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FIRE RESEARCH REPORT NO. 9/75

ESTIMATING THE MAXIMUM DEMAND FOR WATER AT A FIRE

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SUMMARY AND CONCLUSIONS

The object of this study is to derive an estimate of the amount of water which should be provided for firefighting.

Water supplies are provided for fires which may occur in the future. These future fires are uncertain events and the water requirements can only be expressed in probabilistic terms. The most convenient way of representing the probability of requiring a given amount of water is to use a frequency distribution or a cumulative distribution of the required number of jets.

The likely water requirements will vary with the type of building, and figure 3 shows the number of jets required for fires in buildings of different types and occupancies.

Water supplies can be planned by taking into account either the requirements for individual fires or the requirements for the worst fire among all the fires which may occur in the area served by the same water supply. The other factor which must be considered is the probability of the water supply being sufficient. It is impossible to provide a supply which is certain to cover any eventuality. All that can be done is to ensure that there is a high probability of the capacity being sufficient. Figure 5 can be used to determine the number of jets which would be sufficient, with any given degree of probability, for either individual fires or the worst of a sample of fires.

By making a number of simplifying assumptions it is possible to convert the required number of jets to the required flow rate of water (Figure 6).

CONTENTS

ESTIMATING THE MAXIMUM DEMAND FOR WATER AT A FIRE

1. INTRODUCTION

With the exception of special hazards and very small fires, most fires attended by the brigades are extinguished by the application of water. The relatively small amount of water (up to about 400 gallons or 1800 litres) carried in fire appliances is sufficient for the extinction of about 80% of fires in buildings. The 1972 fire statistics show that about 40% of the fires in buildings were extinguished using hose reel jets and a further 40% using other small means, including chemical extinguishers.

If the fire is large however, or if fire fighting is prolonged, additional water supplies must be procured. Water is usually obtained from the mains supply accessed by a fire hydrant. If a mains supply is unavailable or inadequate then additional water will be obtained from sources such as rivers, canals, ponds or perhaps a water relay from a distant main. The need to obtain water from distant sources imposes an additional load on men and equipment that might otherwise be used for firefighting.

In this study we have attempted to estimate the maximum demand for water at a fire in a given occupancy and building type. At the outset it should be made quite clear that we are not trying to prescribe how much water should be used at a fire of any given type. We have merely used the records of how much water was used at fires of different types, in order to estimate the maximum amount of water which may be used at that type of fire. In practice the amount of water which was used at the fires for which we have fire reports will depend not only on the fire size and situation, but also on the judgements and decisions made by the officer in charge of the firefighting, and on the amount of water that was actually available at the time.

One of the most important factors determining the water requirement at a fire is the size of the fire. The relationship between the number of jets used and the fire size has been the subject of a number of investigations (References 1, 2, 3). The relationship between the size of fire and the number of jets required would be relevant to estimating the water requirements at a particular fire of known size. In this study we have taken a different approach, and considered only the effect of the building type, building size and occupancy. The results derived from this study are therefore relevant when considering what water supplies may be required in a particular building for any fire which may occur in that building in the future.

2. A MEASURE OF THE AMOUNT OF WATER USED

Useful measures of the water used at a fire might be the maximum discharge rate, the maximum number of jets in use at any time, or the total volume of water used. In choosing a measure we are however limited to the information provided on the standard fire reports.

There are two possible sources of data:- the K433 fire reports and the SAF2 fire reports. The K433 fire report defines the building type and contains a record of the number of jets used or the number of jets plus hosereels used. If the number of jets, or jets plus hosereels, is more than 8, this is coded as "8 or more" when the K433 data is transferred to computer files. The advantage of the K433 records is that a very large sample size can be used.

The SAF2 data was collected in a special exercise in 1970 and 1971 and about half the brigades completed the SAF2 data form in addition to the K433 report. The SAF2 form includes a record of the number of jets of each nozzle size used, but there is a far smaller sample of SAF2 records available.

In this study we have chosen to use the K433 data in order to get the largest possible sample size, and have therefore used "number of jets" as a measure of water used at a fire. The more detailed SAF2 data has then been used to find the average flow rate of water provided by a given number of jets. The method of translating number of jets used to amount of water used is described in section 6 of this report.

3. A STATISTICAL DESCRIPTION OF THE AMOUNT OF WATER USED.

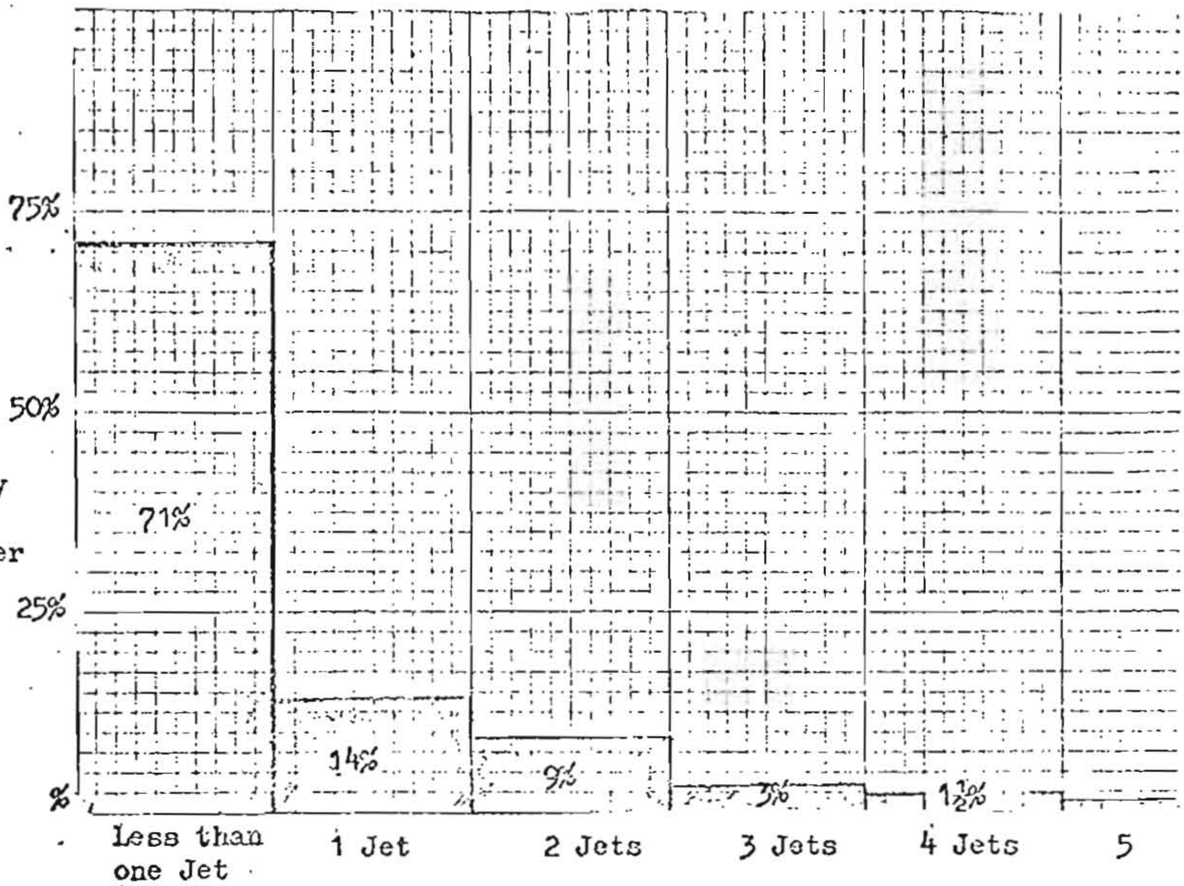
Even for fires in a closely defined group of buildings of the same size, construction and

contents there will be differences in the number of jets used because of the differences in the size of the fire, location of the fire and the intensity of the fire. The number of jets used in fires in this type of building can be represented by a frequency distribution or histogram. Figure 1 shows a typical distribution of the number of jets used. In this example 71% of the fires are extinguished by hose reels or other small means, 14% are extinguished by one jet, 9% by two jets, 3% by three jets etc.

FIG. 1.

Histogram of No. of Jets used

Probability of using a given number of Jets

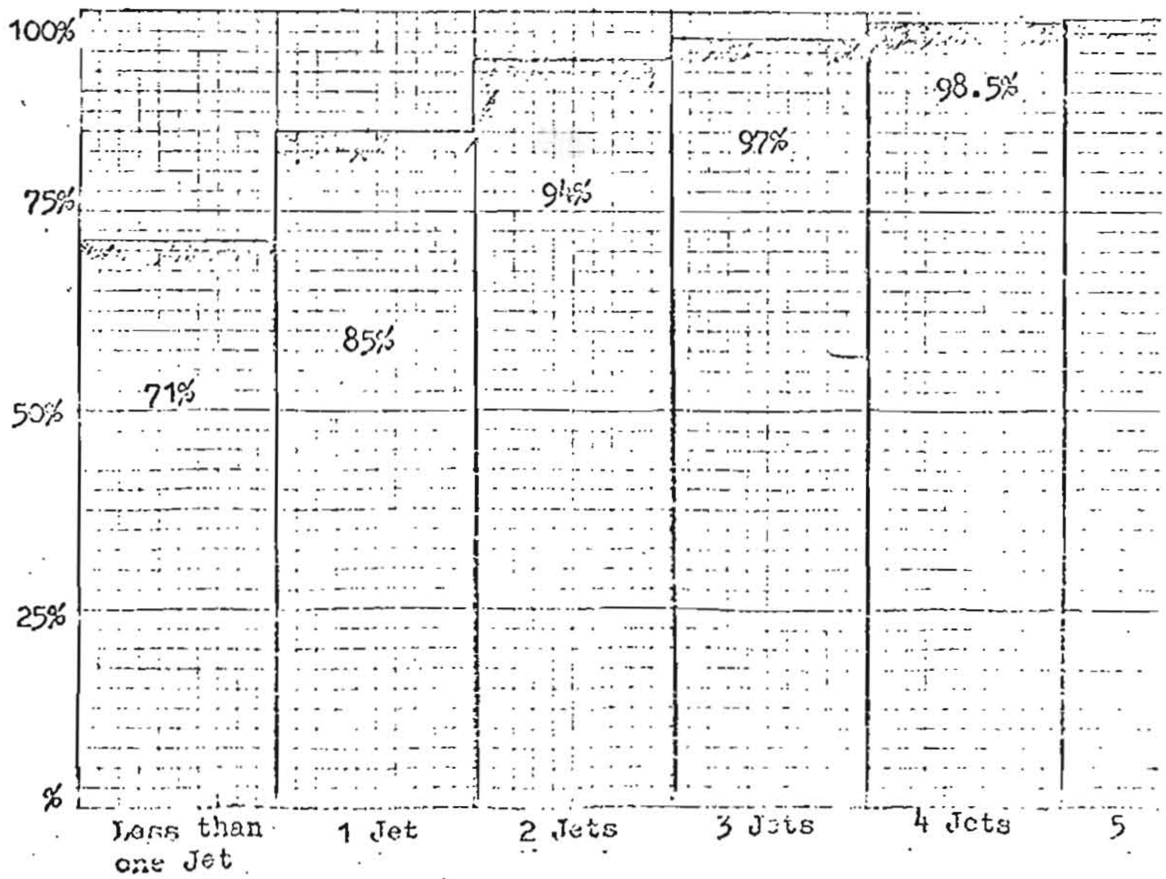


An alternative representation of the number of jets used is the cumulative frequency distribution, shown in figure 2 below. The cumulative distribution can be obtained from the histogram, and indicates the proportion of fires that can be extinguished by N jets or less.

FIG. 2.

Cumulative Distribution

Probability in a given number of Jets being sufficient



Provided that the data used in constructing the frequency distribution is derived from a large representative sample, the information can be given a probability interpretation. From the cumulative distribution in figure 2 we could make statements such as "97% of fires in this group are extinguished by 3 jets or less" or an equivalent statement "Only 3% of fires in this group will require more than 3 jets".

4. CLASSIFICATION OF THE RESULTS

The frequency distributions of numbers of jets used are obtained by aggregating the sample data (the K433 records) into similar groups. The building types in each group should be similar with respect to the likely fire size and the typical fire fighting conditions.

