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CAST AIRFRAME PRIMARY STRUCTURE

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Summary

Substantial cost reductions are available on certain classes of aircraft structure when they are produced using the casting manufacturing process. In order to learn more about this technology when applied to large flight critical structures, a generic development airframe component has been cooperatively produced by Boeing Commercial Aircraft Group (BCAG), Japan Aircraft Development Consortium (JADC) and Hitchcock Industries Inc (HII).

The casting was designed to meet all structure design criteria for large flight critical applications on commercial aircraft. A developmental manufacturing and testing program has seen structures produced and tested under damage tolerance and fail safe regimes. The joint program, and some of the preliminary test conclusions are briefly presented in this paper.

Structural Casting Background

Motivation

Aircraft prime contractors continue to explore technologies for reducing the cost of airframe manufacture, while maintaining safety and performance. Airline economics are such that a major part of operating costs is related to aircraft purchase price. The airframe manufacturer's major competitive tool is the reduction of structure manufacturing cost. In the last 5 years or so, cast aluminum structures have been introduced into production. They have provided substantial cost saving while maintaining weight neutrality. Examples are included below.

Historical Position

The casting manufacturing method has always been regarded as an economical manufacturing process in general; this is the primary reason it is so widely used in the commercial and automotive industries. A one time investment in tooling is re-paid with lower recurring man-hour content in production. Liquid metal in a complex tool can produce considerable detail and configuration that would otherwise have to be manufactured with machining or fabrication and assembly operations.

In aerospace, the quality requirements, and conservative approach of the structures engineering community to new materials, have up until more recently limited the widespread use of casting technology (with notable exceptions in military aircraft and missiles) in structural applications. This has been due to historically larger than normal material property and process variations. These typical variations led to the requirement for a casting factor.

The casting factor has not been well understood. It is used to cover the potential property variation, it is not included because of the lower static strength of some of the casting alloys. (Note: Casting alloys are less strong because they have *different metallurgy*, not because they are "poor quality".)

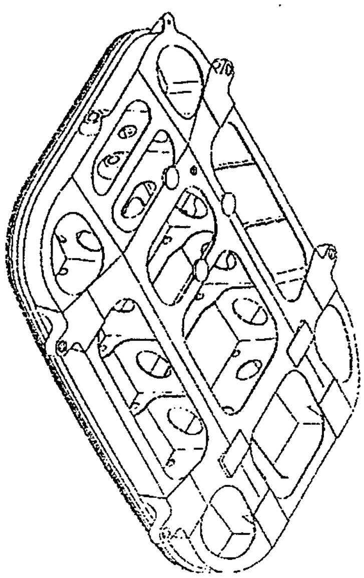
Manufacturing process improvements have led to the development of material specifications (such as AMS 4241 for D 357-T6 Aluminum), that when used by qualified foundries, now produce material of high consistency. Such consistency means that statistically valid static design allowables are available for design, and thus a casting factor is not needed. Indeed the presence of allowables for D 357-T6 in Military Handbook 5 means that a casting factor is not required for military aircraft design.

Work is presently underway to re-examine the casting factor in the Commercial Aircraft Airworthiness Regulations. Despite its presence, all the examples below have been weight neutral at worst. In general, the weight impact of a casting factor of 1.5 on fatigue driven designs is very small if present at all.

Present Structural Usage

Equipment Bay Access Door.
(Pressurised application)

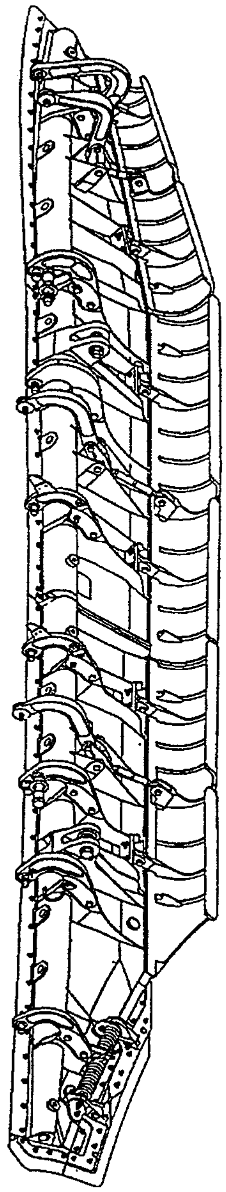
- Cast Skin.
- Cast Seal Groove.
- Machined OML Surface
- Cost reduction.
- Parts count reduction.
- Easy final attachment of hinge and mechanism.
- Weight neutral, increased static margins.
- Enhanced fatigue and damage tolerance demonstrated under test.



