# Achieving Safety: A Field Study of Boundary Objects in Aircraft Technical Support

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**ABSTRACT**
Boundary objects are a critical, but understudied, theoretical construct in CSCW. Through a field study of aircraft technical support, we examined the role of boundary objects in the "achievement of safety" by service engineers. The resolution process of repair requests was captured in two compound boundary objects. These crystallizations did not manifest a static interpretation, but instead were continually re-interpreted in light of meta-negotiations. This suggests design implications for organizational memory systems which can more fluidly represent the meta-negotiations surrounding boundary objects.

**Keywords**
Organizational memory, boundary objects, collaborative work, information reuse, technical support, hotlines, safety, service engineering, high reliability organizations.

## INTRODUCTION

Star [13] developed the idea of boundary objects, shared informational objects that can be used by different groups for their own purposes. Other work has found boundary objects to be critical components of common information spaces [2, 12] and organizational memory [1]. Examples of boundary objects include:

- Employee payroll records in a database. A personnel department, responsible for the records, fully understands any employment issues for each employee. Yet others can use those records to identify employment status without knowing any of the details.
- Student grades. Future employers will not have access to the details of grading, using the course grade alone as an overall measure of academic achievement.

Despite boundary objects' theoretical importance in collaborative work, surprisingly little empirical work has examined boundary objects in themselves. Our work examines the use of boundary objects in a field setting, in order to further the design of organizational memory systems.



We wanted to explore boundary objects because we needed to understand how to augment memory when it is used by multiple groups in different ways. We were especially interested in what contextual information could or should be supplemented to provide greater flexibility in unanticipated reuse. As will be seen, we found certain meta-negotiation information to be most useful, extending the concept of boundary objects.

The study took place in a technical support center, which we call GTS-West. GTS-West is a high-reliability, safety-critical organization: It supports maintenance engineers dealing with passenger airplanes. For example, if a baggage handler slams the conveyor against a plane while loading suitcases, GTS-West takes the call to help evaluate the damage. GTS-West also handles a wide variety of service requests, determining whether suggested repairs or modifications will be adequate.

Such an environment facilitates the examination of boundary objects. Numerous repair requests run through GTS-West everyday; every one is unique though within recognizable patterns. As well, diverse groups actively collaborate in finding solutions, crossing many inter- and intra-organizational boundaries in the process. Most importantly, because GTS-West is a safety-critical organization, the creation and use of information artifacts are more controlled, providing an easier examination of their use.

The paper proceeds as follows: After a brief literature review focused on boundary objects in CSCW, we will present the site, the primary groups, and their organizational routines and information flows, both official and informal. The paper then proceeds to present two service requests. The first, a relatively simple case, reveals the basic use of boundary objects in this environment. The second uncovers some of the exceptional and situated handling of the boundary objects. The paper concludes with some theoretical extensions to boundary objects and design implications.

## LITERATURE REVIEW

Star [13] and Star and Griesemer [14] initiated the discussion of boundary objects. For them boundary objects are:

> …objects which both inhabit several intersecting social worlds and satisfy the informational requirements of each of them... They have different meanings in different social worlds but their structure is common enough

to more than one world to make them recognizable, a means of translation. ([14], p. 393)

The work has traveled in several directions since. Bowker and Star [5] recently have focused on the role of boundary objects in translation, specifically how boundary objects assist in classification and how they calcify into standards. Other studies have focused on how boundary objects play in the micro-negotiations within developing shared understanding. Henderson's work with design engineers [7] centered on how engineers use diagrams, drawings, and blueprints as points of negotiation. She focused specifically on the changes, both positive and negative, occurring as the CAD revolution shifted these artifacts from paper to digital form. Bechky [3] also attended to the role that drawings play in negotiations among engineers. However, she focused on drawings that explicitly span social world boundaries (e.g. moving from design to manufacturing).