In this analysis the basic groups have been defined in terms of the following factors.

Building Size -
- i Ground floor dimensions less than 4,000 ft^2
- ii Ground floor dimensions 4000 - 10,000 ft^2
- iii Ground floor dimensions greater than 10,000 ft^2

Number of storeys
- i Single storey
- ii Multi storey

Use of building - As defined by building regulations sub-group and/or standard industrial classification (S.I.C.) (References 4).

Other relevant factors such as degree of compartmentation within the building or amount of separation from other buildings have not been considered as this information is not available on the K433 fire report.

The frequency distributions of number of jets used for this basic classification of building type are summarised in Figure 3. Figure 3 shows two representative points from the frequency distributions - the proportion of fires extinguished by one jet or less and the proportion of fires requiring four jets or more. From this graph it can be seen that certain groups - for example small private houses, and flats and maisonettes - are similar with respect to the demand for water. By combining the basic groups which are "clustered" together we can obtain larger groups and hence more reliable frequency distributions.

The final groupings, and the frequency distributions of the number of jets used for each of the final groups, are shown in table 1.

The summary information in figure 3 also provides a simple means of identifying those groups of buildings which have a higher than average probability of requiring four or more jets, and those groups of buildings where there is a higher probability of one jet being sufficient.

The frequency distributions for all the basic groups are derived from the 1971, 1972 and 1973 K433 records. These records include some instances where the fire spread beyond the building of origin. In these cases the fire is still recorded as a single fire according to the building type in which the fire originated, and the number of jets includes those jets used in all the buildings involved in the fire.

The K433 records do not provide detailed information where more than 8 jets were used. To get this more detailed information we need to refer to the SAFA data, which is a far smaller sample. Because of the small sample size, and particularly the very small number of fires requiring eight or more jets it is not possible to include the detail for more than eight jets in the frequency distributions for each building type. However by combining all the non-dwelling groups we can obtain a frequency distribution for 1 to 20 jets. These detailed frequency distribution are shown in table 2.

5. INTERPRETATION OF THE RESULTS

5.1 The Water Requirements for a Particular Building

The probability of requiring any given number of jets in a particular building type is shown in table 1. The probabilities from those frequency distributions can also be used to construct cumulative frequency distributions to answer questions of the form "what is the probability that four jets (or any given number of jets) will be sufficient for a fire in this particular type of building?".

However when using these results the following limitations must be borne in mind:

1. These results are derived from observations of brigade practice, and they are not a prescription of the number of jets that should be used.

2. These results are derived from the 1971, 1972 and 1973 K433 records, and no allowance has been made for any time trend in the type of fire or method of fire fighting.

3. These results describe the water requirements for a typical building within a fairly broad group. These frequency distributions may not be representative of any exceptional or special risk buildings. Any exceptional buildings must be considered as special cases and the water requirements estimated by reference to the maximum fire size that might occur in the particular situation in that building.

4. There is a fairly small sample in some of the building groups and the results may be subject to small sample variation. This is particularly true for the probabilities associated with large number of jets, because there are so few records of these fires.

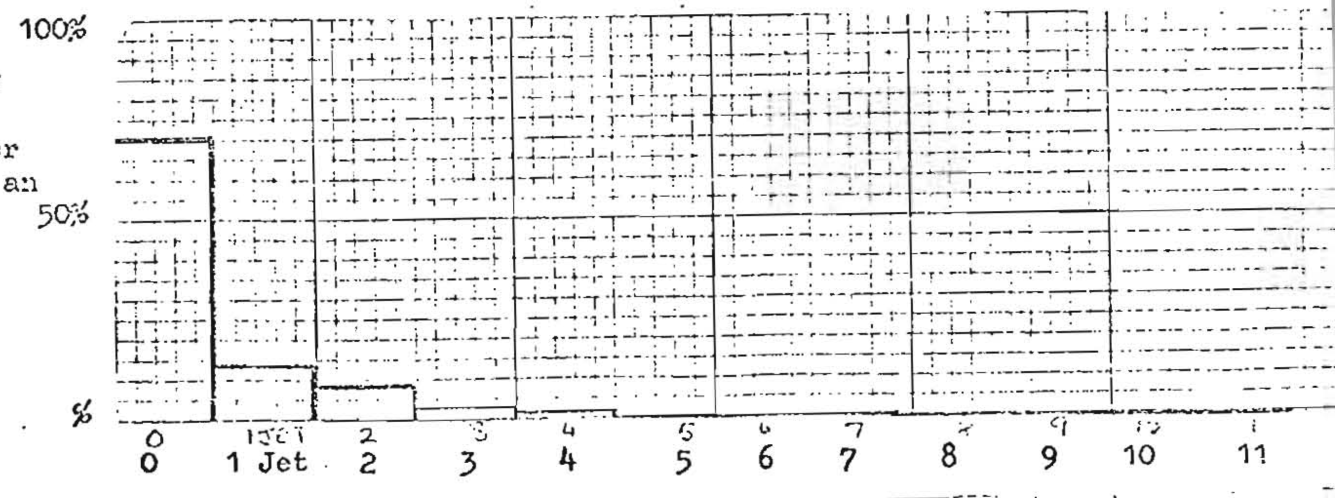
5.2. The Water Requirements for a group of buildings

The frequency distribution of water requirements for an individual fire can be used to estimate the water requirements for any specific building. However any water main, or system of mains, will serve a number of buildings and should be sufficient to provide the water required for a fire which may occur in any of the buildings served by that main. If we look at the problem from the point of view of a group of buildings then the relevant factor would be the largest fire which might occur in the group of buildings. It is possible to derive the distribution of the maximum water requirement in a sample of fires from a knowledge of the distribution of the water requirements at each individual fire. The statistical theory used in this estimation is described in the Appendix.

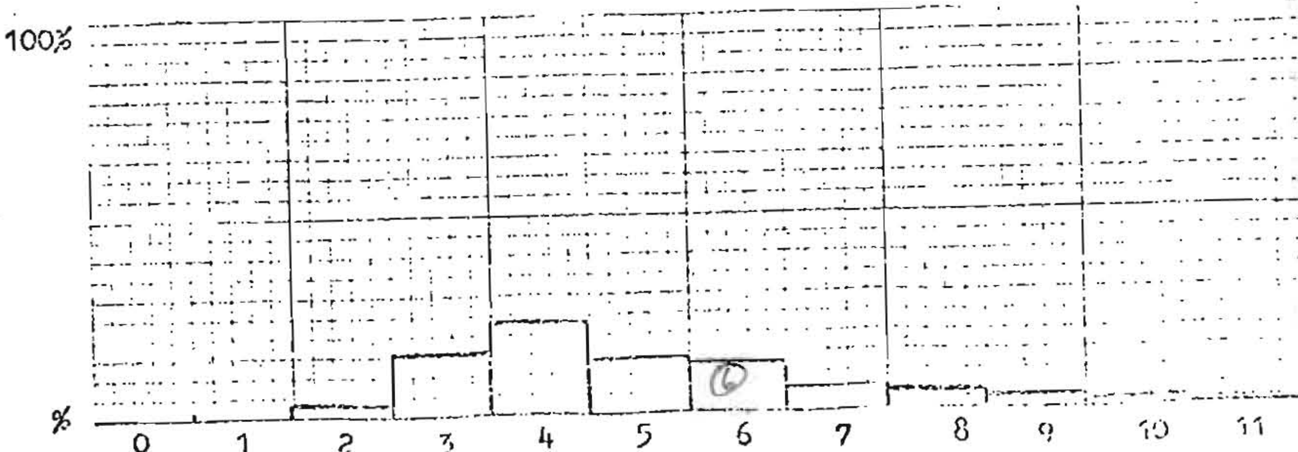
The larger the sample of fires that is considered the higher the chance that a very large fire will occur somewhere in the sample. This is shown in Figure 4 below where the frequency distribution of water requirements at a single fire is compared with the distribution of the maximum water requirements from samples of 50 and 100 fires. The distribution of the maximum water requirements merely represents the probability that the largest number of jets used will be of some given value. It does not give any indication of which of the fires in the sample will be the largest, or what the water requirements will be for fires other than the largest.

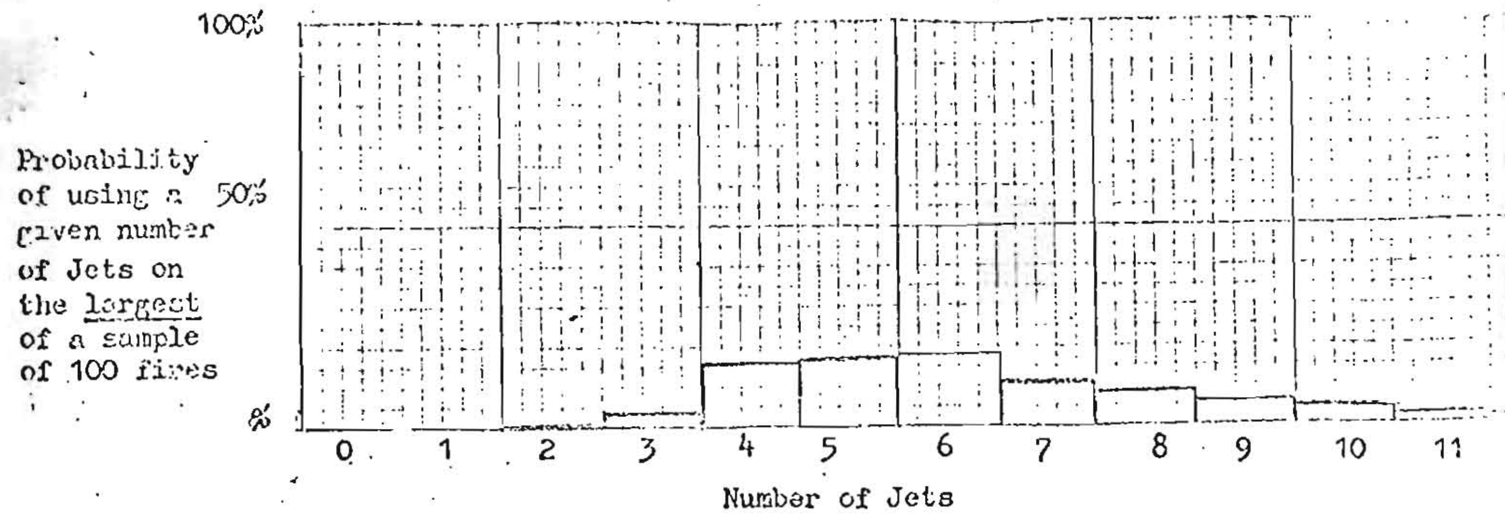
FIG. 4.

Probability of using a given number of Jets on an individual fire



Probability of using a given number of Jets on the largest of a sample of 50 fires





The frequency distribution of the maximum water requirements can be expressed as a cumulative distribution. The cumulative distribution describes the probability that a given number of jets will be sufficient for the largest fire in the sample, and therefore sufficient for every fire in the sample.

In order to use the concept of the maximum water requirements a risk level (R) and a sample size (N) must be chosen. The sample size should be the number of fires expected in some future time period in an area served by a system of mains. The cumulative distribution of the maximum water requirements can then be used to determine the capacity of the main required such that there is an R% probability that none of the N fires will require more water than is available. Figures 5a, b, c, d show the water requirements for various risk levels and sample sizes for fires in a, a typical mix of buildings b, a commercial area (offices and shops) c, an industrial area (industry and storage) and d, a typical non residential area (industry, storage and commercial).

The average size of the largest likely fire is not a valid statistic for the planning of water supplies. The water supplies should be sufficient to cope with the largest fire which is likely to occur and not merely sufficient for an average fire. Because the majority of fires are small the average water requirements would be low and might be a very misleading statistic if used for planning purposes.

When using the statistics relating to the maximum water requirements the following points should be noted.

1. The number of jets required at any given risk level will depend on the sample size, and the sample size is a somewhat arbitrary concept. If, say, a twenty year view is taken rather than a ten year view the calculated sample size will be larger and hence a larger capacity main will be indicated.

2. The sample size used in calculating the maximum water requirements is the expected number of fires, not the number of buildings.

3. The statistic derived from the cumulative distribution is the probability that N jets will be sufficient for all the fires in the sample. It does not indicate where the largest fire will occur or what risks are associated with any specific building.

