Systematized A/C analysis and feedback ensures that experiences and lessons learned are acquired by the organization and translated into improved productivity. As work progresses, all results from check sheets and reported accuracy problems are analyzed by the A/C group before they are sent to concerned organizational divisions. The evaluations include:

- analysis, and
- recommendations which, as shown in Figure 5-1, are performed on either a regular or an urgent basis.

5.1 Regular analysis

If an analysis discloses an apparent area for improvement an A/C engineer pursues one or more typical options as follows:

- more detailed investigation of the data,
- investigation of instruments used for measuring,
- verification of alignment of facilities such as platens for flat-block assembly and cribbing for erection,
- review of work methods, and
- study of specified amounts for excess.

Workers perform self checks daily to insure compliance with accuracy standards. These are again checked and recorded by their work leaders. Properly collected data, even if all measurements are within accuracy standards, are used to identify the characteristics and tendencies of variations. Such knowledge leads to further improvement in production processes. An example of data collection and analysis for determining excess allowances is included in Appendix E.

Feedback of analyzed A/C data is vital because it encourages planners to review matters such as:

- whether schemes for amounts of excess, vital points and dimensions, etc. were satisfactory,
- whether block divisions and shell straking were optimum,
- whether work-process standards were suitable, and
- whether sufficient work instructions were provided.

5.1.1 Significance of Mean Value

Generally, a mean value is significant only when associated data is obtained by random sampling. Data gathered from a small sample may not be a valid representation of the work process being analyzed. For most work processes, the mean value for variations is planned to be zero. If the actual mean value differs from zero, it should be changed to match results of the work process or the work process should be changed so as to yield the planned mean value (zero). The following examples apply:

- *Example 1*: Consider a particular dimension for panels, such as for a longitudinal bulkhead under a tank top, which were cut with some allowance for shrinkage. After welding during sub-assembly work, the mean value of the dimension was determined to be negative, i.e., some shortage exists compared to the planned zero value.

  Analysis: Check kerf compensation; if sufficient, the allowance for shrinkage was too small.

  Remedy: Add the absolute mean value to the previously planned allowance for shrinkage.

- *Example 2*: Near the end of flat-block assembly, checking discloses that plates in tank-top panels are deformed at their centers with a mean value of ½ inch.

  Analysis: Check the level of the platen on which the flat blocks were assembled.

  Remedy: If the platen is true, improve the assembly work processes, e.g., apply pre-tensioning or change weld sequences.

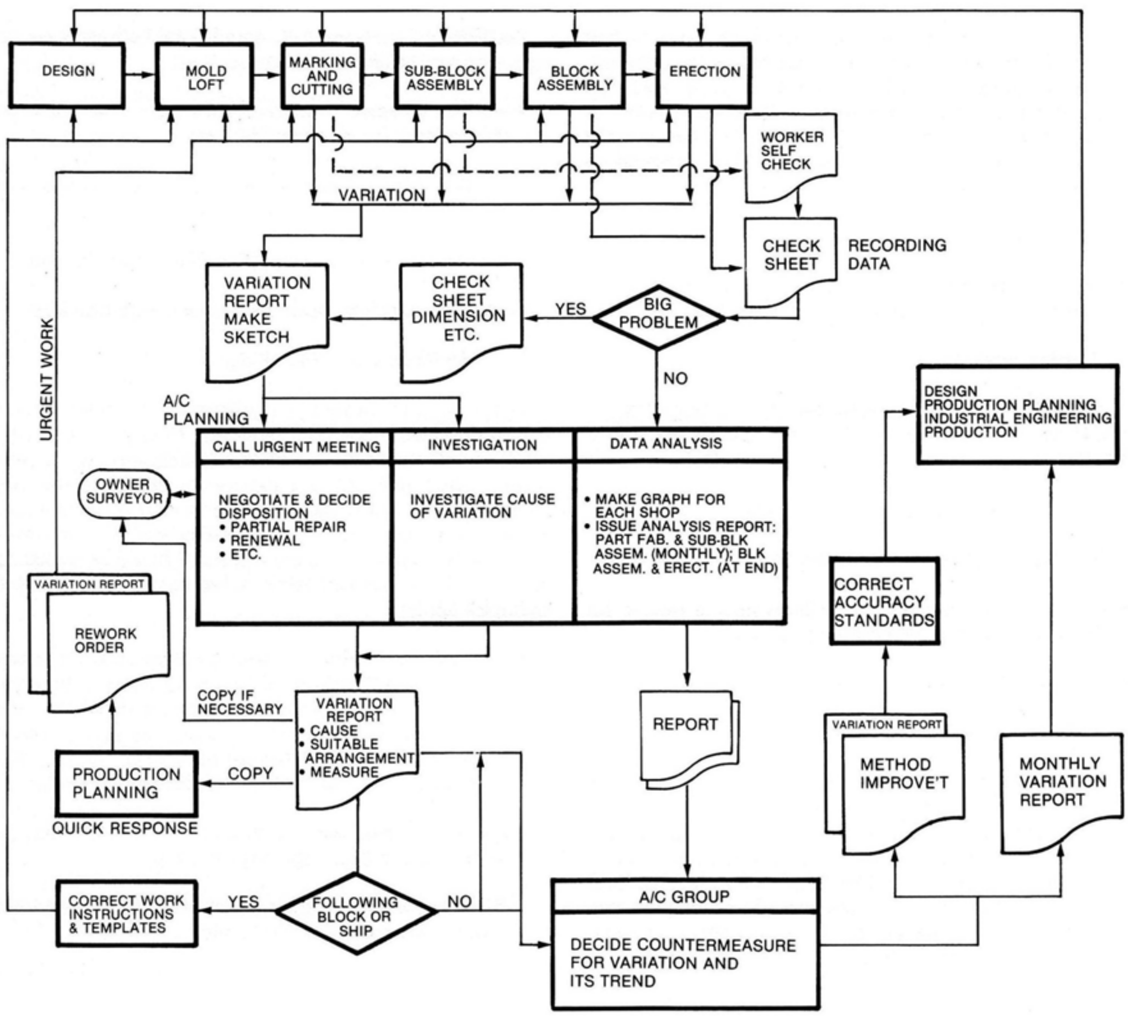


FIGURE 5-1: Feed back flow provides for regular and urgent situations.

