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ASSURANCE AND MEASUREMENT OF SPACE VEHICLE ALIGNMENT

PREPARED BY
A.W. DRYDEN
QUALITY ENGINEER
QUALITY ENGINEERING, RELIABILITY ASSURANCE
SPACE SYSTEMS CENTER
DOUGLAS AIRCRAFT COMPANY, INC.
HUNTINGTON BEACH, CALIFORNIA

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ASSURANCE AND MEASUREMENT OF SPACE VEHICLE ALIGNMENT

A. W. Dryden, Quality Engineer
Reliability Assurance
Douglas Aircraft Company, Inc.
Space Systems Center
Huntington Beach, California

INTRODUCTION

This paper discusses the techniques implemented at the Douglas Aircraft Company, Inc., Missile and Space Systems Division (MSSD), to measure and ensure that alignment of space vehicles conforms to design requirements. The intent of the paper is to disseminate useful specialized information and knowledge to enable those interested to keep abreast of technical advances. Equipment and methods used to align large space vehicles are illustrated. Combinations of standard commercial tools, optical instruments, specially designed tools, fixtures, and equipment are employed to prove vehicle alignment. Special techniques developed to align large cylindrical, spherical, and conical structures for rotational displacement, relationship of true centerline, and engine geometry to vehicle axis are discussed. Consideration is given to future alignment problems created by technological advances and quality controls to ensure high standards that meet tomorrow's requirements.

SPACE VEHICLE ALIGNMENT--ASSURANCE AND MEASUREMENT

Alignment is the adjustment of a component or the interfacing of a subassembly and major structure to a predetermined line, point, or basic reference system. Alignment requirements must be imposed upon contractors to ensure uniformity of product. Accurate alignment data are of great value in determining various design parameters.

Contractual Requirements

In the space program, numerous contractors participate jointly in the design and fabrication efforts to produce multistage boosters and space vehicles. To meet the demands for greater dimensional accuracy and interface and interchangeability requirements, the contractors must adhere strictly to a rigid system of measurement. Contractual alignment requirements provide the customer with objectives that ensure that structural components achieve acceptable and compatible structural integrity.

Data for Product Evaluation

Accurate alignment data are extremely important since they enable the engineer to evaluate the effects of allowable structural and control misalignments. Data furnish the basis for the analysis of permissible and expected dimensional tolerances, load distribution, load limits, and structural adequacy.

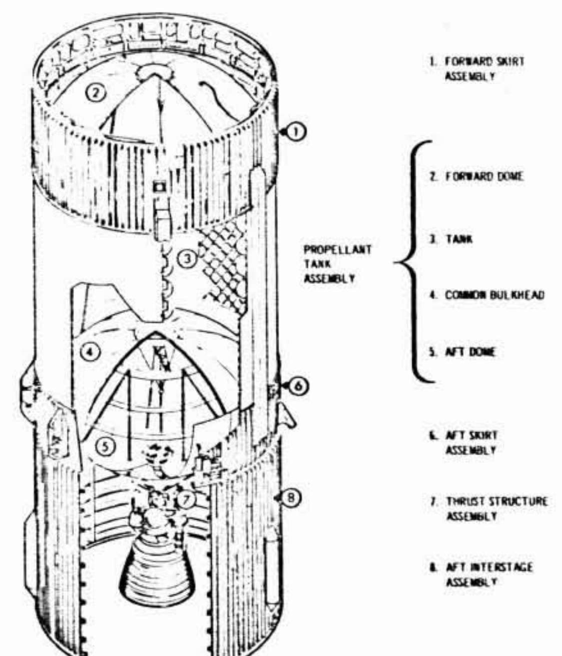

Figure 1. Saturn IB/S-IVB Location of Major Components

Types of Structures Aligned

It is interesting to note the various configurations involved in alignment. Figure 1 illustrates the three types of structures that are of primary concern: cylinders, partial spheres, and cones.

The basic cylinder section is constructed of aluminum alloy segments. The interior of the segments are milled to a waffle-like pattern, then formed to contour. The segments are progressively joined by welding until the cylinder is complete (Reference 1).

"Orange peel" segments of partial spheres or domes are formed to a spherical radius, then mounted in special fixtures and welded progressively to completion.

The thrust structure is an example of a conical component. The assembly consists of attach angles and stringers riveted to aluminum skins and joined to the engine-mount casting.

ALIGNMENT METHODS

The size of large components and their relationship to required accuracies generate numerous problems in the areas of alignment and measurement. To meet these complicated and challenging problems, it is necessary to develop mechanical and optical techniques far more sophisticated than those applied to normal aircraft methods (Reference 2). Specially designed tools are fabricated to assemble huge components to exacting tolerances. The design emphasizes precision and simplicity. A tool-proving cycle is performed thoroughly to guard against the pressures of tight manufacturing schedules and loss of dimensional integrity (Reference 3). Proven success in the performance of the tools is necessary to ensure accurate results in the alignment process.