4. The maximum water requirement in a sample of fires may be very much larger than the water requirements in the majority of fires in the sample.

5. The maximum water requirements in Figure 5 are calculated for broadly defined groups of typical buildings. The results may not be valid for buildings where the fires may be exceptionally severe.

6. THE RELATIONSHIP BETWEEN NUMBER OF JETS USED AND THE WATER SUPPLY

The analysis so far has been in terms of the number of jets used, but the more relevant factor for planning purposes is the amount of water actually required.
There are however difficulties in doing this conversion. It is difficult to estimate the

discharge rate from a given number of jets because the jets may be of different nozzle sizes or may be variable jets operated at some unknown discharge rate. Even for a fixed nozzle size the discharge will depend on the water pressure available. We can only convert number of jets to water supplies by making use of a number of simplifying assumptions.

The jets of fixed nozzle sizes must be assumed to be operating at the pressures recommended in the Manual of Firemanship /Reference 5/, although these recommended discharge rates may not be achieved in practice. 35% of the jets recorded in the 1970 SAF2 sample were variable jets and the estimate of water requirements is therefore strongly dependent on the assumed discharge from the variable jets. We have assumed an average discharge of 10 litres/sec (130 gals/mm) for these variable jets. Using these assumptions together with the SAF2 records of the total number of jets used, and the number of jets of each nozzle size used we can derive an estimate of the average discharge rate for a given number of jets. This relationship is shown in Figure 6. Figure 6 also shows the relationship between the median number of jets and the fire size. The fire size/number of jets relationship is the average for all non dwelling building fires (Reference 3). The median number of jets is the number of jets exceeded by 50% of the fires (ie if the median is J, 50% of the fires require more than J jets, and 50% require less than J jets).

We can make no estimate of the size of water main required to provide any given discharge rate, since the flow obtainable is very dependent on local conditions. The flow will depend not only on the size of the water main, but also on the distance from the pumping station, the pressure at which the main is operating, and the age and condition of the main.

References

1. THOMAS P H — Use of Water in the Extinction of Large Fires. Inst. Fire Eng. Quarterly. 19 (35) p. 130. 1959.

2. BALDWIN R — The Use of Water in the Extinction of Fires by Brigades J.F.R.O. Fire Research Note. No. 803 March 1970

3. BARNES R J — The Use of Water in the Extinction of Large Fires Home Office Scientific Advisory Branch. Fire Research Report No. 5/74 1974.

4. Standard Industrial Classification. Central Statistical Office. HMSO London 1968.

5. Manual of Firemanship Part 3: Hydraulics and Water Supplies HMSO 1972.

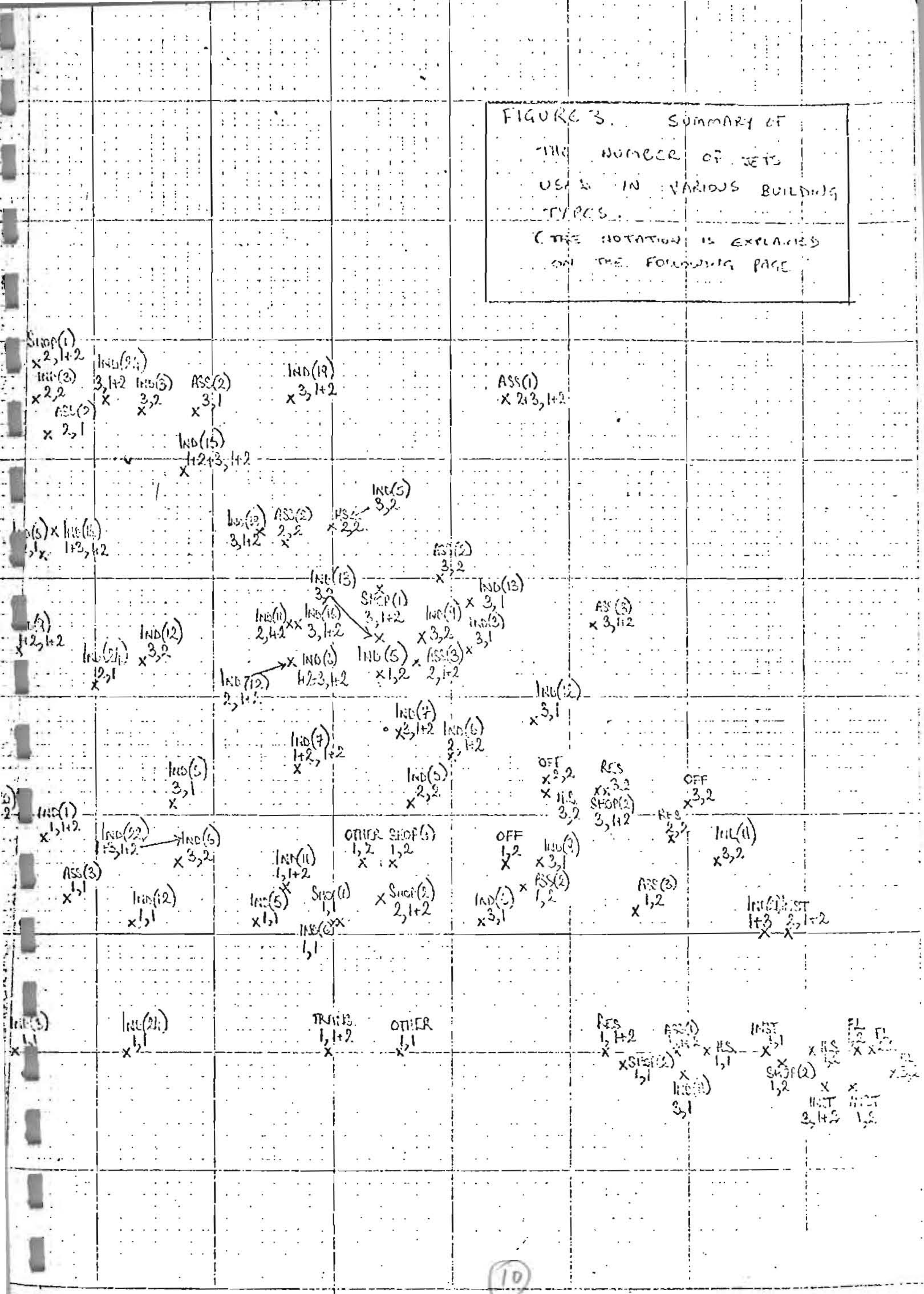
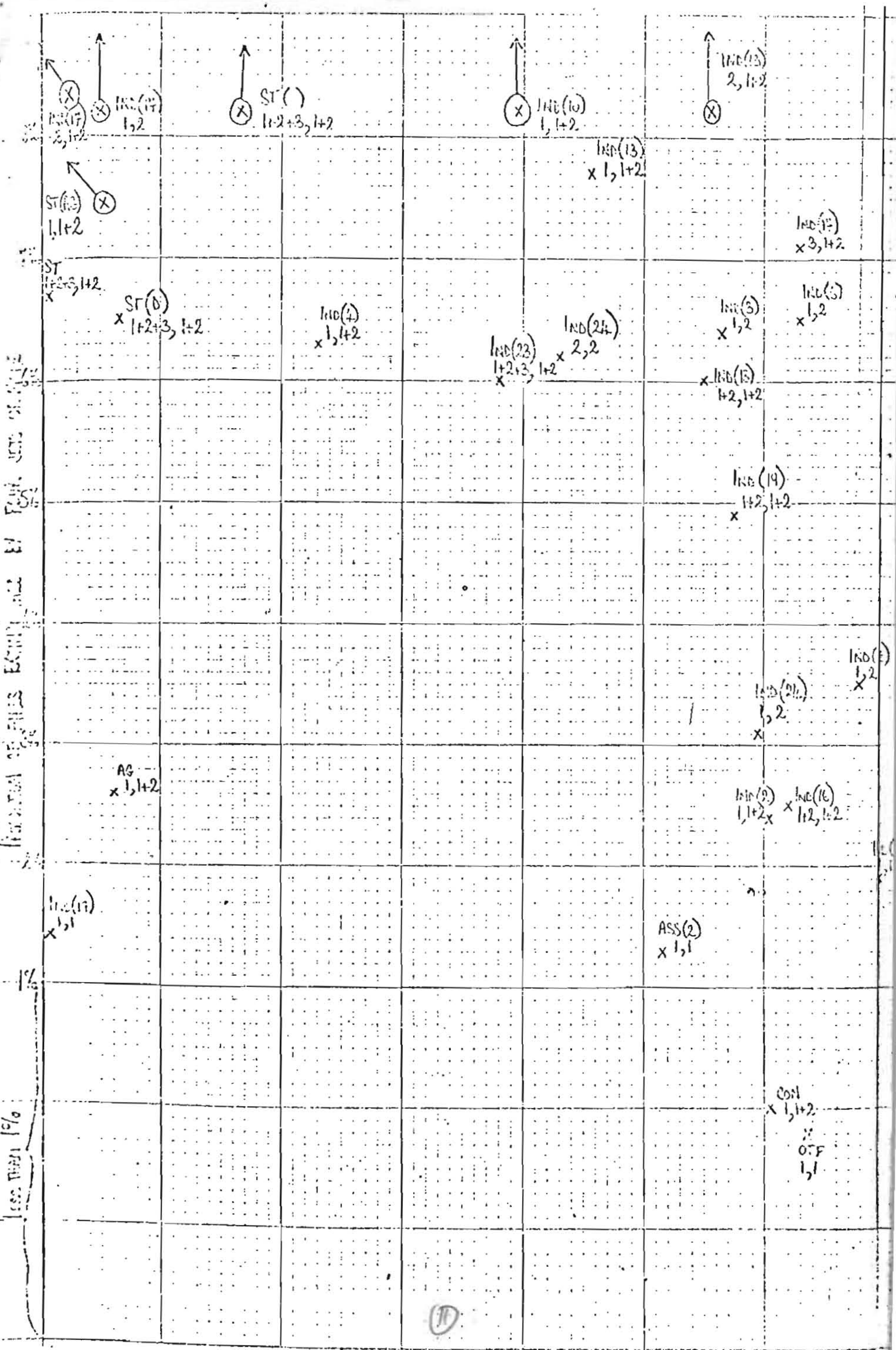


FIGURE 3. SUMMARY OF THE NUMBER OF JETS USED IN VARIOUS BUILDING TYPES. (THE NOTATION IS EXPLAINED ON THE FOLLOWING PAGE)



IND(17)
1,2
ST()
1+2+3, 1+2
IND(10)
1, 1+2
IND(13)
2, 1+2
IND(13)
1, 1+2
ST
1, 1+2
IND(17)
3, 1+2
ST(0)
1+2+3, 1+2
IND(4)
1, 1+2
IND(24)
2, 2
IND(23)
1+2+3, 1+2
IND(3)
1, 2
IND(19)
1+2, 1+2
IND(24)
1, 2
AG
1, 1+2
IND(16)
1+2, 1+2
IND(17)
1, 1
ASS(2)
1, 1
1%
CON
1, 1+2
OTF
1, 1
Less than 1%
5%

the building ground floor dimensions and the number of storeys. The notation used is ABB where ABB is an abbreviated group description, N1 is the building size and N2 is the number of storeys.