More to the point of this paper, other researchers have examined what is inscribed on the boundary objects in the processes of negotiation, and the meanings behind those inscriptions. Berg and Bowker [4] detail how patient records in hospitals act as boundary objects "producing" the patient for physicians, technicians, and nursing staff via the mappings between the individual and their surrogate representation in the record. Mambrey and Robinson [10], in the GMD's POLITeam project, looked at boundary objects and their inscriptions, primarily those of workflow. In their study of a German ministry, inscriptions detailing workflow allowed groups to understand the relative meanings for an artifact. They also noted that boundary objects could be compound: Folders circulated with enclosed papers and documents. Ackerman and Halverson [1] reported on a personnel hotline, detailing the information flows within telephone calls and the construction of the answers. In all of these, as Star points out, boundary objects were necessarily decontextualized on one side of the boundary, and reconstructed on the other. The reconstruction of the boundary object, for example a personnel record, was found to be critical to reusing information in organizations.

Several other streams of research in CSCW are of importance in this work. Boundary objects allow an ability to represent multiple perspectives of a single information artifact, interpret the negotiations that govern its creation and evolution, and map the intersection of social worlds onto aspects of the artifact itself. In this function, boundary objects are similar in their negotiation affordances to coordination mechanisms [11]. As well, Bannon and Bødker [2] points out the importance of what they call punctuation in informational artifacts, moments when informational artifacts cease to be dynamic and changing, and instead crystallize. We will return to these points below.

## SITE AND DATA COLLECTION

Customer support is a rich venue for exploring the use of organizational information in general [1]. Hotline situations have sufficient routine work to map their information processes; yet, there are always new questions and problems. Technical support work is time critical and extremely information intensive

As mentioned, this paper reports on a field study of Global Technical Support (GTS), the division within Global Airframe that provides technical support for the operators of Global aircraft (e.g., airlines and airfreight companies). Technical support in this domain involves assisting in creating, validating, and authorizing one-of-a-kind maintenance repairs to individual aircraft in an airline's fleet. This support is required of all airframe manufacturers by the Federal Aviation Administration (FAA), but technical support has also been a key selling point for Global Airframe.

GTS offices are located throughout the United States; the study focused on one in particular, GTS-West. This office is responsible for an entire family of aircraft models, dating back to the early 1930s. (The FAA mandates that as long as a single plane remains in service, the entire model must be supported.) GTS-West supports over three thousand in-service aircraft, all of which are post-production, having been manufactured by a merger-partner.

In many ways GTS-West is a typical technical support environment; however, it exhibits some uniquely defining characteristics. As mentioned, it has a high requirement for reliability and safety, but with growing requirements for turnaround time and price. Furthermore, this situation exists within a complex regulatory and legal liability web, which must be addressed by all information processes. Finally, there is a constant concern about the public visibility of mistakes.

The analysis of GTS-West here is based upon thirteen months of participation observation at the site by the first author [8]. The findings discussed in this paper emerged from a detailed analysis of twenty cases of airline support requests followed throughout the organization. Because of access restrictions, additional complete cases could not be obtained, nor could audio- or video-taping occur. These cases, therefore, were supplemented with over 210 critical incident descriptions (i.e., parts of cases) captured in field notes, as well as over 80 detailed interviews with service personnel, similarly captured. The first author also had extensive access to archival and secondary materials (including critical information artifacts) and participated in twenty-five weeks of business process re-engineering meetings. The cases, critical incidents, and interviews were coded and analyzed according to standard qualitative techniques [15].

All identifiers, including the site and people, have been made anonymous. Any quotations are from the fieldnotes.

## GTS-WEST

The GTS-West staff takes pride in the quality of their work and their industry-wide reputation for service. They are very successful with respect to their key metrics of time-to-response, completeness of answers, and overall customer satisfaction. They can accomplish this with limited staffing and resources because of two inter-related factors. The first is the highly generalized knowledge of the workforce. (Unlike the tight specialization common in the industry, all GTS-West engineers are expected to work outside their immediate expertise.) The second factor, which supports the first, is a culture of information reuse.