5.1.2 *Significance of Standard Deviation*

Standard deviation is significant for a number of reasons. *Variance* as defined in statistics is the square of the standard deviation; it provides the linkage between the accuracies of earlier work processes and the accuracy of a final process. The linkage is called the theorem of addition of variance:

$$\sigma_0^2 = \Sigma \sigma_i^2 \text{ or } \sigma_0 = \sqrt{\Sigma \sigma_i^2}$$

where σ_i is the standard deviation of earlier processes and σ_0 is the standard deviation of a final process. Without this relationship, analytical A/C does not exist.

Further, during analysis A/C engineers are very watchful for a change or shift in the standard deviation for each work process. Such behavior could indicate that something about how a work process is executed has changed. Many reasons exist including a worker perfecting a better technique which should be adopted by others and erratic operation of or deteriorating machinery.

- *Example*: The standard deviation for the length of manually fabricated longitudinals suddenly increases, decreases or shifts.

  Analysis: Examine how and by whom the longitudinals were fabricated. Methods, particularly sequences, should be thoroughly analyzed.

  Remedy: There could be many solutions dependent upon results of the detailed analysis. At least one shipbuilder reacted by finish cutting longitudinals before bending, i.e., end margins to permit grasping for bending at the ends were eliminated. Following the mechanical bending process line heating was introduced to bend the finish-cut ends. Accuracy was improved and the wasteful margins were eliminated.

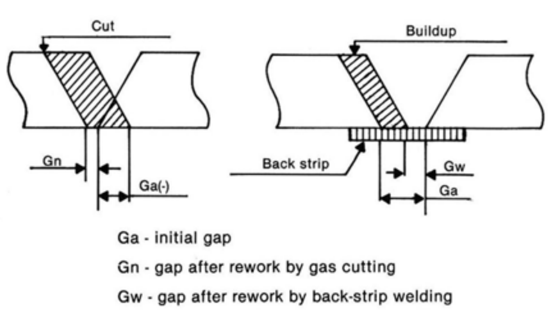


FIGURE 5-2: A/C is most effective when it focuses on minimizing the two kinds of rework commonly encountered when joining hull blocks, i.e., gas cutting and back-strip welding.

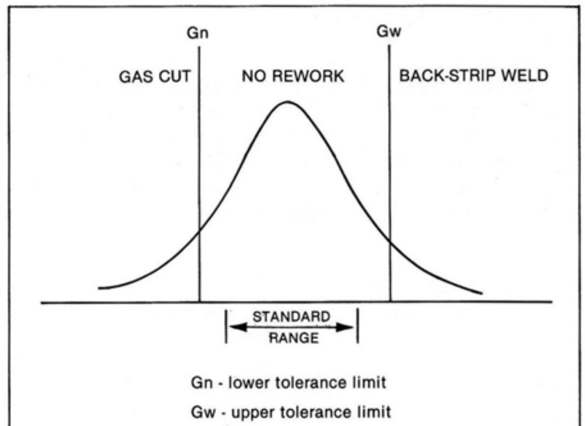


FIGURE 5-3: The lower tolerance limit stems from having to create an erection-joint gap or make it wider. The upper tolerance limit arises from having to make a gap narrower.

5.1.3 *Setting Accuracy Standards*

Data analysis quantitatively sets accuracy standards. For example, when erection joints are aligned the achieved distribution of gap variations will, at the extremities of the distribution, show requirements for rework:

- cutting where a gap is too small or negative, or
- building on an edge where there is too much gap.

As shown in Figure 5-2, when G_a is less than 0, *minimal* material is cutoff to achieve the gap G_n because it is cheaper to retain as much of the original material as possible. When G_a is more than 0, a *minimal* amount is built-up to achieve the gap G_w because the buildup process is expensive. Thus, G_n is always smaller than G_w.

The condition for avoiding rework is:

$$G_n \leqslant G_a \leqslant G_w$$

Therefore, by definition the lower tolerance limit is G_n and the upper tolerance limit is G_w. A standard range to be used as a goal for improving G_a can be established accordingly; see Figure 5-3.

5.1.4 *Modifying Distributions*

Consider traditional rework for adjusting erection gaps. Cutting dominates because *experienced* people know that generally, cutting costs are less per lineal foot than for back-strip welding. The mean value of the pertinent distribution of gap variations favors the lower tolerance limit accordingly. Figure 5-4 shows this intentional bias and also shows the impact of shifting the mean value toward the upper tolerance limit.

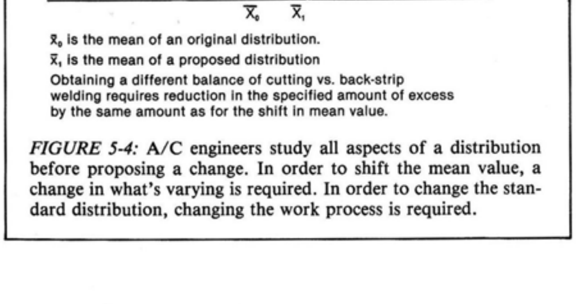
Because of the nature of normal distributions, the nominal increase in back-strip welding is overwhelmingly offset by the substantial decrease in cutting required. Further, the prospects for exceeding the lower tolerance limit are reduced. Thus, analytically derived goals proposed by A/C engineers will sometimes significantly differ from those adhered to by traditionalists who operate without the benefit of carefully collected and analyzed data.

In shipyards where A/C is practiced, operations managers benefit from detailed reports of productivity during hull erection which relate total lengths of gas cutting and back-strip welding to the total lengths of erection gaps. In an actual report for erection of a 167,500 DWT bulk carrier, see Figure 5-5, rework was only required for 32.6% of total gap lengths. That is, 67.4% which had been finish cut did not require rework.

5.1.5 *Sequence for Analysis*

Ongoing review of accuracy standards by continuously analyzing data is very important. The following procedure for analysis of data obtained during flat-block assembly is typical:

- prepare separate histograms of variations for each characteristic, e.g., length, width, etc., as shown in Figure 5-6,



$\bar{x}_0$ is the mean of an original distribution.
$\bar{x}_1$ is the mean of a proposed distribution
Obtaining a different balance of cutting vs. back-strip welding requires reduction in the specified amount of excess by the same amount as for the shift in mean value.

FIGURE 5-4: A/C engineers study all aspects of a distribution before proposing a change. In order to shift the mean value, a change in what's varying is required. In order to change the standard distribution, changing the work process is required.