List of Abbreviations

	Building Regulations	S I C
HS	Private Houses	-
FL	Flats or Maisonettes	-
AG	Not industrial or storage	(Agricultural
CON	"	(Construction
TRANS	"	(Transport
OTHER	"	(Remaining SIC groups
SHOP (1)	Shops	Distributive Trades
SHOP (2)	Shops	Miscellaneous Service
OFF	Offices	-
ASS (1)	Places of Assembly - Group 1	-
ASS (2)	" - Group 2	-
ASS (3)	" - Group 3	-
IND (I)	Industrial	SIC Group 1 - 23
IND (24)	"	SIC group 24 - 27
ST (AG)	Storage	(Agricultural
ST (D)	"	(Distributive Trades
ST (T)	"	(Transport
ST	"	Remaining SIC groups
RES	Residential	-
INST	Residential Institutional	-

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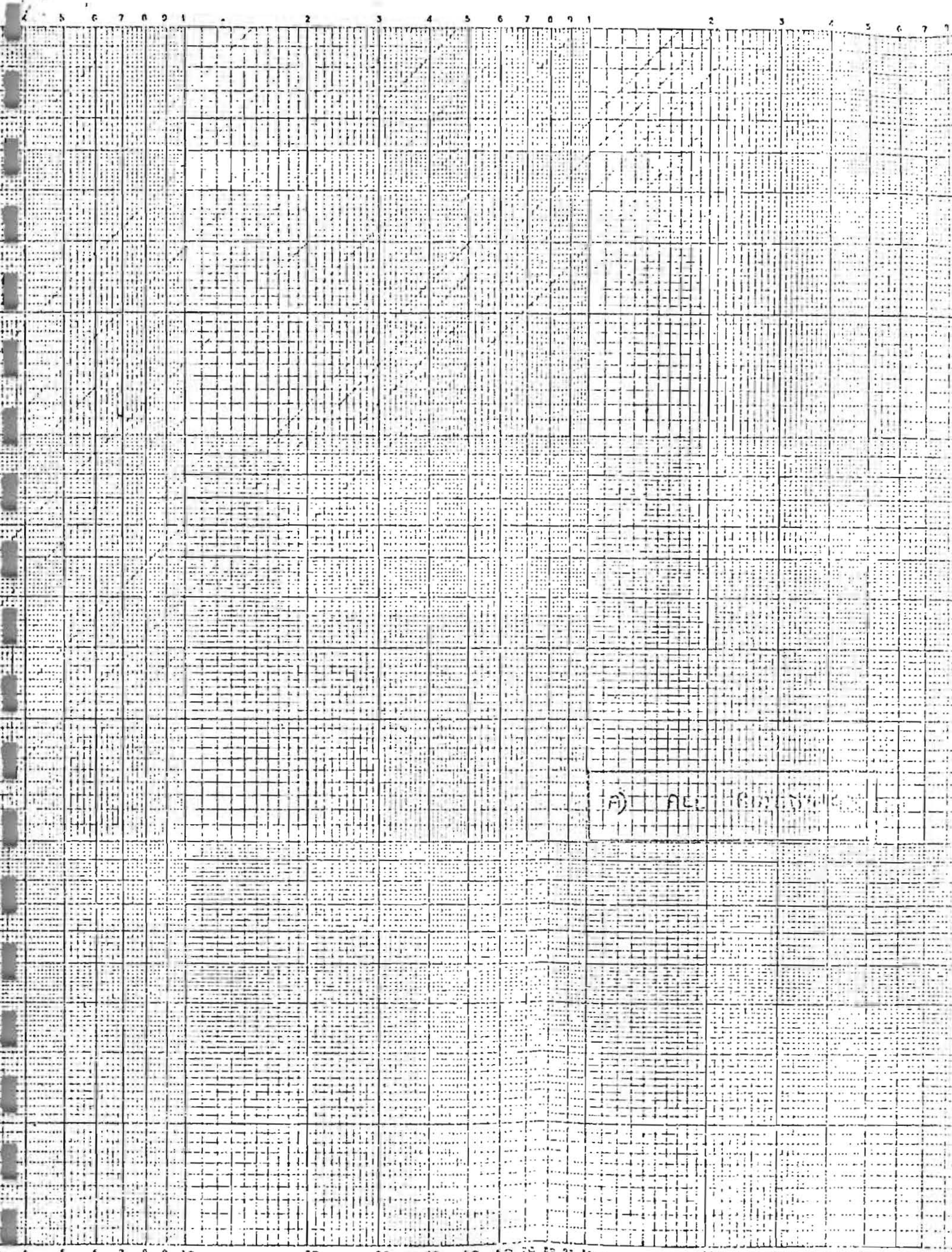
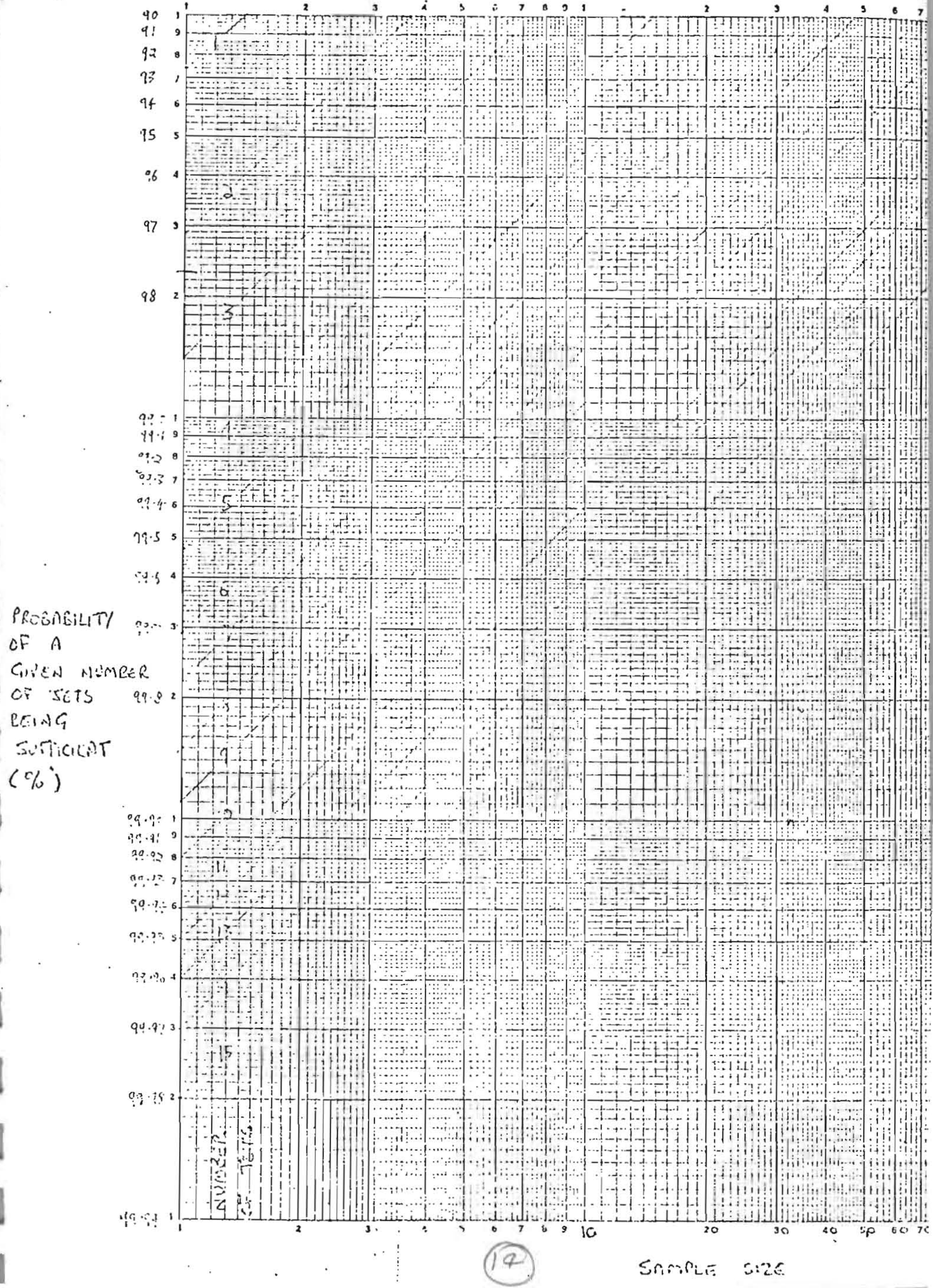
MBER OF JETS REQUIRED FOR VARIOUS SAMPLE
ZES AND RISK LEVELS.



SAMPLE SIZE

FIGURE 5a NUMBER OF SETS REQUIRED FOR VARIOUS SIZES AND RISK LEVELS.



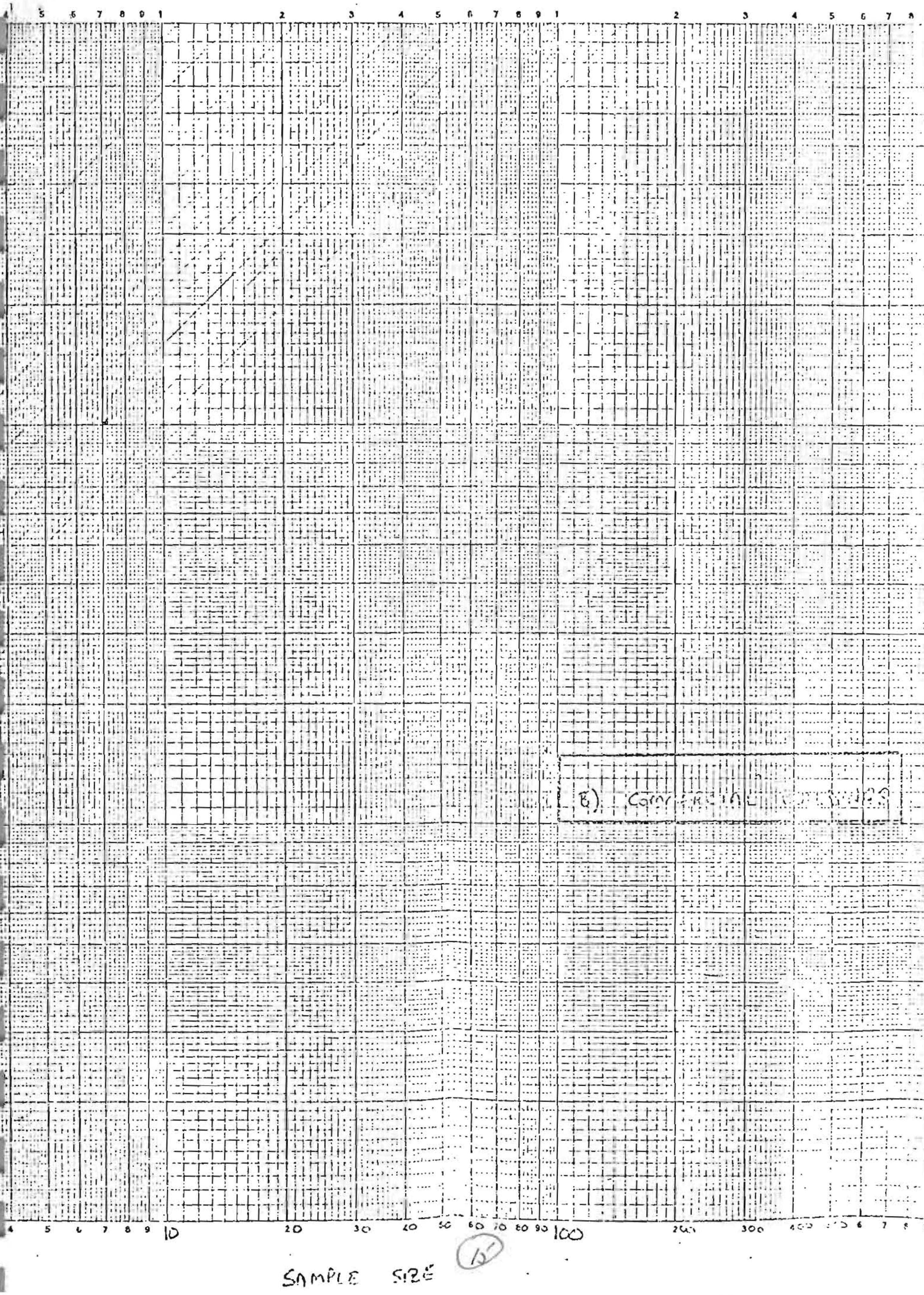
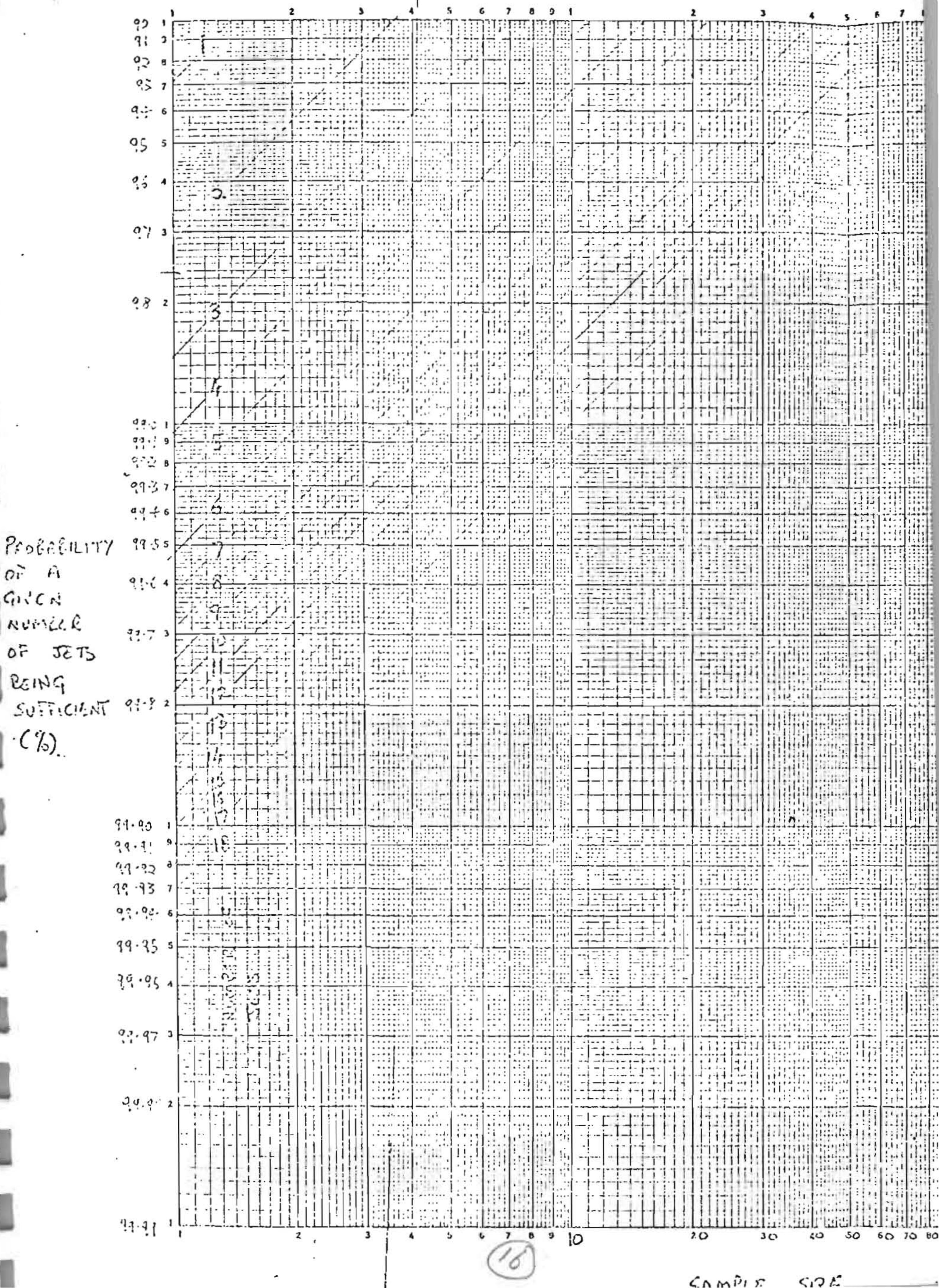