Cast Electrical Access Bay Door

Leading Edge Flap.

- Cast OML Skin of complex curvature.
- Cast Lugs.
- Cast Torque Tube Backbone.
- Complex curvature attained at no extra cost.
- Very consistent geometry in production.
- Machined hinges are very simple though the design of optimum double shear attachments to the casting.



Cast Leading Edge Flap

Test Structure Project Description

Objectives

The purpose of this work was to demonstrate through test that an aluminum casting could meet all the design criteria that apply to large flight critical structures on certifiable commercial airliners.

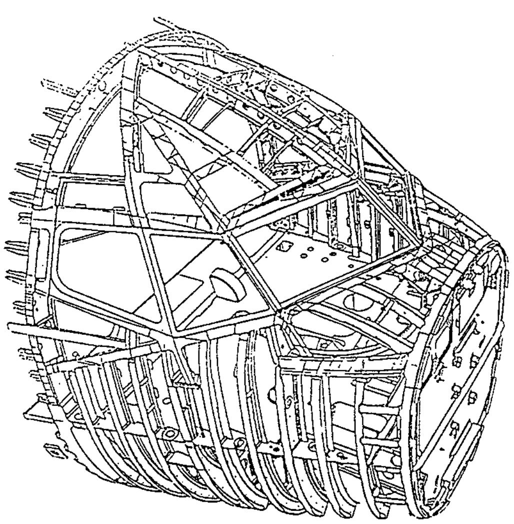
The requirements on the structure are from three sources:

- Airworthiness Requirements of FAR / JAR 25.
- Airline requirements for economics and repairability, and
- Internal organizational standards that the airframer, in this case Boeing, applies to attain damage tolerant and fail safe designs that will perform well and can be certificated. Most of these "philosophies" go beyond the "letter of the law". They have been developed over the years with much in service experience.

Key among these requirements, and the one that generates the most discussion, is the means to achieve fail safety. In conventional structure the redundant load paths needed to meet this criteria are separate structural elements, frequently completely discrete pieces.

The primary objective of this program was to design, produce and test a structure using a one-piece casting that could meet these requirements. At the same time the economical advantages of such a structure in a production context were to be evaluated.

The program was called CAPS for Cast Aluminum Primary Structure. In order to facilitate realistic comparisons between conventional fabrications and cast structure, the decision was taken to cast a generic version of an existing structural assembly on the 737.



Forward Fuselage Showing Many Complex Fabricated Assemblies

Design and Procurement Process

Design

A central part of achieving the objectives as outlined above was to develop a new structural configuration that synergistically matches the flexibility of the casting manufacturing process with the needs of the structure to meet the full set of criteria. The casting process is not well understood by many aircraft designers, and indeed it is highly dependent on configuration, so the input of all disciplines is required. Product and process design needs to go "hand in hand".