The GTS-West team consists of over 200 engineers and administrators divided among core aircraft service areas (e.g., Structures, Payloads, Hydraulics), analytic support for these areas (e.g., Stress, Repair Design, Damage Tolerance Analysis), and general customer service groups. Aircraft are exceedingly complex pieces of machinery, with many interdependent systems. Thus, it is the exception, rather than the rule, that a service request can be resolved without collaboration between at least two of these groups. This study concentrated primarily on the relationship between the Structures group and their primary analytic support group, Stress.

Structures is a group of 27 service engineers, responsible for supporting all aspects of the airframe on both cargo and passenger aircraft. They are subdivided into three teams by aircraft type (long-haul, short-haul, and heritage aircraft). These teams are managed as a single group, with a joint manager, but in day-to-day operations they operate quite independently under their own supervisors. Structures had the heaviest volume of service calls at GTS-West, more than double the nearest group. In 1999, they fielded approximately 12,000 actions and this number was climbing rapidly. (The increase has been 8-10% annually since 1993, and it is expected to be even higher now that its entire fleet is post-production.)

Structure's primary support team is Stress. Stress provides all of the advanced stress analysis for the air-worthiness of repair actions generated by the operators and approved by Structures. These analyses are mathematical models of varying complexity which determine the impact the repair will have on the sustainable strength of the assembly and assist in predicting the repair's longevity. Typical results of these models involve maximum load tolerances, expected lifetime of repairs, safety characteristics of repairs, and materials performance. Stress also initiates and coordinates the FAA approval process for these repairs. Structures works closely with Stress for over 80% of their actions; the job simply could not be done without this collaboration.

Organizationally, Stress is equivalent in size with 32 engineers. Stress has a single manager, but is subdivided into four teams, each with its own supervisor. Three teams are arranged to mirror Structure's subdivisions and one exclusively serves the special analysis needs of the Hydraulic and Mechanical groups. The emphasis in the study was on the three teams that interacted directly with Structures.

As with all the other GTS facilities, the GTS-West office is located onsite at the production facility. This location decision is deliberate, providing the service engineers with easy access to all of Global's expertise for their airplanes, from original designers, to sales staff, to technical writers, to the team that rivets the nose cone fasteners. This proximity also allows GTS-West to draw its staffing heavily from those who have worked on particular aircraft models within another functional division (e.g. design, manufacturing).

Their actual office is a vast, open floor plan with a combination of open desks and low (3') cubicle dividers. Stress is physically sandwiched between their two primary service engineering teams, Structures and Hydraulics, facilitating frequent face-to-face interaction. For the majority of the study, the first author sat at the physical boundary between Stress and Structures, near the supervisors for Stress.

In order to understand routine interactions in this environment, it is critical to understand the groups more fully. The following sections detail the core differences between the groups, as well as their functions.

## STRUCTURES AND STRESS

The engineers in Structures and Stress belong to different communities of practice [18] – they have different professional backgrounds, working cultures, and vocabularies. Culturally, the Structures group resembles customer service organizations, with its attention to timeliness, while Stress is more akin to a quality assurance team. While relations between the groups are usually cordial, the tensions sparked by these often opposing worldviews are frequently palpable. It was not uncommon for Structures engineers to toss a request packet onto a Stress desk and demand immediate attention for their job. One particularly difficult month seeded the departure of both groups' line-managers and provided the genesis for the business process reengineering effort to address their collaborative processes. In order to better interpret the interactions surrounding a service request resolution, some of the groups' core differences will be addressed next.

### The Structures Group

As service engineers, the people in Structures are the interface with the airline's maintenance engineers. They directly handle all structural support queries from the airlines. In this capacity their experience is quite similar to other second-tier technical support environments. The days are long, grueling, and high-stress. The stream of incoming requests is unrelenting. Praise for a job well done is rare, while operator complaints are the norm.

The service engineers know their customers well and are quite savvy at tailoring information to match their needs and abilities. Many of these service engineers have worked their way up through the field support or manufacturing segments of Global Airframe and are accustomed to being close to both the customer and product. They tend to be gregarious, extroverted, and cynically humorous.