4 5 6 7 8 9 10 20 30 40 50 60 70 80 90 100 200 300
B)
SAMPLE SIZE

FIGURE 5b.


PROBABILITY OF A GIVEN NUMBER OF JETS BEING SUFFICIENT (%)
SAMPLE SIZE

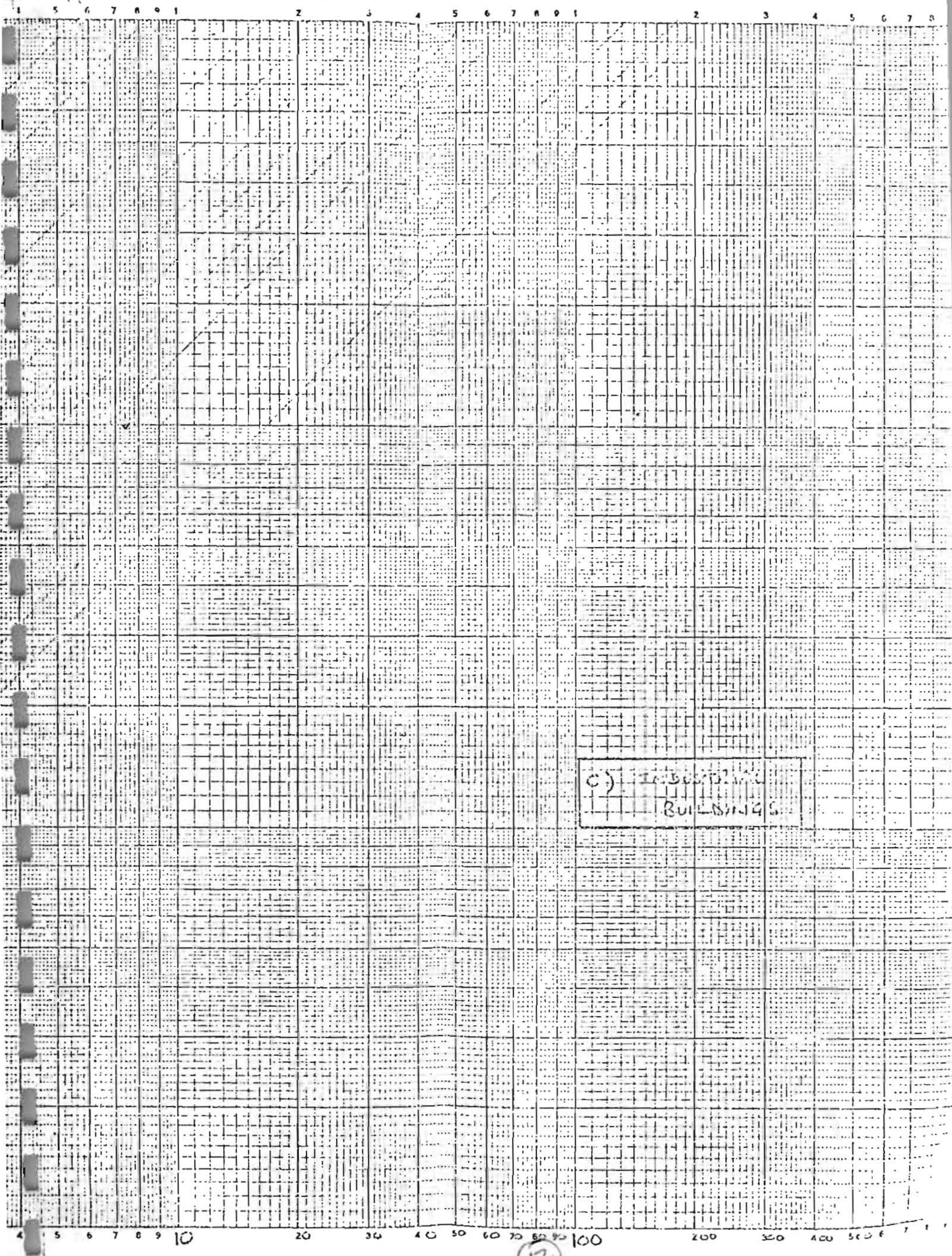
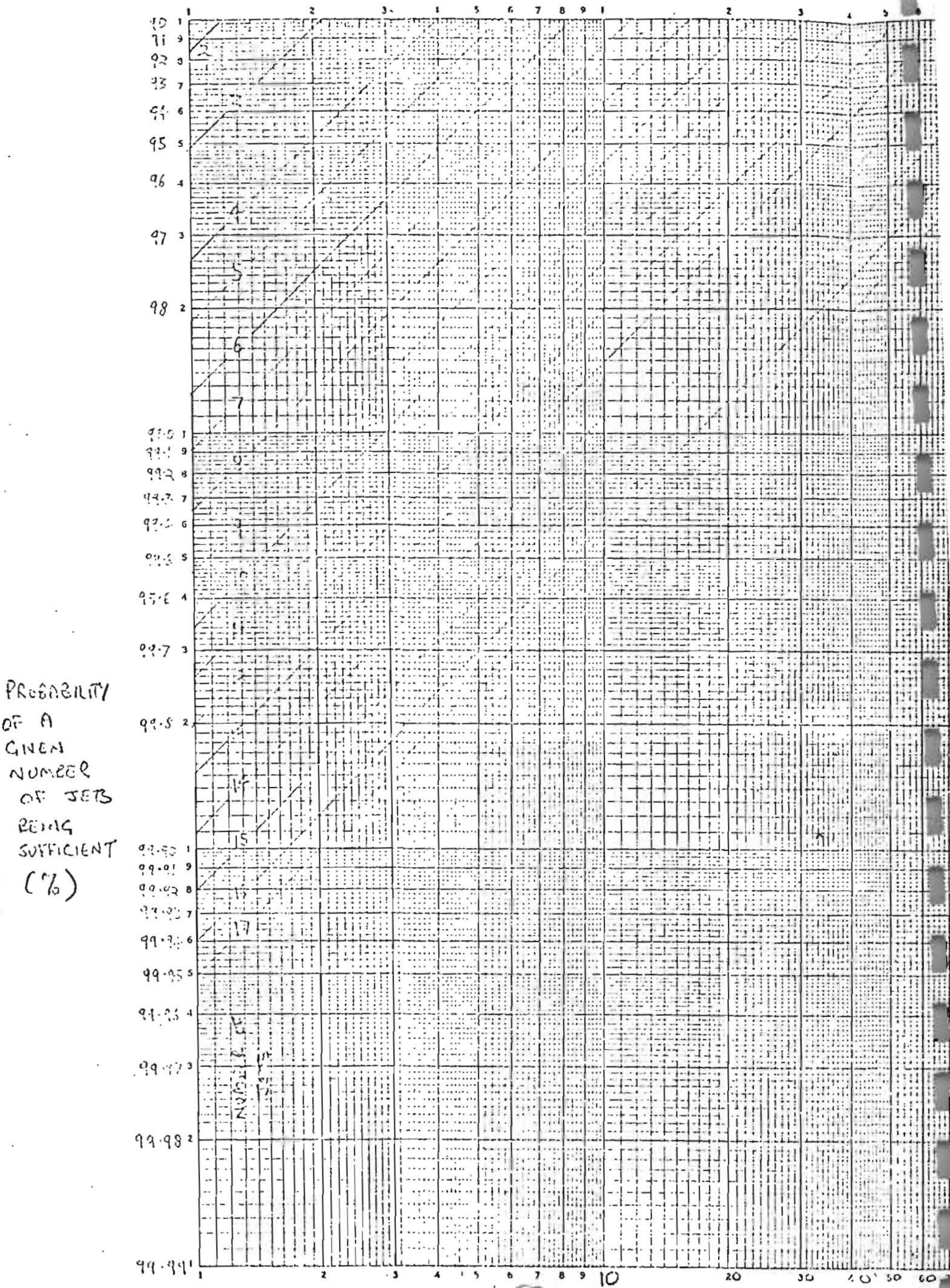