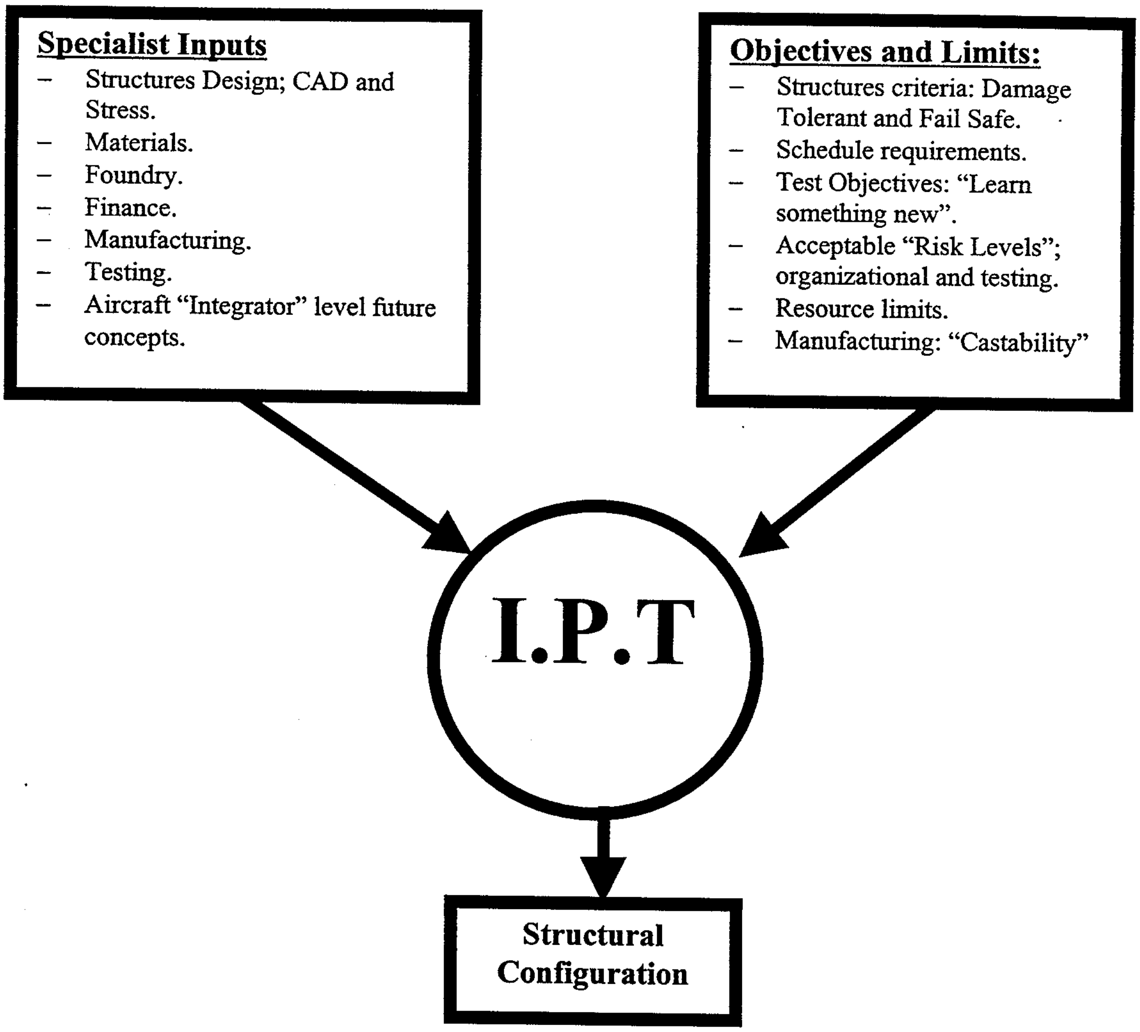
With the recognition up-front by Boeing and JADC that the design activity was of fundamental importance, the decision was taken to form a broadly experienced "Integrated Product Team". The figure below shows some of the inputs and considerations of the team.

The supplier was involved at the very beginning during conceptual layout. In these first few days, issues of overall configuration and the producibility of different concepts were addressed. As an example of the benefits of such cooperation, the decision was taken to design a structure with certain elements of symmetry, this allowed a considerable reduction in the amount of tooling, leading to non recurring cost and time savings.

Procurement

This program was different to a normal casting procurement process in a number of ways:

- The whole program from launch, through selection of the foundry, design, manufacture and test was only 15 months long.
- The foundry was selected (based on competitive bid) before any design had been done. This allowed the supplier (in this case Hitchcock Industries) to be fully involved in all design decision making.
- Normal procurement specifications were relaxed. Their individual requirements were applied prudently to ensure relevance to technical needs. This gave savings on non value adding requirements.
- Key characteristics geometry inspection approach; as compared to 100% dimensional inspection as normally required.



Description

Structural concept
At this time the actual configuration of the test structure remains proprietary. It utilizes casting configuration flexibility to include dual load paths in all areas. Also the casting demonstrates the "out of the plane" configuration elements that are uniquely feasible with a casting.

Exploration of limits
The team sought to retain what could be considered "poor detail design" features, giving high stresses. This was done in order to attempt to obtain cyclic crack growth during test. All previous structure testing in this material had been associated with certification programs and so stress levels and detail design features have always been managed to produce a low chance of fatigue damage occurring naturally. Consequently, there have been very few observed fatigue damage initiations and even propagation after damage introduction.