Because of a customer-centered business model, Structures breeds a culture of efficiency and expediency. Everything is monitored and measured by management: timeliness, completeness of response, and customer satisfaction. These metrics are directly tied to each individual's performance rating, salary increases, and bonuses.

These engineers have the final say on all repair recommendations and are ultimately held individually responsible for them. They are meant to be the sole contact the operator has with GTS-West, black boxing all other functions.

### The Stress Group

The Stress analyst's job consists largely of gathering information to build an evidentiary case for a particular repair decision and then running through the requisite mathematical models to test that case. The analysts stand in ultimate judgment on each repair – either it is safe or it is not, period.

By deliberate organizational design, Stress engineers do not have contact with the operators. This objective detachment is one critical component of the system of checks and balances that yields the high-reliability of response required by aircraft repair. Not having to please the customer allows Stress to be more impartial in their assessments. However, this detachment is a perpetual source of friction between the two groups, as Stress often has to work in a contextual vacuum, solely dependent upon the Structures engineer for the relevant details surrounding the current job.

The Stress team consists of "engineers' engineers" – more abstract and theoretical than the service engineers, some even hold doctorate degrees. In recent years, intense downsizing of the design and production units at this plant has enabled some of the best analysts from these groups to join Stress.

The organization's emphasis on safety has fostered within Stress a culture obsessed with reliability. Stress engineers will proudly tell you that their calculations determine whether a plane flies or not. Nearly all will work on a problem until they are convinced beyond reasonable doubt that the repair is suitable for strength. This passion for error-free evaluations comes at the cost of timeliness (sometimes the calculations for particularly onerous problems can stretch over days), which clearly puts them at odds with Structure's response-time focused service engineers. It is in this tension of tight conflict and collaboration that all routine work is accomplished.

The following section provides a high-level overview of the routine collaborative work between Structures and Stress.

## ORGANIZATIONAL ROUTINES

The vast majority of technical problems arising in the usual operation of an airline fleet are resolved locally by the operator's maintenance crews using the structural repair manuals provided by the manufacturer. For anything standard, maintenance engineers can look up solutions in the Service Request Manuals (SRMs), roughly analogous to FAQs for maintenance questions. Only exceptional problems, or problems requiring special certification, are routed to GTS.

These operator requests arrive via an augmented e-mail system, GlobalCOM, which routes them to service engineering supervisors based on the aircraft type or section in question. Each supervisor assigns the request to an appropriate service engineer based on its content and their workload. The engineer will then contact any number of the analytic support teams necessary to resolve the problem.

In order to complete each service request, Structures and Stress rely not only upon each other, but also upon a vast, complex web of information resources. This web often includes local experts, specialists throughout the company, blueprints, design specifications, regulatory guidelines, technical journals, records of operator communications, myriad databases, and a division-wide workflow management system. In addition, for every action requiring stress analysis both groups use a legacy STAIRS database of "Records of Conversations" (ROCs) – summaries of all prior operator requests, stress analyses, final answers, and FAA approvals. The simple distinction between these two systems is that GlobalCOM manages all external coordination while the ROC coordinates all internal collaboration. Every repair request is a unique boundary object instance in each system, with crisp boundaries between GTS-West and the operator, and between Structures, Stress, the FAA, and the other analytic support teams.

For Structures and Stress there are three standard classes of prioritization. The most pressing is "aircraft on ground" (AOG) which deals with aircraft in revenue operation and requires a same-day resolution. The second class, "urgent," covers a range of situations that require next-day turnaround. These most often involve work stoppage crises at repair stations. The final class provides for the industry standard 3-5 business day response time. A rough distribution of these jobs in 2000 was 30% AOG, 55% urgent, 15% regular. (This distribution was quite different for the other groups at GTS-West, as Structures routinely received the highest percentage of both AOG and urgent jobs.) The first case below is an AOG request; the second is an urgent.