C)
BUILDINGS
4 5 6 7 8 9 10 20 30 40 50 60 70 80 90 100 200 300 400 500
SAMPLE SIZE

FIGURE 5c


PROBABILITY OF A GIVEN NUMBER OF JETS BEING SUFFICIENT (%)
95
97
98
99.98
10
20
30
60

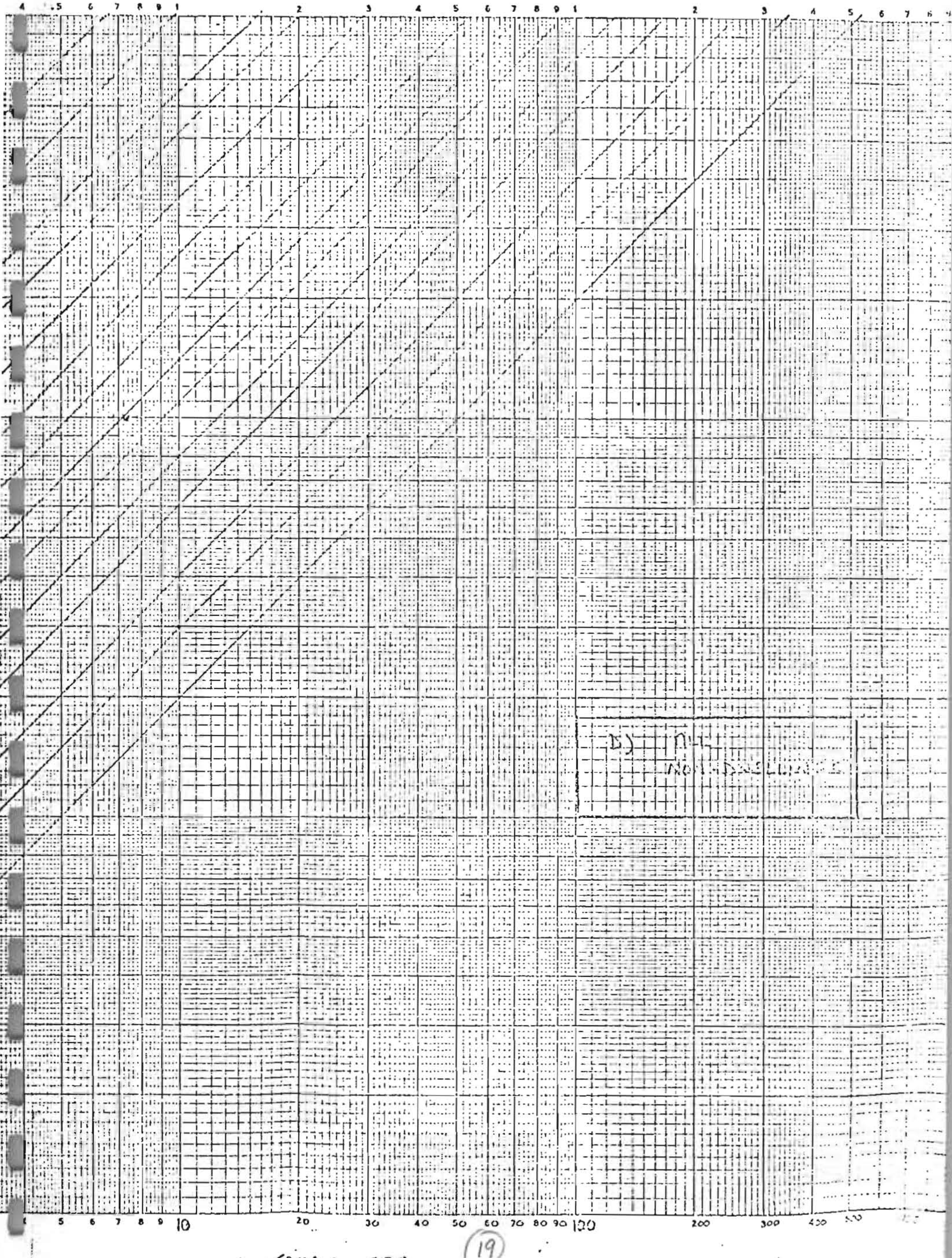
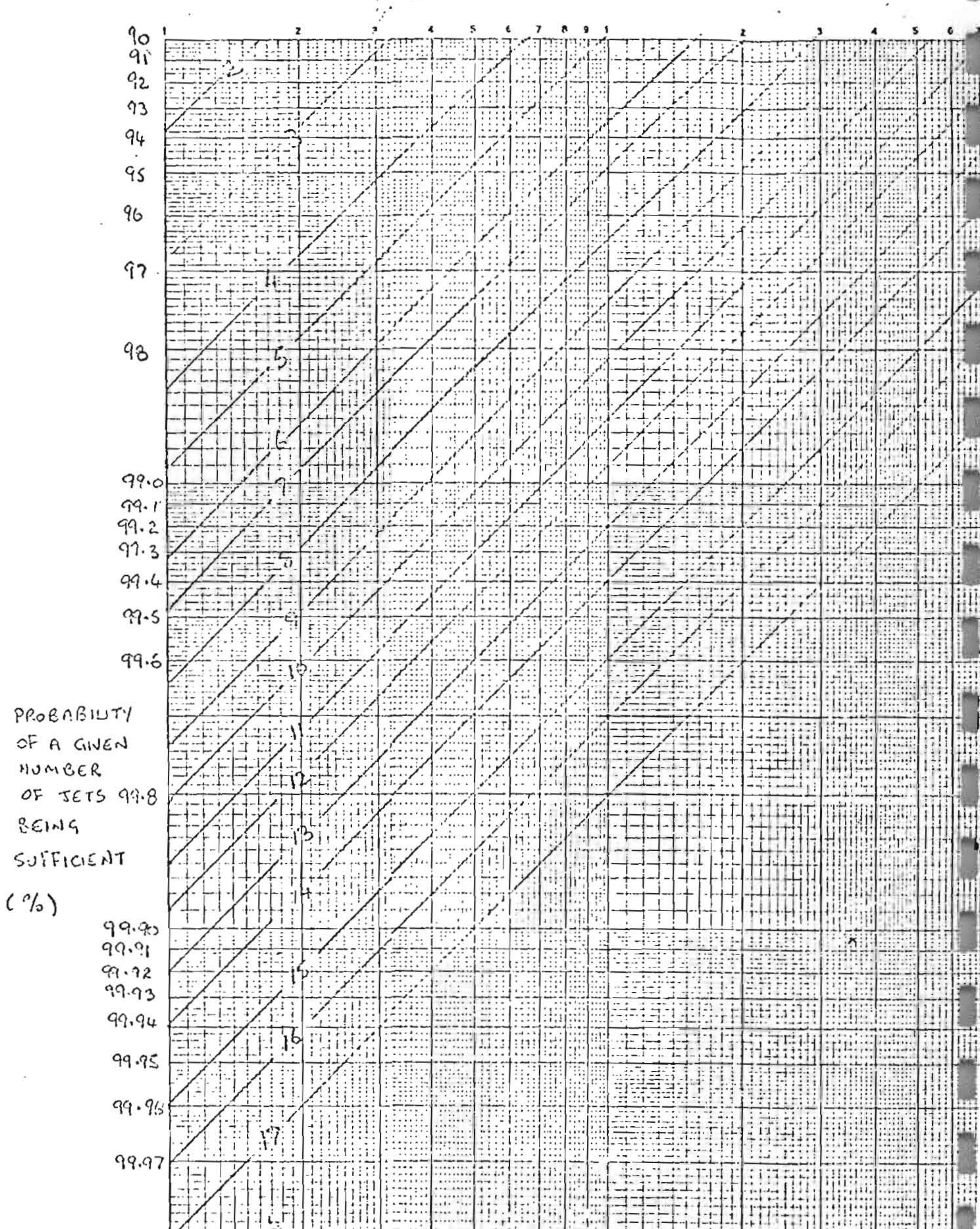

B)
5 6 7 8 9 10 20 30 40 50 60 70 80 90 100 200 300 400
SAMPLE SIZE

FIGURE 5a



PROBABILITY OF A GIVEN NUMBER OF JETS BEING SUFFICIENT (%)
SAMPLE SIZE
90
91
92
93
94
95
96
97
98
99.0
99.1
99.2
99.3
99.4
99.5
99.6
99.8
99.90
99.91
99.92
99.93
99.94
99.95
99.96
99.97
99.98
99.99
1
2
3
4
5
6
7
8
9
10
20
30
40
50

(20)

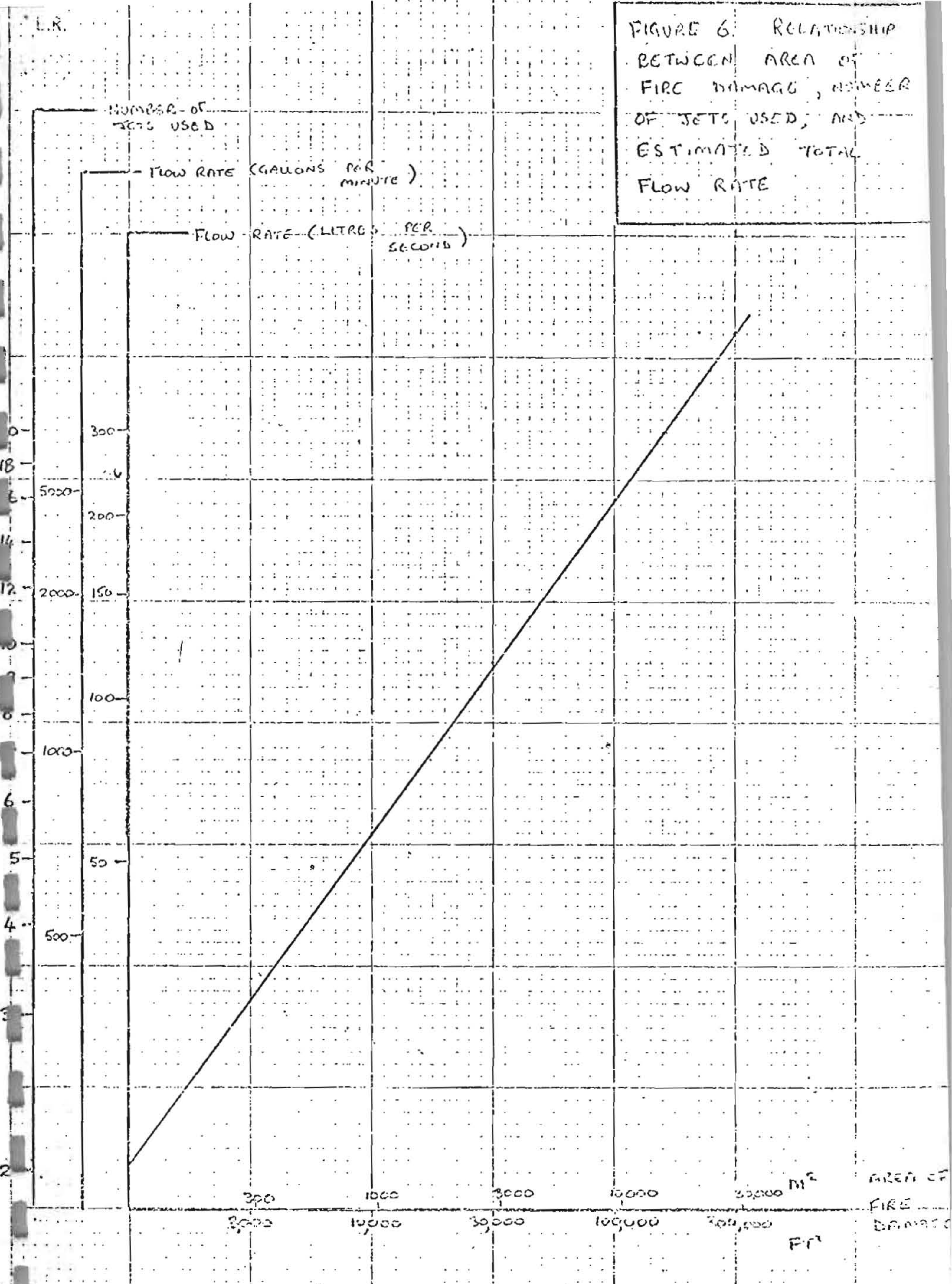

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FIGURE 6. RELATIONSHIP BETWEEN AREA OF FIRE DAMAGE, NUMBER OF JETS USED, AND ESTIMATED TOTAL FLOW RATE
NUMBER OF JETS USED
FLOW RATE (GALLONS PER MINUTE)
FLOW RATE (LITRES PER SECOND)
300
200
150
100
50
5000
2000
1000
500
18
14
12
6
5
4
2
300
1000
3000
10000
30000
M²
3000
10000
30000
100000
300000
FT²
AREA OF FIRE DAMAGE

Frequency Distribution of Number of Jets Used

Notes

1. These distributions are derived from the Combined 1971, 1972, 1973 K433 data. On the coded K433 records the data is recorded as "Number of jets or number of jets plus hose reels used". A recorded value of 1 must indicate 1 jet, and it is likely that where a large value is recorded this will consist only of jets. However a value of 2 or 3 might in some cases imply a mixture of jets and hosereels. It is assumed that any error introduced by this amibuity would not be significant.

2. It can reasonably be assumed that the underlying distribution of number of jets used would have a smooth, monotonic shape. Where the observed data shows obvious inconsistencies due to small sample variation, the data has been smoothed.

