1 1 1 1 1 1 1	IAN U	PPLES CLASS SALS 35 1911 32b 3C0b 209 186	11F1E0 1: WED CL U B 1U+A 114 9094	C 2 1/ 40 2/168 AV	131 3174 10 19	1 d 3 0 0	31 31 31

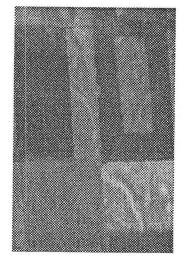
Table B-16. Test Class Performance - Reference Data, Full Sampling Rat

						4)	ARNELS USEC					
	LHAN	ntt i	5810	IRAL HAI	NII 0.52	10 0.55	FICHL#114H	5 CAL	IRRATION CO	00f - 1	(0 . 1	1.00
		A11 .	5211	TPAC HA	MI 0.4.	10 0.00	PICHIPFICP	S CAL	INRAFICM CO	DUE - 1		1.00
		4t	SPEC	-	ND 5-12	1C 4C	PICACPETER		IBRALICA CO			1.00
	- 144		·r) (IRAL MA	WI 0.40	16 1.60	MICHOMFIER	S CAL	INPATION CO	nne • 1		1.00
							CLASSES					
			CLASS	UNL	UP THRE	S PCT				GREUP	IHAES PE	
		1	CYNE AN	S SCYBE	ANS 0	. 1		162	ALFALIA	AL F &L F &	0.5	•
			LLBN	LORN	g	. 5		,	441	276	0.5	
		y	6415	CALS	a	. 3		н	8# NG11	88 201F	0.5	
			WELAT 1	AH! A!	1 0	. 5		.,	artaf fl	are at	0.5	
				H HEL C		. 5		••	artaf fl	urf & f	0.5	
						. 4	SS PERFORM		artaf []	urf 41	0.5	
		•	#ED CLY		.LV# 0	. 5	**********	anct.		arf41	0.5	
1,#0	ur				.LV# 0	1151 CLA	PERFORMI	ONCE SIFIED F				Inst Spila
1,HQ		•	#ED CLY	H #{L.	.L VP 0	1151 CLA	PPEES (LAS:	ONCE SIFIED F	NTC		on Still	
		SCHAS	PCCI	M MEL.	LVP 0	IFST CLA	PPEES (LAS:	ALC CE	NTC VN 4LPALFA	WYE		THE SHOLL
		NO CF	MED CLY	H MEL . KHEAI WASH	LVM 0 NUP! NUP! NUP!	IFST CLA BER DE SA VS CURN 21	PPCES (LASS	MCF MFTED F	NTC VR 4EPALFA C	MAE	ыя 5(1) (18	30
464 4 5078		10 CF 14885 5VIB 27110	ALD CLY	H HEL . KHEAT 4568 2005	NOPE AT LETES	IFST CLA HER DE SA NS CURN 21 810	#PEES (LAS: UATS 61 1951	MCF MFD CL	NTC VIR LEPALFA L 2	#YE Let	3# S(II)	30
SUTE COMM CALS	! ! #N\	\$6 (7 14#85 5918 27170 16515	CACI	M MEL C MHEAT MAGE 7005	NOPE SUYBEAN 31 18183	1151 CLA NER DE SA NS CURM 21 810 8709	PPEES (LAS: (IATS 61 1951 517	##CF ### ### ##########################	NTC VR REPARFA C 2 11	1et	BH Still IB 4 U	30 24 6
SUTE COMM CALS	I I ANS	NG C/ 1AMPS NVID 2/1/10 1G515	#ED CLY	H HEL (HHEAT 4568 1065 11	NUPT O	1151 CLA 1151 C	PPEES (LAS: UATS 61 1951 717	ALO CL	NTC VR 4EPALFA C 2 11 12	#YE LE! +11/	ын 5(18), 18 4 О	30 3 24
SUTE COMM CAIN MEC.	I I ANS	NE (/) 14PPS NVIB 2/1/10 16515 2864 1/14/	#ED CLY	H HEL . KHEAT YSSB /C85 IL 85	NOPE AS SELECTION OF ASSESSED AS SELECTION OF AS SELECTION OF ASSESSED	1151 CLA NER DE 54 NS CURM 21 810 8709 191	PPEES (LAS: UATS 61 1951 717 4975	SIFIED F HED CL 	NTC VR GEPALFA C 2 11 12 2245	#VE Let VII / Co	BW Stiff IB 4 U G	30 24 6
SUTE COMM CAIN MEC I	I EANS LLVA	NE (7) 14PPS NVID 27110 16515 5864 17147	#10 CLY	WHEAT 4758 / / / / / / / / / / / / / / / / / / /	NOPE AS	1151 CLA 1151 C	PPEES (LASS (AFS) (AFS) (AFS) (AFS) (AFS) (AFS)	SIFIED F	NTC VR 4EPALFA C 7 11 12 2224 2349	#VE 1ei **!/ **	BW Stiff IB 4 G G G	30 24 6 81 74

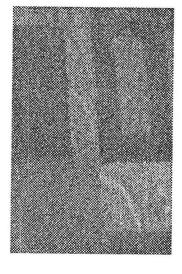
Table B-17. Test Class Performance - Compression #1, Full Sampling Rate



Original Data 97.7%



Low Noise 74.7%



High Noise 95%



Higher Nove but Noise Correlated from channel to channel

From Warid Leadgrebe