Understanding of the crack growth behavior in a monolithic part made from this material is fundamental to future certification of such large critical structures that need to be damage tolerant. Because of this, the opportunity was taken to include design features operating at different levels throughout the casting. In this manner the test article is not representative of a production design.

Material Specification and Properties.
D357-T6 Aluminum Silicon Magnesium casting alloy per AMS 4241:

- Statistically valid static design strength allowables in Military Handbook 5
- F_{TU} = 50 ksi (344 MPa)
- F_{TY} = 40 ksi (276 MPa)
- Elongation = 5%
- Isotropic: No LT, ST properties.
- Good general corrosion resistance.
- Good Fracture Toughness K_{IC}=20-27 ksi.in$^{0.5}$.
- Crack growth comparable to 7075-T651.

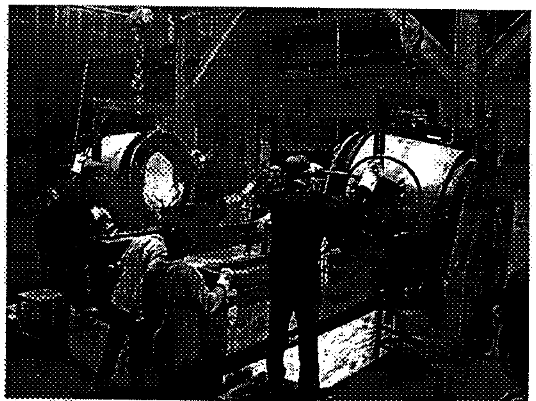
Composition per Aerospace Material Specification AMS 4241 for D357-T6:

	(Range WT %)	
Element	**Min**	**Max**
Silicon	6.5	7.5
Magnesium	0.55	0.6
Titanium	0.04	0.20
Beryllium	0.04	0.07
Strontium	0.008	0.016
Iron	--	0.20
Manganese	--	0.10
Others, each	--	0.05
Others, total	--	0.15
Aluminum	BALANCE	

Manufacturing

Because of the tight time scale, the manufacture of the test units was different to a conventional casting development program in a number of ways:

- Larger than normal casting, suiting the premium sand process, approximately 80 inches maximum dimension.
- The use of symmetry as already mentioned allowed a reduced core box tool count.
- Much of the tooling was "soft-rapid" tooling, which can be quickly produced without the use of conventional patterns. This kind of tooling is ideal for a program such as this because it is affordable and has a life of around 15-20 castings.
- Structural casting utilize machining of key and functional dimensions. Normally this machining is an integral part of the manufacturing process. For the CAPS program no machining was required. Test fixtures were built and shimmed to fit the few interfaces that existed.
- Digital Coordinate Measuring Machine (CMM) inspection of profile features. This reduced the conventional layout time required to characterize the geometry of the part.
- Minimal casting process development was undertaken. Metallurgical properties were acheived on casting number 2. Casting 4 was shipped for test. For the purposes of the structural testing program, mechanical properties and wall thickness where the main requirements. Some manufacturing issues associated with heat treat distortion were revealed.
- Not converged on production ready process, as the primary objective was to provide structures suitable for testing.



Pouring

Structural Test

Test data remain proprietary, however general comments can be made at this stage. Tests concerned the damage tolerance and failsafe performance of the generic structure.

Damage Tolerance:
The test structure was subjected to multiple lifetimes of cyclic pressure loading. As expected (and hoped for!) some cracking initiated naturally at areas of intentionally high stress concentration. In general this damage propagated in an orderly fashion for a short portion of the life, and then stopped growing. The conclusion being that in all cases of natural fatigue damage, the cracking changed the load distribution in the part which unloaded the cracked area. The damage was considered benign and easily inspectable.

Fail Safety:
To demonstrate fail safety, artificial damage was introduced into the casting by severing several of the multiple load paths. A structure with substantial damage including multi-bay saw cuts and severed frames etc was taken up to the fail safe load successfully.

Conclusion

The CAPS (Cast Aluminum Primary Structure) program has successfully increased knowledge about the behavior of large critical airframe structures that must meet the requirements for fail safe and damage tolerance. The design, casting manufacture, and structures testing program has been executed in 15 months using enlightened arrangements for teaming and procurement. Rigorous economic comparisons made by the finance organization have projected real and substantial cost reductions in production programs.

Acknowledgements

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