3. When frequency distributions are constructed from sample data there comes a point where there are so few many jet fires that the sample data no longer provides an adequate estimate of the true distribution. At this point the distribution must be truncated and all the remaining observations accumulated in the last group. In the tables which follow the last value is always an "accumulated" value.

TABLE 1 (continued)

Group	Storeys	Building Size	Proportion of fires fought by J Jets: 0+1	2	3	4	5	6	7	8	Sample Size
Industry											
Metal Manufacture	SS	1	0·886	0·082	0·022	0·010					717
Metal Goods Not Elsewhere Specified	SS	1									
Metal Manufacture	MS	1	0·827	0·077	0·021	0·055	0·020				145
	SS+MS	2	0·904	0·051	0·026	0·016	0·003				688
Metal Goods Not Elsewhere Specified	SS+MS	2									
Metal Manufacture	SS	3	0·926	0·045	0·015	0·007	0·007				[illegible]
Metal Goods Not Elsewhere Specified	SS	3									
Metal Manufacture	MS	3	0·875	0·081	0·023	0·008	0·013				753
Metal Goods Not Elsewhere Specified	MS	3									
Mechanical Engineering	SS+MS	1+2	0·902	0·055	0·016	0·014	0·013				718
	SS+MS	3									
Instrument Engineering	SS+MS	1+2+3	0·906	0·056	0·014	0·019	0·005				213
Electrical Engineering	SS+MS	1+2	0·840	0·080	0·035	0·020	0·010	0·010	0·005		200
	SS	3	0·932	0·049	0·019						[illegible]
	MS	3	0·930	0·035	0·035						[illegible]
Shipbuilding and Marine Engineering	SS+MS	1	0·754	0·108	0·046	0·046	0·015	0·015	0·015	0·001	65
Vehicles	SS+MS	1	0·835	0·069	0·031	0·008	0·007				130
	SS+MS	2	0·892	0·039	0·029	0·040					102
	SS	3	0·965	0·019	0·009	0·007					1143
	MS	3									
Metal Goods Not Elsewhere Specified	MS	1	0·848	0·063	0·058	0·021	0·005	0·005			191
Textiles	SS+MS	1	0·797	0·091	0·025	0·029	0·008	0·014	0·014	0·020	517
	SS+MS	2									
	SS	3	0·911	0·042	0·010	0·009	0·028				1755
	MS	3									
Leather, Leather Goods and Fur	SS+MS	1+3	0·872	0·065	0·017	0·019	0·007	0·007	0·007	0·002	[illegible]
Clothing & Footwear	SS+MS	1+2+3									
Bricks, Pottery, Glass, Cement, etc.	SS+MS	1+2	0·822	0·103	0·041	0·015	0·012	0·005			[illegible]
	SS+MS	3	[illegible]	0·054	[illegible]	0·022	0·005	0·005	0·007		[illegible]
Timber, Furniture, etc	SS	1	0·737	0·192	0·041	0·025	0·005				[illegible]
	MS	1	0·610	[illegible]	[illegible]	[illegible]·051	[illegible]	[illegible]	0·007	0·006	[illegible]
	SS+MS	2	[illegible]	[illegible]·122	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]

JETS USED IN VARIOUS BUILDING TYPES.

Group	Storeys	Building Size	Proportion of fires fought by J jets: 0+1	2	3	4	5	6	7	8	Sample Size
Private Dwellings											
Houses	SS+MS	1 }	0·982	0·014	0·004						11251
Flats & Maisonettes	MS	1+2+3 }									
Houses	MS	2	0·9[illegible]	0·025	[illegible]	[illegible]	0·01[illegible]	0·002			503
Houses	MS	3	0·928	0·030	0·013	0·002	0·007	0·002			567
Undefined Bldg Type *1											
Agriculture	SS+MS	1	0·618	0·260	0·071	0·034	0·007				385
Construction	SS+MS	1	0·825	0·116	0·024	0·006					2[illegible]
Other SIC Groups	SS+MS	1	0·90[illegible]	[illegible]	0·010	0·00[illegible]					[illegible]
Residential *2											
	SS+MS	1	0·946	0·02[illegible]	0·018	0·001					[illegible]
	MS	2+3	0·951	0·0[illegible]	0·012	[illegible]	0·014				[illegible]
Residential Inst *3											
	SS+MS	1,2+3	0·9[illegible]	0·00[illegible]	0·01[illegible]						[illegible]
Commercial Offices											
	SS	1	0·836	0·121	0·041	0·002					[illegible]
	MS	1+2	0·931	0·034	0·016	0·001	0·010				[illegible]
	MS	3	[illegible]	[illegible]	0·02[illegible]						[illegible]
Shops											
Distributive	SS+MS	1 }	0·9[illegible]	0·0[illegible]	[illegible]	0·001	[illegible]				[illegible]
Other *	SS+MS	2 }									
Distributive	SS+MS	2	0·858	0·06[illegible]	0·02[illegible]	0·013	0·010	0·00[illegible]	0·008	0·0[illegible]6	5[illegible]1
Distributive	SS+MS	3	0·907	0·036	0·012	0·005	0·003	0·005	0·02[illegible]		559
Other *	SS+MS	1	0·973	0·021	0·006						35[illegible]
Other *	SS+MS	3	[illegible]	[illegible]	0·01[illegible]	[illegible]					1[illegible]
Assembly											
Group 1 *4	SS+MS	1	0·962	0·023	0·013	0·002					397
	SS+MS	2+3	0·930	0·025	0·017	0·012	0·009	0·006			[illegible]

NOTES:- *1 = Not defined as storage or industrial

*2 = Residential clubs, colleges and schools.
Residential ecclesiastical buildings. Hotels, hostels, motels,
lodging/boarding houses. Public houses with residential accommodation
attached.

*3 = Children's homes —— old peoples homes. Hospitals, private nursing
homes. Sanatoria, special schools for handicapped children.

*4 = Passenger stations, grandstands, stadiums

* = Other groups — mainly miscellaneous services.

TABLE 1 (continued)

Group	Storeys	Building Size	Proportion of fires fought by J jets: 0+1	2	3	4	5	6	7	8	Sample Size
Assembly											
Group 2 *5	SS	1	0·805	0·142	0·034	0·010	0·004				2770
	MS	1	0·933	0·036	0·014	0·008	0·006				[illegible]
	SS	2+3	0·862	[illegible]	0·023	0·015	0·014	0·013	0·011		[illegible]
	MS	2	0·895	0·039	0·024	0·013	0·011	0·009	0·009		1395
	MS	3	0·921	0·034	0·015	0·012	0·009	0·007	0·012		1433
Group 3 *6	SS	1	0·858	0·105	0·025	0·011	0·001				646
	MS	1	0·951	0·023	0·009	0·007	0·005				[illegible]
	SS+MS	2	0·911	0·031	0·025	0·017	0·016				[illegible]
	SS+MS	3	[illegible]	0·021	0·013	[illegible]	0·031				[illegible]
Industry											
Agriculture, Forestry, Fishing	SS+MS	1	0·850	0·104	0·028	0·013	0·005				684
Construction	SS+MS	1									
Transport and Communications	SS+MS	1+3									
Mining & Quarrying	SS+MS	1	0·821	0·095	0·060	0·024					84
Food, Drink & Tobacco	SS	1	0·846	0·107	0·028	0·017					[illegible]
	MS	1	0·806	0·075	0·050	0·028	0·017	0·006	0·006	[illegible]	[illegible]
	MS	2+3	[illegible]	[illegible]	[illegible]	0·011	[illegible]	0·022			[illegible]
	SS	3	0·921	[illegible]	0·017	0·006	0·006	0·006	0·005		178
Coal and Petroleum Products	SS+MS	1	0·745	0·123	0·064	[illegible]	0·020				47
Chemicals & Allied Industries.	SS	1	0·885	0·079	0·022	0·011	0·002				395
	MS	1	0·907	0·032	0·023	0·015	0·011	0·006	0·006		[illegible]
	SS	2	0·861	0·064	[illegible]	0·010	0·005	0·015	0·005	[illegible]	[illegible]
	MS	2	0·920	0·049	0·031						[illegible]
	SS	3	[illegible]	0·092	0·021	0·007	0·016				[illegible]
	MS	3	0·900	0·042	0·014	0·010	[illegible]	0·008	0·012		[illegible]

Note :-

*5 = Non-residential clubs.
Colleges, Schools, Ecclesiastical Buildings
Meeting houses, Clinics and Public houses.

*6 = Theatres, Cinemas, Radio and Television studios to which the public are admitted.
Concert halls, Restaurants, Cafes, Exhibition halls, Dance halls

TABLE 4 (CONTINUED).

Group	Storeys	Building Size	Proportion of fires fought by J jets: 0+1	2	3	4	5	6	7	8	Sample Size
Industry											
Timber, Furniture, etc.	SS+MS	3	0.827	0.086	0.014	0.019	0.006	0.016	0.012	0.020	[illegible]
Paper, Printing and Publishing	SS+MS	1+2	0.805	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
	SS+MS	3	0.870	[illegible]	0.015	[illegible]	0.024				689
Other Manufacturing Industries	SS+MS	1+2	0.815	0.055	0.042	0.051	0.006	[illegible]	0.013		637
	SS+MS	3	[illegible]	0.033	0.022	0.022	0.014	0.012			634
Gas, Electricity & Water	SS+MS	1+3	[illegible]	0.012	0.006	0.005	0.005				[illegible]
Distributive Trades	SS+MS	1+2+3	[illegible]	[illegible]	0.054	0.018	0.014	0.020			[illegible]
Insurance, Banking, Finance and Business Services	SS	1	0.864	0.096	0.026	0.008	0.003				2212
	MS	1	0.825	0.103	0.038	0.021	0.009	0.004			632
	SS	2	0.860	0.064	0.043	0.016	0.011	0.004			442
	MS	2	0.734	0.103	0.044	0.020	0.026	0.005	0.005	0.014	203
	SS+MS	3	0.865	0.054	0.027	0.020	0.020	0.011	0.003		443
Storage											
Agriculture	SS+MS	1	0.477	0.329	0.122	0.050	0.011	0.005			3095
Transport	SS+MS	1+2+3	0.712	0.140	0.050	0.036	0.013	0.013	[illegible]	0.030	2300
Other S.I.C. Groups	SS+MS SS+MS	1+2+3 1+2+3	0.716	0.155	0.043	0.031	0.011	0.013	0.005	0.021	3429

TABLE 2 - FREQUENCY DISTRIBUTION OF THE NUMBER OF JETS USED IN A/ ALL BUILDINGS B/ COMMERCIAL BUILDINGS C/ INDUSTRIAL BUILDINGS D/ ALL NON-DWELLINGS

		NUMBER OF JETS																		
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19 [illegible]
A	·8389	·0573	·0453	·0143	·0070	·0025	·0018	·0007	·0007	·0004	·0003	·0002	·0001	·0001	·0001	·0001	·0002	—	—	—
B	·8461	·0827	·0427	·0136	·0053	·0027	·0021	·0010	·0007	·0005	·0004	·0003	·0003	·0002	·0002	·0002	·0001	·0001	·0001	·00[illegible]
C	·6440	·1596	·1070	·0403	·0228	·0078	·0061	·0033	·0026	·0019	·0012	·0008	·0006	·0005	·0004	·0003	·0002	·0001	·0005	
D	·7093	·1418	·0844	·0306	·0157	·0054	·0040	·0016	·0016	·0010	·0007	·0005	·0003	·0003	·0002	·0002	·0001	·0001	·0002	

CUMULATIVE DISTRIBUTION OF THE NUMBER OF JETS USED

		NUMBER OF JETS																			
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19 OR [illegible]
[illegible]OPORTION OF [illegible] FOR	A	·8389	·9262	·9715	·9858	·9928	·9953	·9971	·9978	·9985	·9989	·9992	·9994	·9995	·9996	·9997	·9998	1·0			
[illegible]HICH A [illegible]IVEN NUMBER	B	·8461	·9288	·9715	·9851	·9904	·9931	·9952	·9962	·9969	·9974	·9978	·9981	·9984	·9986	·9988	·9990	·9991	·9992	·9992	1·0
[illegible]F JETS [illegible]S SUFFICIENT	C	·6440	·8036	·9106	·9509	·9737	·9815	·9876	·9909	·9935	·9954	·9966	·9974	·9980	·9985	·9989	·9992	·9994	·9995	1·0	
	D	·7093	·3511	·9375	·9681	·9838	·9892	·9932	·9948	·9964	·9974	·9981	·9986	·9989	·9992	·9994	·9996	·9997	·9998	1·0	

Appendix I

The Distribution of the Maximum Number of Jets Used

The distribution of the maximum sample value depends on the distribution of the individual observations which make up the sample, and on the sample size.