Although this section has been quite general, it has introduced the primary flows and the information systems which support them. The following case, among the simplest in the field notes, will embody these processes by following a service engineer and a stress analysis through a typical Monday morning job. This case highlights the officially sanctioned and unofficial organizational processes applied to understand and solve the problem. (A simplified mapping of the core information flows is provided in figure 1.)

## CASE 1: BASIC INFORMATION PROCESSES

Beechwood International Jet experienced damage to the auxiliary power unit (APU)[1] cover ("door") on one of their short-haul N-27 jets upon landing. Beechwood did not have the replacement part in stock, nor did any of their vendors. The earliest they could have the part delivered was two weeks - extremely expensive downtime for their jet, especially for an important but non-critical component such as

[1] The APU is a small turbine engine used to generate electricity while the airplane is not in flight. Its primary purpose is to act as a starter for the main jet engines and run lighting and environmental systems while on the ground.

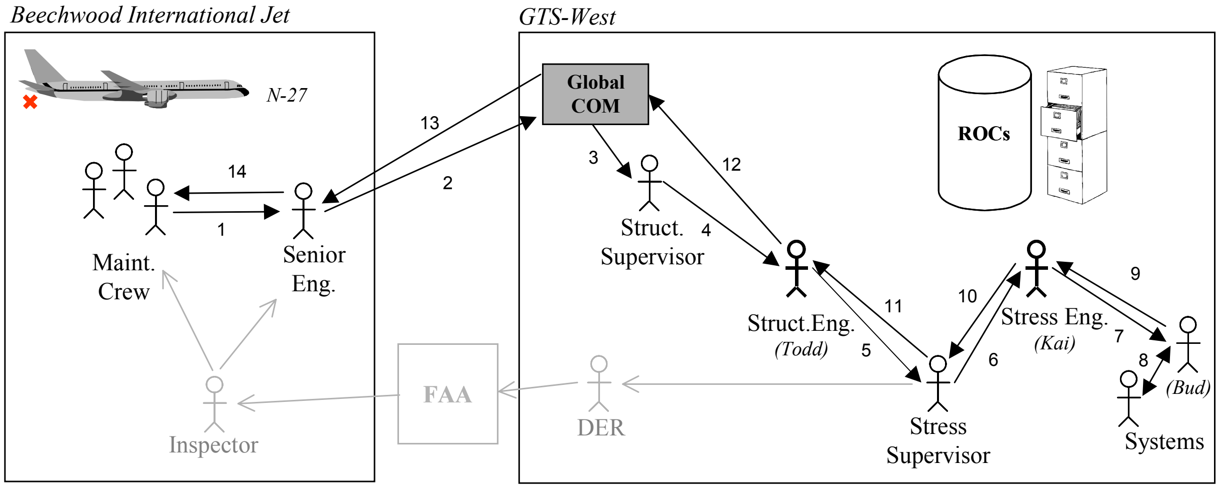


**Figure 1: A simplification of the information flows in Case 1.**

the APU. In their search, however, they did find a replacement door to an N-23, part of the same N-20 model family as the N-27. They needed to contact the manufacturer to verify if this replacement would be acceptable for a ten-day temporary repair.

It was early Monday morning when this high priority, "airplane on ground" call from Beechwood was routed to Todd, a senior structures engineer, by his supervisor. Todd was sifting through the seventy e-mail messages that had backed up in his inbox from the last couple of hectic AOG-filled days, trying to prioritize them into a reasonable schedule for the day. With this new AOG interruption, he abandoned his effort and got to work right away, remarking "in today, due today!"

After a quick review of Beechwood's request, Todd concluded that this proposal was a reasonable course of action, but that it would require both a Stress analysis and a Systems consultation before final approval. (Systems is responsible for propulsion and environmental components.) "We have to see if the door fits. Systems has to see if it works." He edited Beechwood's request to create an initial ROC, which he then submitted to Stress.

Kai was assigned as the Stress analyst for this job. His task was to confirm that "this [door] fits as the other would fit. [To do this] the door has to fit perfectly -- hinge, latch, everything."