- calculate the mean value, $\bar{x}$, and standard deviation, σ, for each characteristic,

- use each standard deviation to determine how the data conforms to its pertinent standard range, e.g., competitive shipbuilders define standard range as $\bar{x} \pm 2\sigma$,

- when the data for a characteristic does not conform with its standard range ($\bar{x} \pm 2\sigma$ means conformance with 95% probability), A/C engineers:
  - confirm that the standard range is appropriate, investigate and make necessary recommendations, e.g., adjust excess allowance, change methods, supplement worker training, etc., or
  - propose changes in the standard range which do not impact on end-product tolerances.

Appendix E contains a good example of a sequence for analysis.

5.2 *Urgent Analysis*

In real shipbuilding circumstances no one can eliminate variations which require rework. Moreover, no one can predict exactly when they will occur. Disruption is also caused by the effects of such things as errors, accidents and weather abnormalities, which differ from variations because their occurrences do not adhere to normal distributions. Despite their erratic natures, they too require organized responses and analyses in order to:

- identify short-term or temporary solutions which minimize disruptions, and to subsequently

- achieve permanent means to prevent reoccurrence.

The feedback path for these urgent considerations is included in Figure 5-1.

One shipbuilder's preplanned response to a *serious* inaccuracy immediately summons select members of the A/C group. This trouble-shooting team of specialists for planning, executing and evaluating, meet where the inaccuracy exists to:

- evaluate impact on work flow,

- recommend what, how, where and when rework is to take place so as to minimize disruption, and

- collect evidence for identifying the cause.

Reportedly, the average time for such meetings is short; for the most extreme problem two hours could be required.

After the temporary countermeasures for quickly restoring work flow, investigations continue for the purpose of devising permanent solutions. Usually, work procedures are revised to reflect more A/C philosophy.

5.3 Control

Controls which assure that achieved accuracy conforms with an A/C plan for hull construction, is prerequisite for competitive shipbuilding. They are classified as *regular* or *special*.

Because of the many different parts and subassemblies that are required, regular controls are applied to *repetitive work processes*. Typical regular-control items in an ongoing A/C program, including their measurement frequencies, sample sizes and standard deviations, are listed in Figure 5-7. A control chart for such regular usage is shown in Figure 5-8. Such charts are maintained by A/C engineers for production control purposes. Once people become used to them, they provide guidance to everyone concerned, i.e., workers and their supervisors. Thus, each such control chart is posted at its respective work station. This is important. Descriptions of the types of control charts used for A/C by shipbuilders and how to prepare them, are in Appendix F.

Special controls are based upon the accuracy condition of a hull upon completion. Necessary vital points are defined and included in the A/C plan for a specific hull. When the hull is completed, members of the A/C group accumulate and analyze measurements that relate to predetermined vital dimensions. They look for accuracy trends which should be modified for further productivity improvements.

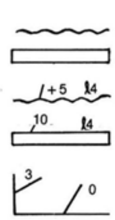
Statistically derived data which predicts variations in block edges is not sufficient for depicting the actual status of each block. Erection planners are concerned with how the exact dimensions and configuration of every block compares with design dimensions. A position-dimension diagram (P/D), as shown in Figure 5-9, satisfied this need. This information is needed to develop variation tables, as shown in Figure 5-10, which are used to determine where gas cutting and/or back-strip welding is required. Similar such information, as for the end positions of girders and longitudinals, as shown in Figure 5-11, is also prepared for the same purpose.

Each P/D assumes that the rectangularity and overall dimensions and shape of the panel on which the block is assembled, are within specified tolerance limits. P/D's would be invalid if control items such as those listed in Fig. 5-6, did not also conform.

Effective control of accuracy is dependent on proper understanding of *variation merging equations* such as those given in Figure 3-2. Too much focus on a merged variation, Z, is not worthwhile. It is more important to focus on each factor on the right side of each equation. If these factors are sufficiently controlled, nominal checks will suffice to confirm each merged variation. Some of these nominal checks, usually by sampling, are useful for balancing alternatives such as gas cutting vs. back-strip welding as shown in Figures 5-2 through 5-4. More examples of control charts are contained in Appendix F.

ANALYSIS REPORT FOR HULL ERECTION

	Erection Gap Length (M)	Gas Cutting Length	%	Back-Strip Welding Length	%	Rework (%)
Upper Deck	1,548.2	452.3	27.4	65.6	4.2	31.6
Side Shell	797.8	203.8	25.5	53.2	6.6	32.1
Longitudinal BHD	652.2	324.0	49.6	34.0	5.2	54.8
Tank Top	431.8	27.3	6.3	17.5	4.0	10.3
Bottom Shell	1,453.7	344.8	23.7	102.5	7.0	30.7
Total Hull	4,883.7	1,325.2	27.1	272.8	5.5	32.6



.... Gas cutting
.... Backing strip welding
.... designates surplus of 5mm over 4m length
.... designates gap of 10mm over 4 m length
.... are position/dimension indicators: see Figure 5-9.

Gas cut .... When surplus was 3 or more mm
Back-strip weld .... When gap was 5 or more mm too wide

Length 281M
Breadth 48M
Depth 28.2M
Dead Weight .... 167,500 Tons
Launching .... April 12, 1977

FIGURE 5-5a: An analysis report for hull erection is prepared at the end of each project. Final data organized as shown is a "report card" of the hull construction department's productivity. The little gas cutting of 20mm or more on a few bow and stern blocks was for trimming margins, i.e., predesignated rework.