Assume that the individual observations are generated by the discrete distribution which is defined as follows:-

$$\text{Prob}(j \text{ jets required}) = p_j \quad , \; j = 0, 1, 2 \, \dots \, M$$

$$\text{Prob}(j \text{ jets or less required}) = \sum_{r=0}^{j} p_r = P_j \quad , \; j = 0, 1, 2 \, \dots \, M$$

If the sample size is N the probability that the largest observation is L is:

$$\text{Prob}(x_{(1)} = L) = N p_L P_{L-1}^{N-1} + \binom{N}{2} p_L^2 P_{L-1}^{N-2} + \dots + p_L^N$$

$$= \left.\begin{array}{ll} P_L^N - P_{L-1}^N & \text{for } L > 0 \\ P_L^N & \text{for } L = 0 \end{array}\right\} \quad (I.i)$$

The size of the second largest observation in a sample of N is used in the validation described in Appendix II. To calculate the probability that the second largest value, $x_{(2)}$ takes the value K we consider two separate outcomes.

a. The first and second largest value are both equal to L

$$\text{Prob}(x_{(1)} = x_{(2)} = L) = \binom{N}{2} p_L^2 P_{L-1}^{N-2} + \binom{N}{3} p_L^3 P_{L-1}^{N-3} + \dots + p_L^N$$

$$= \left.\begin{array}{ll} P_L^N - P_{L-1}^N - N p_L P_{L-1}^{N-1} & \text{for } L > 0 \\ p_L^N & \text{for } L = 0 \end{array}\right\} \quad (I.ii)$$

b. The largest value is larger than the second largest value

$$\text{Prob}(x_{(1)} = L \text{ and all other } x_{(i)} \neq L) = N p_L P_{L-1}^{N-1}$$

$$\text{Prob}(\text{largest of } N-1 \text{ values is } K) = P_K^{N-1} - P_{K-1}^{N-1}$$

$$\therefore \; \text{Prob}(x_{(1)} = L, x_{(2)} = K, K < L) = \sum_{r=K+1}^{M} N p_r \left(P_K^{N-1} - P_{K-1}^{N-1}\right)$$

$$= \left.\begin{array}{ll} N(1-P_K)\left(P_K^{N-1} - P_{K-1}^{N-1}\right) & \text{for } M > K > 0 \\ N(1-P_0) P_K^{N-1} & \text{for } K = 1 \\ 0 & \text{for } K = M \end{array}\right\} \quad (I.iii)$$

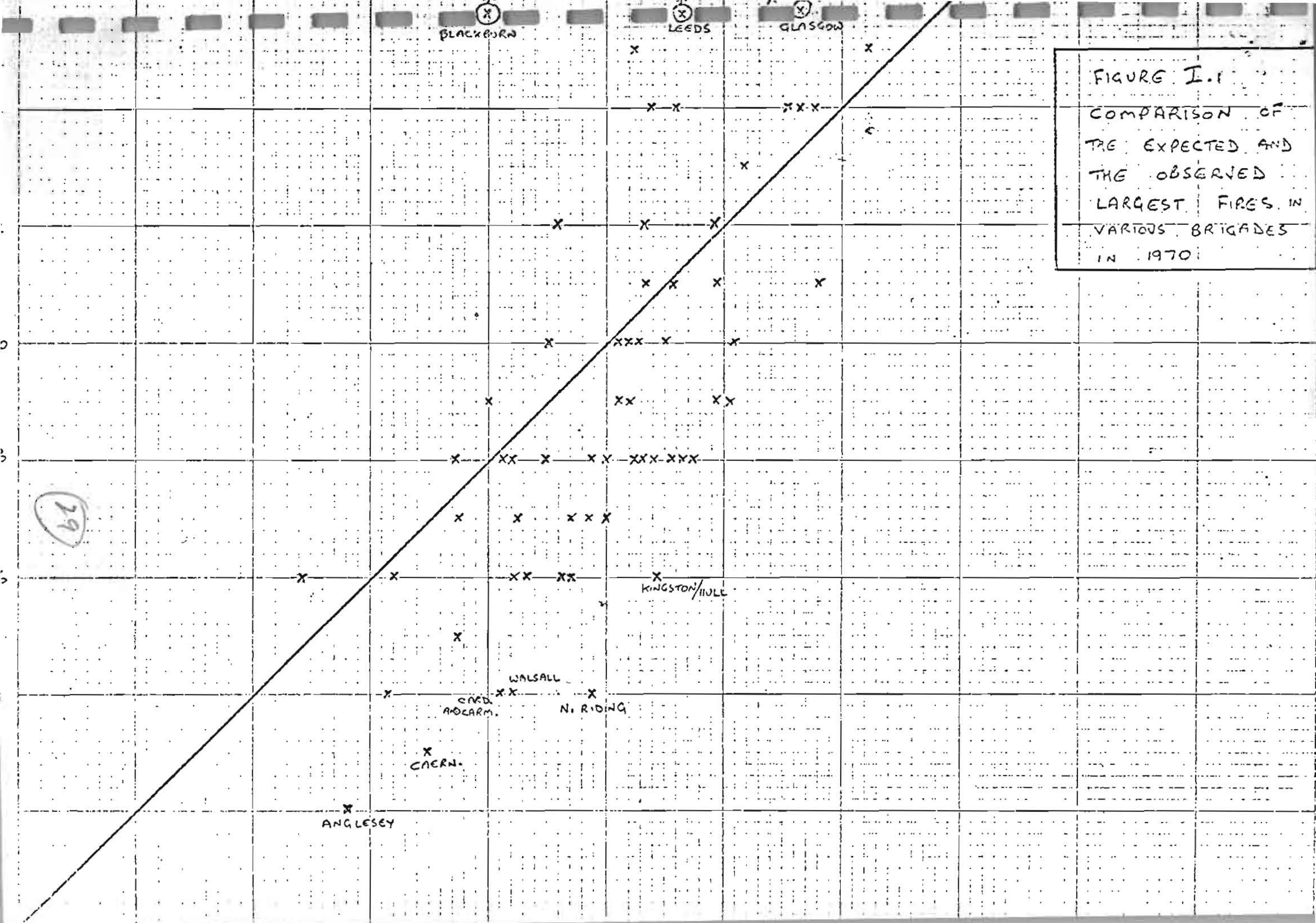

FIGURE I.1 COMPARISON OF THE EXPECTED AND THE OBSERVED LARGEST FIRES IN VARIOUS BRIGADES IN 1970

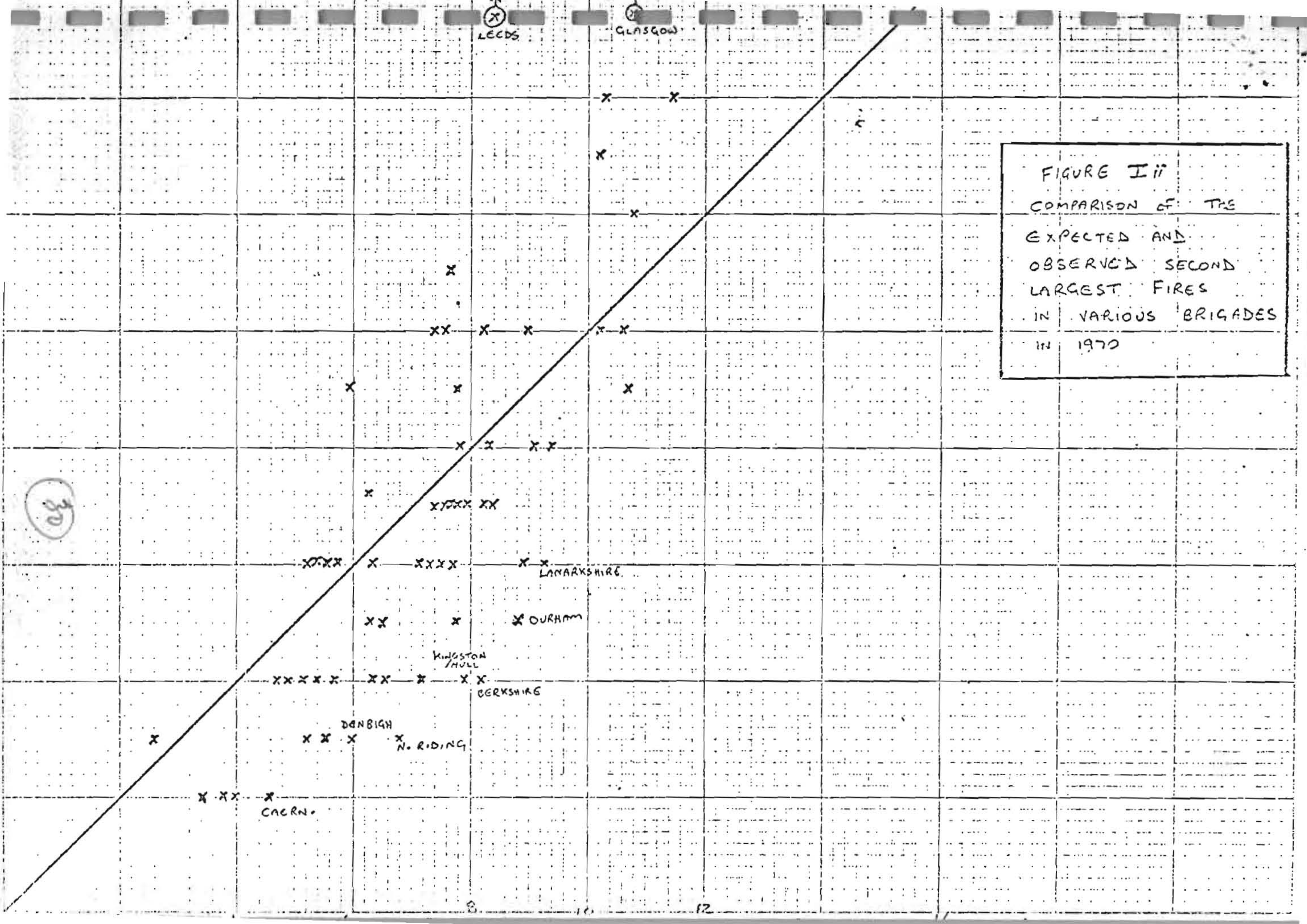

FIGURE I ii
COMPARISON OF THE EXPECTED AND OBSERVED SECOND LARGEST FIRES IN VARIOUS BRIGADES IN 1970

Appendix II

A Check on the Frequency Distribution of Jets Used

The frequency distribution of the number of jets used at a fire is derived from the reported figures on the K433 and SAR2 reports. Because of the sparsity of large fires the upper tail of the distribution is difficult to estimate accurately, and it is this upper tail which becomes critical when the maximum sample value is considered. In order to ensure that the derived distribution of the maximum sample size is valid a check was made by comparing the expected and observed largest values for a number of samples of different sizes. The largest observed value may in practice turn out to be an anomalous, and so the expected and observed second largest values were also considered.

The fires within the separate brigades in 1970 were taken as the samples. The sample sizes are therefore the total number of fires which occurred in each brigade in that year.

The average or expected size of the largest and second largest fires are calculated from equations Ii, Iii and Iiii.

The expected value of the largest observation, $x_{(1)}$ is:

$$E(x_{(1)}) = \sum_{r=1}^{m} r\,(P_r^N - P_{r-1}^N) \qquad (\text{II.i})$$

The expected value of the second largest observation, $x_{(2)}$ is:

$$E(x_{(2)}) = \sum_{r=1}^{m} r\,\{ P_r^N - P_{r-1}^N - N p_r P_{r-1}^{N-1} + N(1-P_r)(P_r^{N-1} - P_{r-1}^{N-1}) \} \qquad (\text{II ii})$$

Comparisons of the expected and observed values are shown in Figures I i and I ii. If the estimated distributions are valid the graphs should show a scatter of points about the 45° line. This appears to the case and we can therefore assume that the distribution of the maximum fire sizes are valid, at least within the limitations described in section