Tooling as an Inspection Medium

Use of tooling as a medium of inspection permits greater flexibility, faster set-up time, and easier verification of control points. Liaison between quality engineering and manufacturing engineering in the tool design and fabrication phase enables implementation of inspection media. Desirable features are as follows:

1. Rotation capability that provides a means for turning the vehicle to perform inspections during manufacturing.
2. Floor target reference points which establish a basic reference plane independent of that of the assembly tool, thus enabling detection of any change or misalignment in the assembly tool by comparison of the reference systems.

3. Interfacing planes accurately machined to within 0.010 in. to ensure control of parallelism while large vehicle components are being assembled.
4. Mastered hole patterns and index points for control of interchangeability requirements of large geometries. Index points furnish positive component location and protect against rotational misalignment.

Dial Indicators--Dial indicators are fine precision instruments which have a number of applications and are capable of reaching virtually inaccessible areas. Fabrication of indicator attach points as part of the assembly tool facilities in-process checking and inspection. Inspections combining rotation and use of indicators are performed to (1) verify horizontal datum plane runout and to (2) obtain concentricity and centroidal data to verify compliance with engineering requirements.

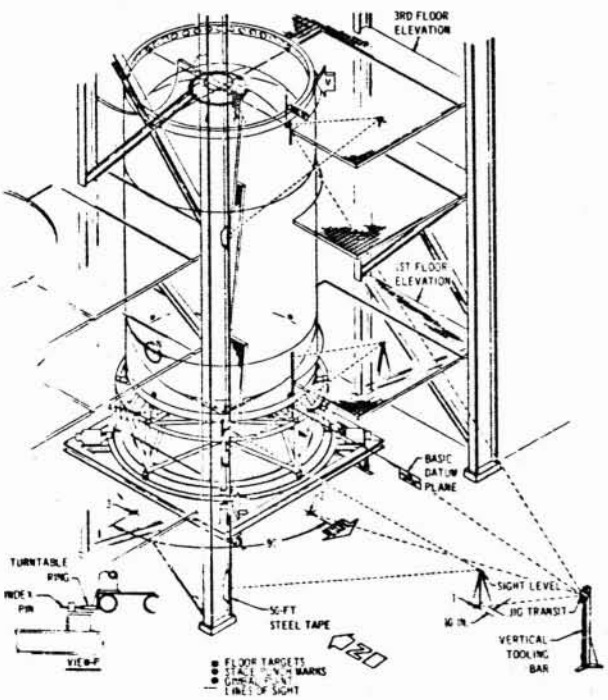

Figure 2. Verifying Alignment with Optical Equipment and Tooling

Optical Instruments--The use of optical instruments and optical tooling has rapidly become established as the only accurate method of performing measurements on objects which are too large to permit use of surface plates or similar fixed machined surfaces as a basis for mechanical measurements. Figure 2 illustrates the use of optical equipment and tooling to verify vehicle alignment (Reference 4).

Jig Transits--The jig transit establishes a vertical plane, in any location desired, between two established points and/or precisely at right angles to any other line of sight.

Precision Sight Levels--Precision sight levels establish a horizontal plane at any desired height.

Microptic Clinometer--The precision microptic clinometer, an instrument capable of measuring minutes of arc, is used to measure angular displacements with consistent accuracies of 10 sec of arc. Values can be read directly.

ALIGNMENT POSITIONS

It is important to consider alignment position. A simple approach is more often the correct and most economically feasible. Experienced judgment must be exercised in a great number of instances.

Horizontal Alignment

Horizontal alignment, though desirable in many respects, has limitations which must be considered:

1. The vehicle configuration must be complete.
2. In the horizontal position, loads are shifted and in many instances stresses are created, making it difficult to obtain accurate data.
3. Additional tooling for supporting and handling the vehicle is often required.
4. Forced implementation of nonscheduled manufacturing flow and out-of-position techniques are utilized.

Vertical Alignment

Vehicle vertical alignment through the central axis must be accomplished during the manufacturing phases. The following significant factors favor adoption of vertical alignment techniques:

1. Large structures and subassemblies are joined with the vehicle in a normal flight attitude.
2. Tools designed to join the assemblies provide an inspection medium.
3. Alignment verification is compatible with the manufacturing schedule.

The critical alignment requirements for achieving vertical alignments are established by measuring the following:

1. Rotational alignment.
2. True centerline location.
3. Relationship of engine geometry to vehicle.

Rotational Alignment--Figure 3 illustrates the method established to verify displacement of assembled components. Marks, precisely punched upon the attach-angle surface of the subassemblies during fabrication, form the component position axis.

Optical tooling establishes a network of invisible lines of sight which can be arranged, rearranged, and adjusted in a variety of sequences as primary and secondary lines of sight. Using these lines, inspectors can adjust and prove dimensional relations, angularity, squareness symmetry, and perpendicularity of large assemblies that require accurate alignment.