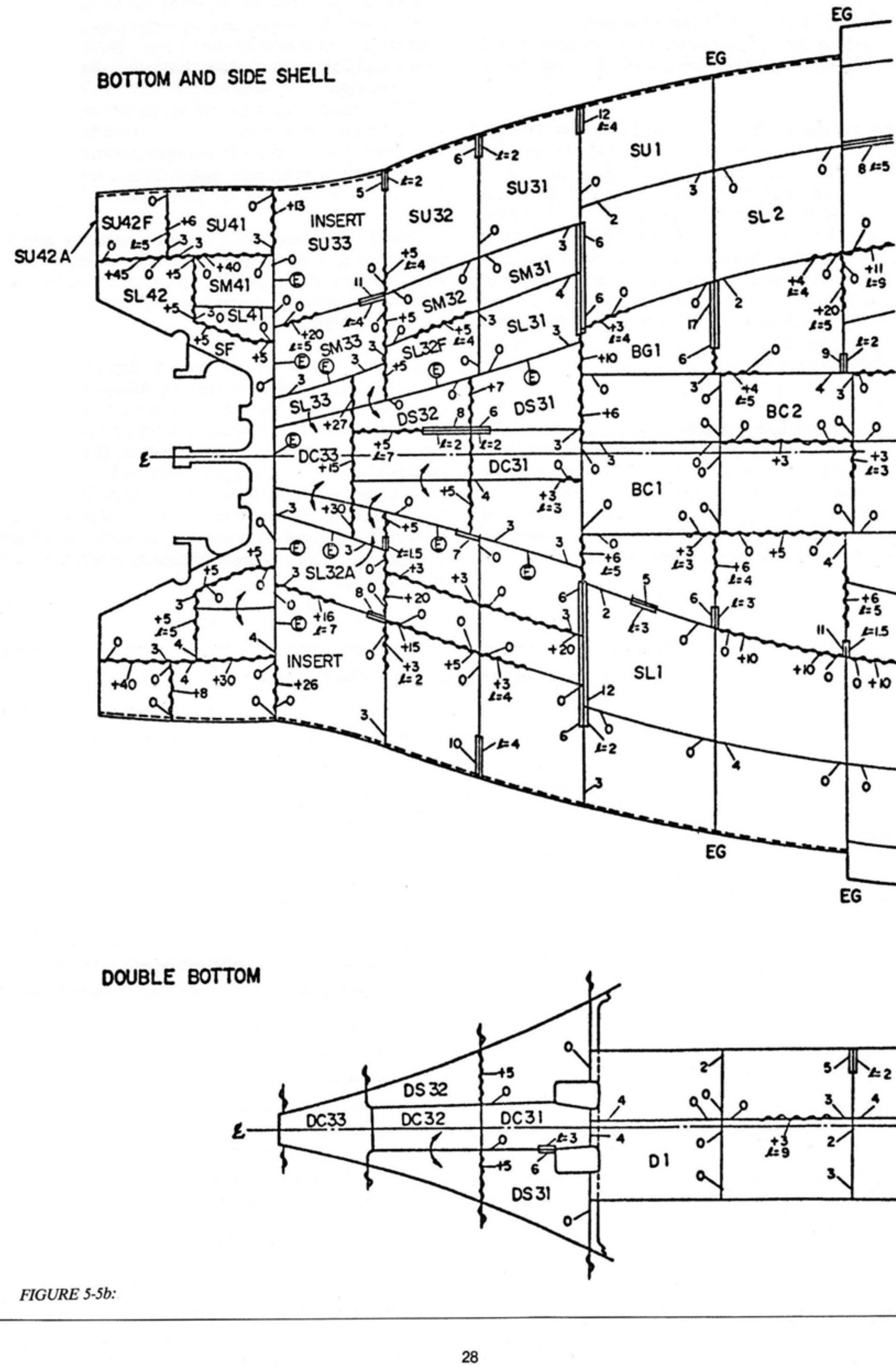

BOTTOM AND SIDE SHELL
EG
SU1
SL2
SU31
SU32
INSERT
SU33
SU41
SU42F
SU42A
SM41
SL42
SL41
SF
SM33
SM32
SM31
SL32F
SL31
BG1
SL33
DS32
DS31
BC2
DC33
DC31
BC1
SL32A
INSERT
SL1
DOUBLE BOTTOM
DS32
DC33
DC32
DC31
D1
DS31

FIGURE 5-5b:

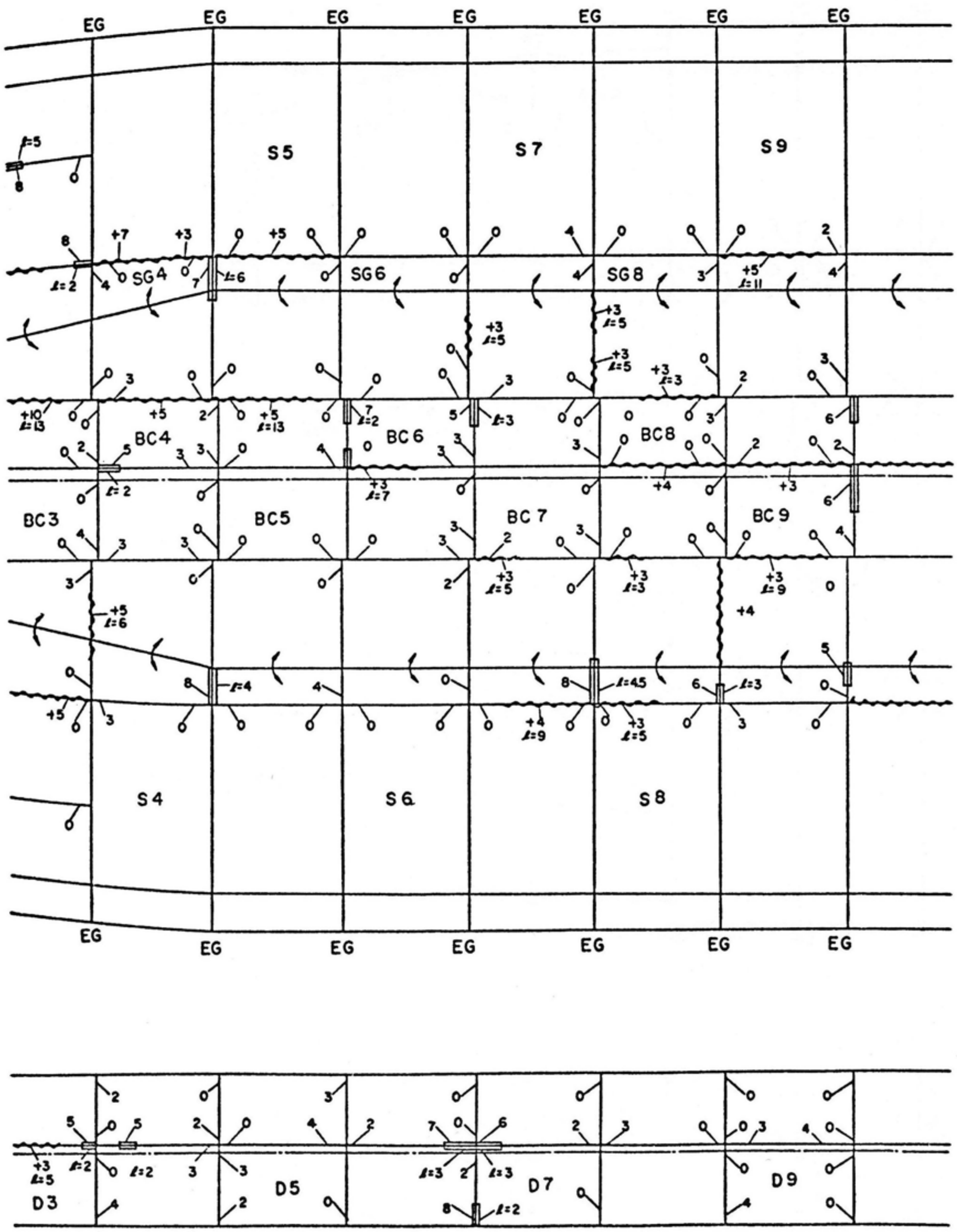

EG
S5
S7
S9
SG4
SG6
SG8
BC3
BC4
BC5
BC6
BC7
BC8
BC9
S4
S6
S8
D3
D5
D7
D9

FIGURE 5-5c:

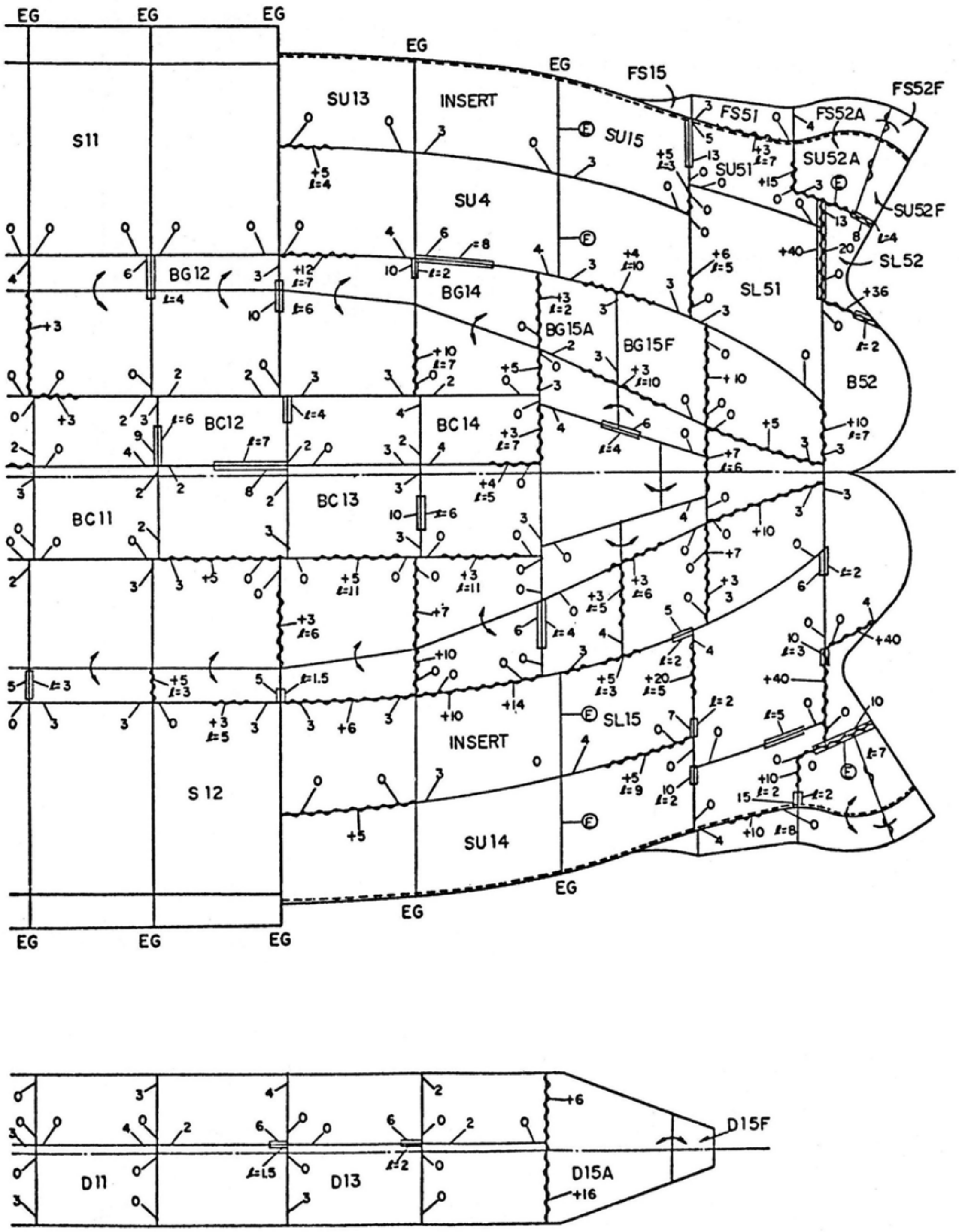

EG
S11
SU13
INSERT
SU15
FS15
FS51
FS52A
FS52F
SU51
SU52A
SU52F
SU4
SL52
BG12
BG14
BG15A
BG15F
SL51
B52
BC12
BC14
BC11
BC13
SL15
INSERT
S 12
SU14
D11
D13
D15A
D15F

FIGURE 5-5d:

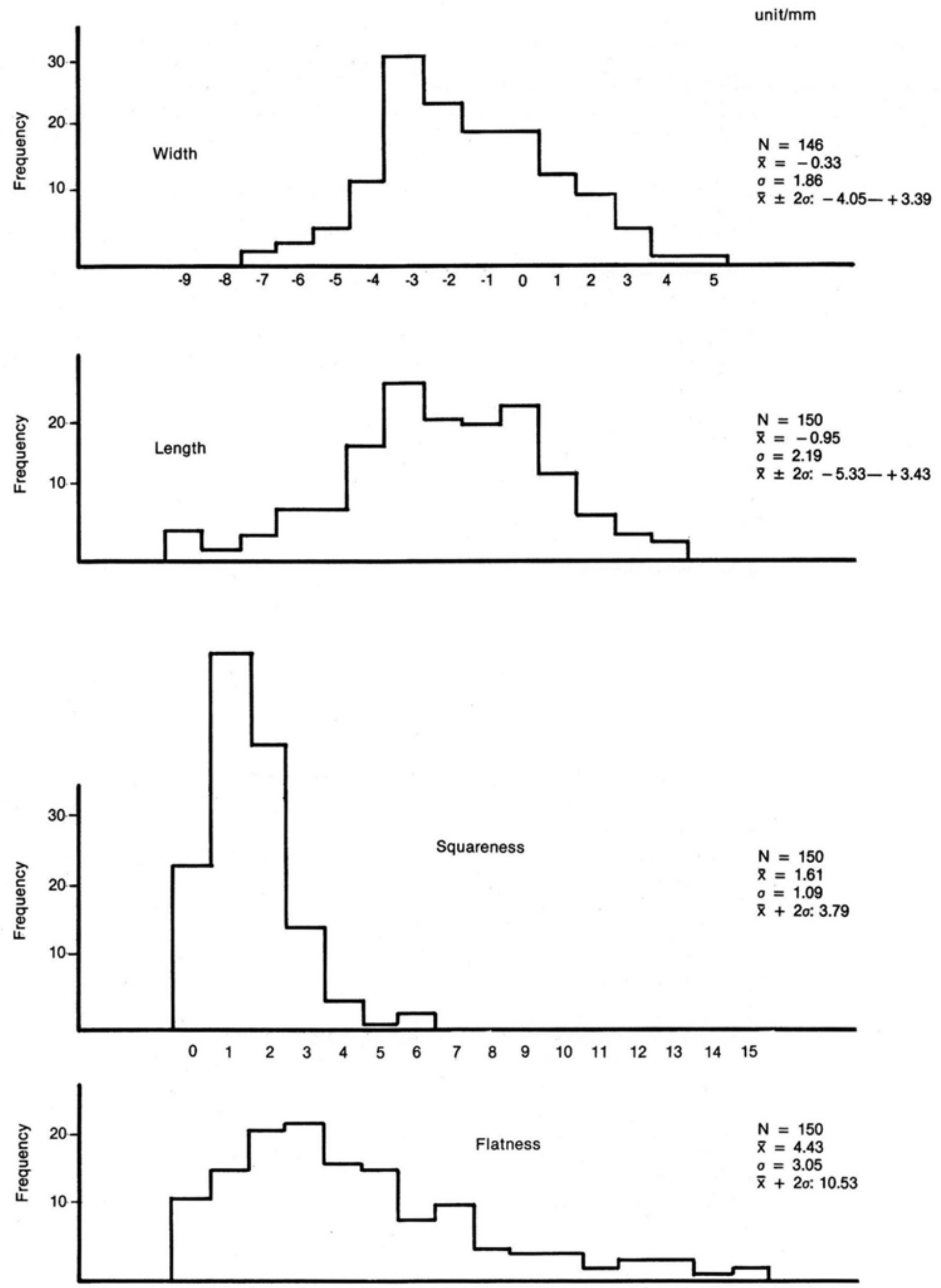


FIGURE 5-6: Each histogram of variations in flat blocks compares identical parameters. Regarding squareness and flatness only absolute values are of concern. Appendix B contains more information about preparing histograms.

Stage	Regular Control Item	Measurement Frequency	Sample Size	Standard Deviation
Template Production	Tape	Week	20	0.4
	Paper Template	20 Days	8	0.5
	Tin Template	20 Days	8	0.4
	Wood Template	20 Days	8	0.5
Part Fabrication	Cutting Plate by Flame Planer-Width	Day	8	0.4
	Cutting Plate by Flame Planer-Straightness	Day	All	-
	Finish Marking Plate Length	Day	All	-
	Finish Marking Plate Main Marking Line	Day	All	-
	Finish Marking Plate Right Angle	Day	All	-
	Bevel Angle for Auto Welder	10 Days	8	1.0
	Curved Plate Marking	Day	8	0.8
	Cutting Accuracy of Curved Plate	Day	8	0.8
	Shape Marking	Day	8	0.5
	Cutting Accuracy of Shapes	Day	8	0.8
	N/C Cutting Machine Plate Width	Day	8	0.6
	N/C Cutting Machine Plate Length	Day	8	0.5
	Cutting Accuracy of Internals e.g., Floor Girder in a Double Bottom	Day	8	0.8
	Cutting Accuracy	Day	8	1.5
Sub-Block Assembly	Accuracy of Fitting Stiffner	Day	6	0.7
	Straightening Deformation by Line Heating	Day	6	0.8
	Accuracy of Fitting Face Plate	Day	8	0.8
	Accuracy of Fitting Angle	Day	–	1/200
Block Assembly	Plate Length	2 Days	8	1.4
	Plate Width	2 Days	8	1.5
	Right Angle (Difference between Diagonals)	2 Days	8	1.2
	Reference Line	2 Days	8	0.8
	Position of Longitudinal Edge	2 Days	8	1.2
	Position of Transverse End	2 Days	8	1.5
	Accuracy of Through Piece	2 Days	6	1.5
	Accuracy of Curved Shell Web	2 Days	6	5/1000
	Curved Shell Plate-Length (After Cutting)	3 Days	4	1.5
	Curved Shell Plate-Width (After Cutting)	3 Days	4	1.5
	Curved Shell Plate-Reference line (After Cutting)	3 Days	8	0.8

FIGURE 5-7: Regular Control Items.