**Workarounds**

The beginning of the case has unfolded in line with the official process. Things now begin to go awry, and to accomplish the everyday activity of the organization, the official processes of the organization must be supplemented and transformed by a set of informal working arrangements [16]. Kai facilely deviates from the official process in favor of quick solutions to potentially time consuming problems to best service this AOG. He will personally research details overlooked by Todd (instead of returning the request to him). When he discovers that a requisite blueprint is missing, he will run to the library and generate a new one (instead of placing an order for a reprint). He will walk the job over to the Systems department for a needed consultation (instead of reassigning the ROC).

Kai started the job by pulling the relevant blueprints, "I'm not one hundred percent familiar with this door." He believed that the two doors look the same but he needed to verify that they had the same material properties. Kai needed to find the supplemental blueprints which specifically described the N-23 and N-27 doors. One of the blueprints was missing from the filing cabinet. He asked around but could not locate it. Instead of ordering a new one, he ran off to the library to generate a new blueprint. With this he discovered that the N-27 door had an air intake hole, not present on the N-23, as well as a different structure on the backside of the door.

Kai acknowledged that this was now outside of his expertise, "well, it looks like the N-27 has a different APU. Different style, model, supplier… something. This requires more room for an input fan. It sits on top. The others don't have one like that." He would ask a service engineer in the Systems department to examine the assembly behind the door, to make sure that the N-23 door will not damage the APU itself -- "to make sure there are not problems and just generally get their okay."

With most routine jobs this would be reassigned to the Systems engineer. But given the AOG priority, Kai commented, "I'll just walk down the hall and list him as a reference. I don't know his name, but I know where he sits. I walked by his desk earlier and he wasn't in. I was just going to write him a note to put on his chair."

Bud, the Systems engineer, returned his evaluation. He had concluded that the door would not interfere with the APU mechanics, but it would render the unit unsafe to operate. In addition to seeking this expertise from Systems, Kai also consulted the Minimum Operating Equipment List (MOEL), a document that lists what subsystems are required to be in operating condition for any given aircraft model. “If it’s not on that list, I’m not approving it [as operational]. No way.”

The APU was not on the list, so the repair instructions back to Beechwood would allow the use of the N-23 door but require that the APU be tagged “in-op” (not operational). “Since it will be in-op they’ll tag it in the cockpit. Put a red tag or tape on it [the physical control switch], and record it in the flight log. That’s all their problem, not ours.”

Kai’s work was then checked by his supervisor. The role of supervisors, both within Stress and Structures, is critical. Kai was confident that his supervisor’s final check of his response would highlight and repair any irregularities.

After the check, Kai approved the use of the N-23 door. He submitted the results of his analysis to Todd in the ROC. In the ROC, however, he also requested that Todd walk through the repair with the Beechwood crew, to make them aware of the differences in the doors. In the ideal blueprint world, the door would be a perfect fit. In the real world the aged fuselage could be slightly worn or warped from years of use. In addition the door might not be new stock, but might be a used part, worn and warped itself from years of use. “They’re [Beechwood] usually pretty good, but there could be a gap this big (holds up index finger and thumb to indicate about an inch).” To prevent this Kai was explicit about the measurements for all of the contact surfaces. “If these measurements were all met, there is no way the door can be a misfit.”

Throughout this Kai was critically aware of the time pressure, “Oh, I know this is an AOG. I should have it done in an hour or so. I know they [Beechwood] are waiting for this. It’s on the ground.” He worked through lunch to finish the job and hand it off to Todd. When he finally was able to take a mid-afternoon lunch break, his chair became buried in “respond to me now” notes. The job was resolved in a matter of hours. “Once we saw that there was no problem with fit, we let it go at that. It is only for ten days, temporary. I sent it off to Todd, oh, about 12:45 or 1:00.” Todd then edited Kai’s response and sent it to Beechwood by 2:15. “We let them go ahead and do it.”

The case has been resolved. The next two sections highlight how safety is achieved, both officially and unofficially, including how the unofficial is officially recognized.