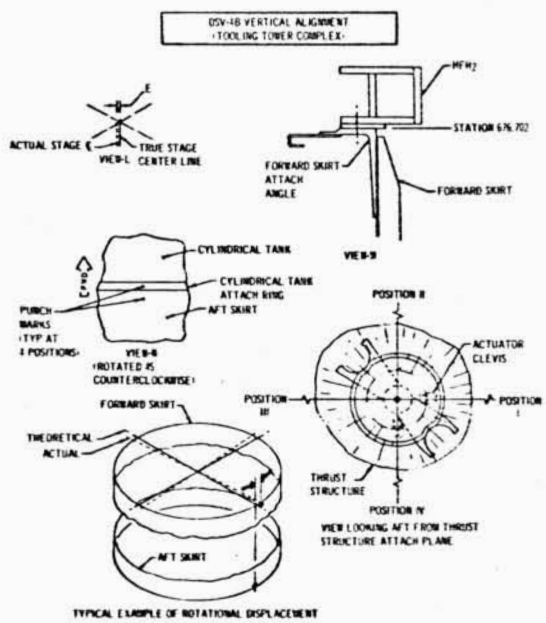

Figure 3. Verifying Displacement of Assembled Components

Figure 2 illustrates the floor reference targets which form the basic datum points for the position axis. A jig transit is adjusted to establish a line on the floor reference target. The assembly jig can be rotated to allow the position points of the jig to coincide with the line of sight of the jig transit. The jig transit is arced to observe attach-angle punch mark. Adjusting the optical micrometer attached to the transit objective lens permits displacement observations to be measured and recorde‘’

True Centerline Location--Analysis of recorded displacement data provides the means for determining

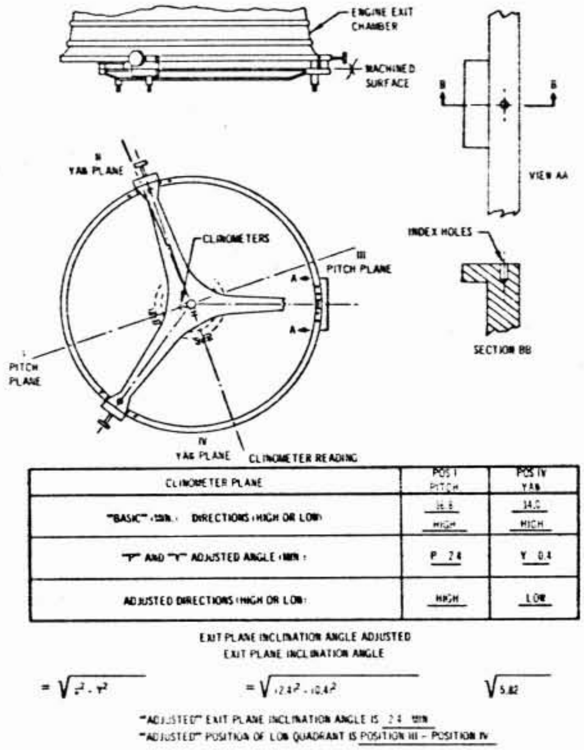

Figure 4. Single-Engine Configuration

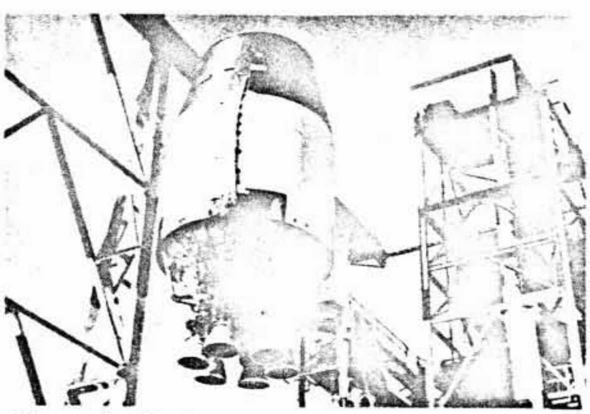

Figure 5. Vehicle with Six-Engine Cluster

location of true centerline and implication of measurement error.

Relationship of Engine Geometry to Vehicle--A single-engine configuration is shown in Figure 4. Relationship of engine to vehicle is verified with a special alignment fixture positioned on the engine exit plane and indexed in tooling holes located in the engine exit flange. Two clinometers positioned on the machined surface block in the center of the fixture are adjusted to permit center-level bubbles to read to the nearest 1/10 min. Clinometer angles and directions for position planes are recorded. The "adjusted" exit plane inclination angle is computed to the vehicle horizontal datum plane. Data recorded must be accurately established in order to be useful and meaningful.

Figure 5 illustrates a vehicle with a 6-engine cluster. Manufacturing techniques implemented to install the engines made it necessary to verify engine alignment by horizontal methods.

FUTURE ALIGNMENT PROBLEMS

Future aerospace business will involve building, testing, firing, recovering, and refurbishing large payload boosters. Large crews on manned space vehicles and longer missions can be expected. Vehicle dimensional tolerances and surface smoothness requirements probably will not exceed current tolerances. Other tolerances may be more critical because of the need for high-performance structures, space limitations, and operating-temperature range. Size alone often will create problems. New materials and requirements for extreme reliability will necessitate development of highly refined manufacturing techniques and new skills.

Continued development of inspection criteria and quality control methods is necessary to keep pace with advancements of the space age.

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