$\bar{x}$ - R CONTROL CHART

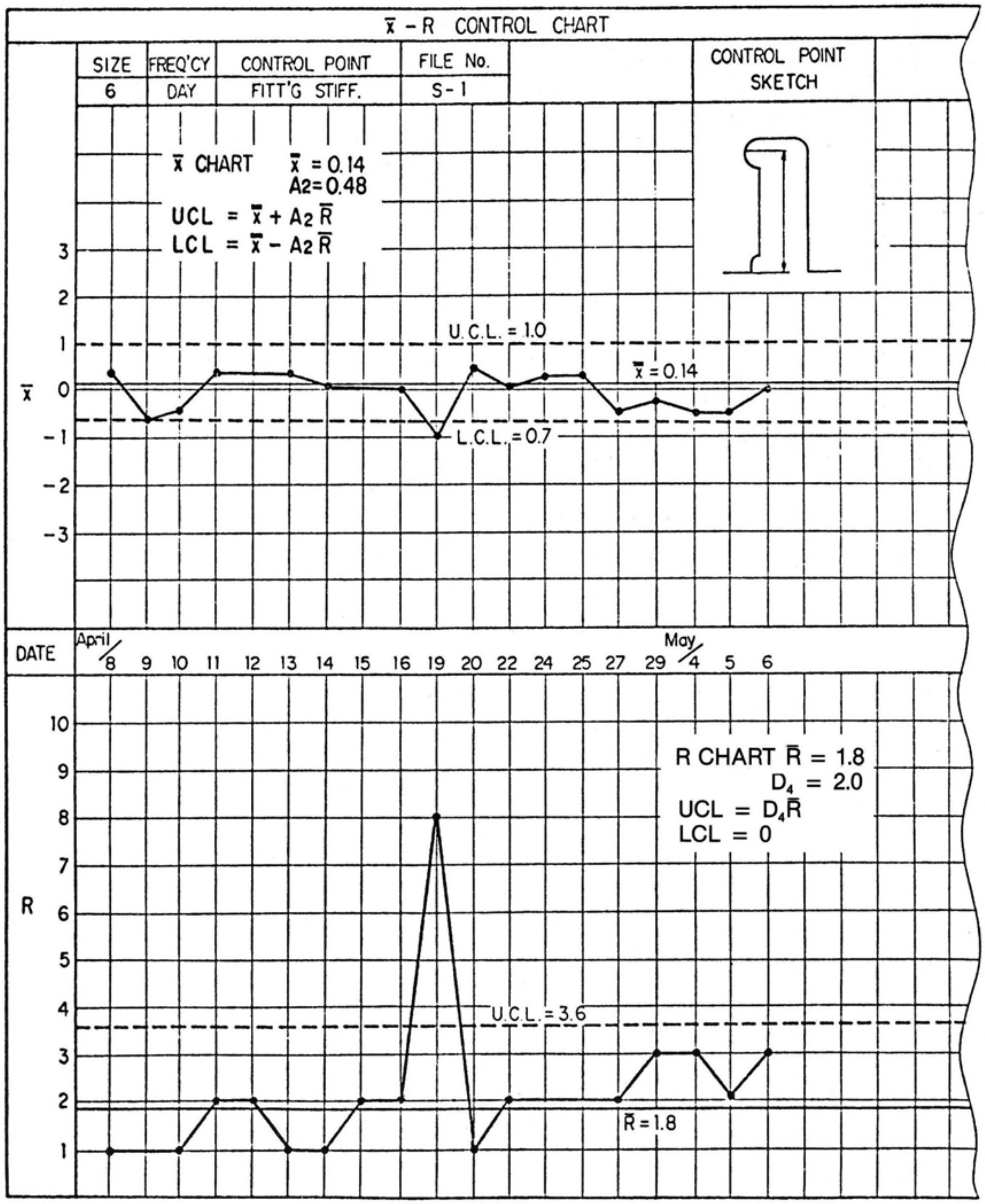


FIGURE 5-8: The $\bar{x}$ chart shows that on 19 April some measurements caused the mean value to drop below the lower control limit. The R chart shows a sudden increase in range for the same day. The two facts considered together indicate that a few dimensions were short by large amounts. $\bar{x}$-R charts for A/C are the same as used for quality control theory. How they are prepared is described in Appendix F.

P-D DIAGRAM

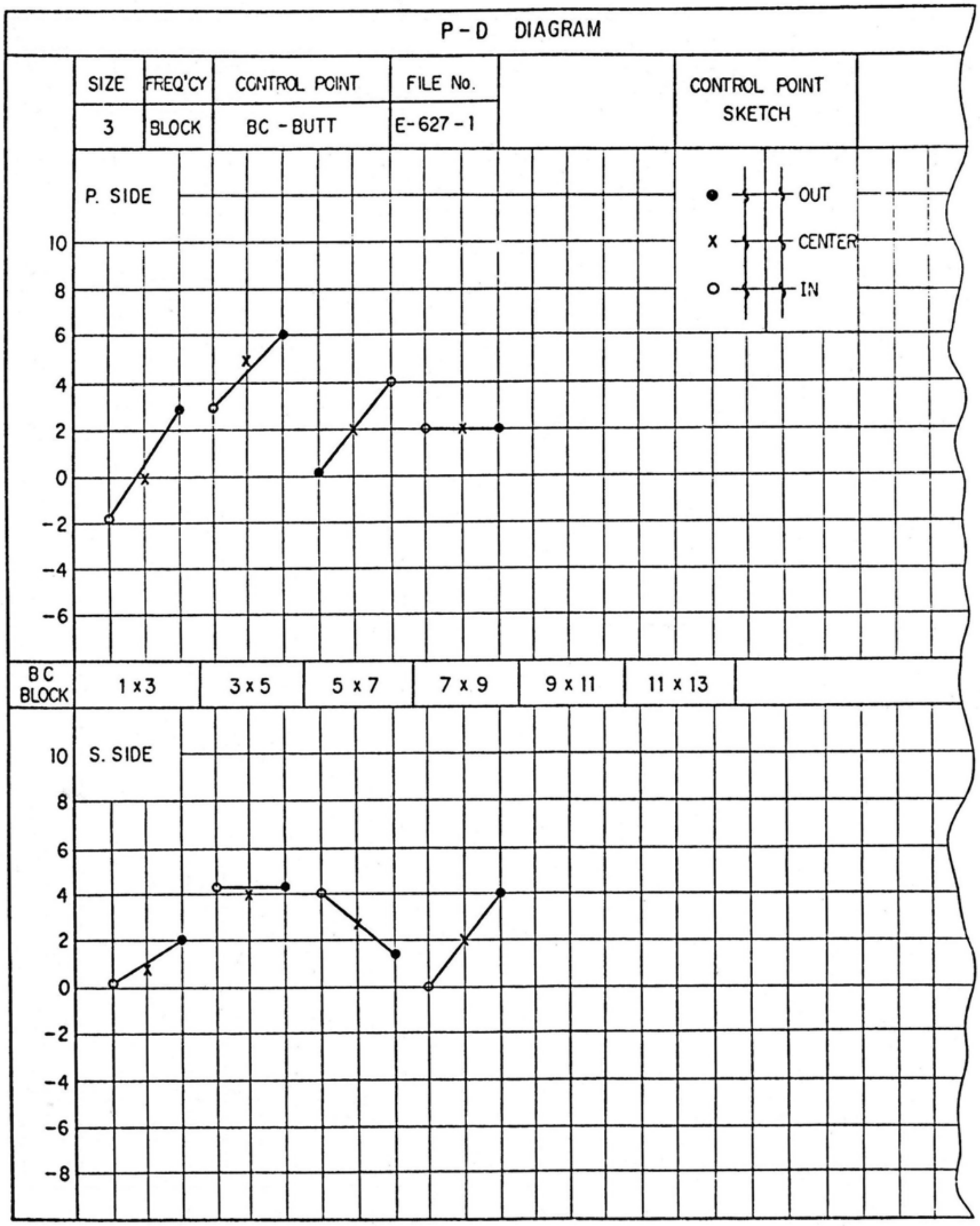


FIGURE 5-9: Position-dimension diagrams are needed by A/C engineers to plan hull erection. Each diagram informs of how a block deviates from design dimensions. One shipbuilder is working toward an in-house photogrammetric capability to obtain accurate position-dimension data for very large blocks.

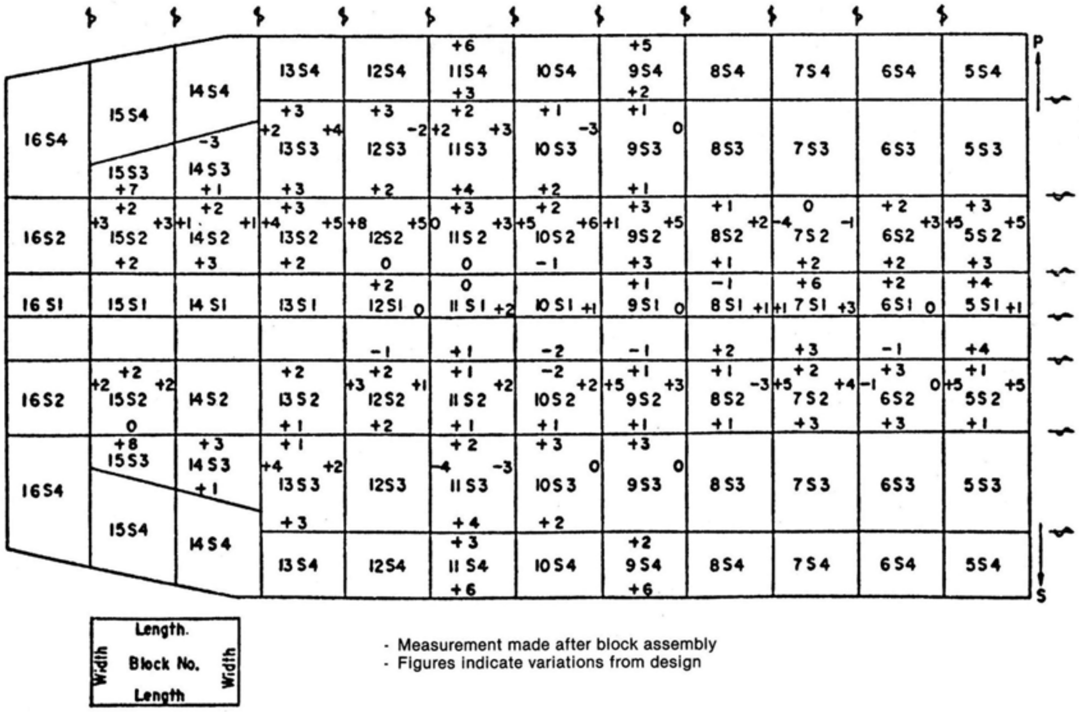


FIGURE 5-10: Knowledge of variations in each block is needed to plan hull erection.

Block No. / Fore or Aft / Longl. No.	D1 F	D1 A	Gap & Overlap	D2 F	D2 A	G or O	D3 F	D3 A	G or O	D4 F	D4 A	G or O	D5 F	D5 A	G or O	D6 F	D6 A	G or O	D7 F	D7 A
10																				
9					0	0	0	0	0	0	+2	+2	0	0	0	0	0	0	0	0
Gir. 8		0	0	0	-1	0	+1	-1	-1	0	0	0	0	0	+6	+6	0	0	0	+1
7		0	+1	+1	-1	-1	0	0	0	0	+1	0	-1	0	0	0	-2	-2	0	+1
6		+1	+1	0	0	0	0	-1	-1	0	0	-1	-1	0	0	0	0	0	0	+1
5		0	+1	+1	0	0	0	+1	+1.5	+0.5	-1	-1	0	0	0	0	-1	-2	-1	+2
Gir. 4		-1	0	+1	0	0	0	0	+0.5	+0.5	-1	0	+1	0	+1	+1	-1	-1	0	+2
P 3		-1	0	+1	0	0	0	0	+1	+1	-1	-1	0	0	0	0	-1	-1	0	+1
2		0	0	0	0	0	0	-1	0	+1	-1	-1	0	0	0	0	0	-1	-1.	+2
Gir. 1		-1	0	+1	+1	+1	0	-1	0	+1	-1	0	+1	0	+3	+3	0	0	0	+2
℄		-1	-1	0	0	+1	+1	-1	0	+1	0	0	0	0	+2	+2	+1	+1	0	+2
Gir. 1		-2	-1	+1	-1	-1	0	-1	-1	0	-1	-2	-2	+1	+1	0	0	-1	-1	+3
2		-1	0	+1	-2	-2	0	-1	-1	0	0	0	0	+2	+1	-1	0	0	0	0
S 3		0	0	0	0	0	0	.0	+0.5	+0.5	-1	+1	0	0	0	0	0	-1	-1	+4
Gir. 4		0	0	0	0	+0.5	+0.1	-2	-2	0	0	+1	+1	-2	-1	+1	+1	+1	0	+2
5		0	+1	+1	-1	-1	0	0	0	0	-1	-1	0	0	0	0	0	0	0	+5
6		0	0	0	+1	0	-1	-1	-1	0	-2	-2	0	0	0	0	+1	+1	0	+3
7		0	0	0	-1	-1	0	-1	0	+1	0	0	0	0	0	0	0	0	0	+3
Gir. 8		0	0	0	0	+2	+2	-1	-1	0	0	0	0	-1	0	+1	0	0	0	+3
9					0	0	0	0	0	0	+2	+2	0	0	0	0	0	0	0	0
10																				
CUT CORRECTION (Over 3mm)															2					6
BACKING STRIP CORRECTION (Over 5mm)																				

FIGURE 5-11: Knowledge of accuracy achieved for the ends of girders and longitudinals in each block is needed to plan hull erection.

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