#### Achieving Safety

What is most important to Todd and Kai is safety within the efficiency requirements of the situation. For them, this is “achieving timeliness”. It is not considered “cutting corners,” which to the participants implies jeopardizing safety. Achieving timeliness and safety simultaneously occurs through the support of official organizational structures as well as the informal workarounds that achieve outcomes suitable for the official process.

We have already highlighted many of the organizational structures that promote safety and guide the informal work. There were several official processes described above. As well, this entire story was surrounded by the regulatory oversight of the US government’s FAA, which monitors aircraft maintenance and operation. The internal, operating processes at GTS-West are all regulated by the FAA and are open to audit by the agency at any time.

The FAA appeared at several points in this case. The MOEL document, which lists the equipment necessary to fly a plane, is an agreement between Global and FAA, required for the original airline certification for the N-27 by the FAA. In addition, GTS-West personnel know that at the repair facility, an FAA inspector will ensure that the repairs are carried out by the operators according to the guidelines provided by GTS-West.

More to the point, Beechwood requested an FAA certificate, the 8110. An 8110 signifies that a repair has been done in accordance with all FAA regulations, and is required for all major repairs completed by US operators. As well, 8110s must be supplied for all repairs to aircraft sold to US operators.

Within the standard process, after the ROC has been approved by the Stress supervisor, a request for an 8110 is made and is approved by another level of double checking, the designated engineering representative (DER). The DER is a GTS-West employee who has been selected, trained by, and jointly reports to the FAA. They are considered by their colleagues and by themselves to be the most experienced and expert of the GTS-West engineers.

In the above case, Beechwood optimistically requested an 8110 on the off-chance that the N-23 door replacement could be permanent. Because the repair was found suitable only for 10 days, this repair was not submitted to the DER.

In Weick and Roberts’ [17] terms, the DERs provide a added level of redundancy to a High-Reliability Organization (HRO). HROs are organizations with zero tolerance for error, where even the slightest mistake can have catastrophic consequences. As a result, HROs have multiple layers of redundancy designed into their procedures. At first glance, the DER arrangement, with the DER being a GTS employee, may seem suspect as a level of redundancy. However, as with the labor inspectors in Bødker and Bannon [2], this arrangement is the only one that could preserve the trade secrets of Global Airframe. If the DERs were federal employees, the trade secrets would be subject to US Freedom of Information Act requests. A more important consideration, though, is that only someone internal to GTS, with an understanding of its planes, processes and people, could determine what is “achieving timeliness” and not “cutting-corners.” Officially, this is recognition of how things really are made to work to accomplish safety.

The official structures play only a part in accomplishing safety and timeliness simultaneously. We observed several workarounds above. For example, in handling a routine job, Kai should have reassigned the Beechwood ROC to the Systems department for consultation. The officially sanctioned process would have allowed the Systems supervisor to make an expert assignment of one of her engineers, and the results of this workflow element would have been automatically captured in the ROC. In the interest of time, Kai made the expertise judgment himself and inscribed the information on the ROC directly. His selection appeared to be appropriate, though the Systems engineer, Bud, did consult with one of his colleagues to confirm the response to Kai. As another workaround, Kai wrote Bud's name into the ROC as "a reference", a free-text list of resources consulted in building the evidentiary case for his recommendation. (However, Kai's supervisor edited the ROC to represent Bud as if the official workflow had been followed. Kai could not do this on his own.)

In general, people in both Stress and Structures are ultimately concerned with safety, making decisions that do not lead to incidents or accidents. However they approach this goal differently. For Stress, safety is primarily achieved through confidence in the strength modeling of the repair. They refer to this as the "quality of response." (This is reliability in the accountant's sense of consistency.) Structures, having more contextual understanding of the operator and the particulars of each unique repair request, achieves safety by finding feasible solutions that they know the operators can perform within their resource constraints. For them this is the "timeliness or fit of response". (Organizationally they are also rewarded for meeting request deadlines, which are set by the operators.) Safety is a practical accomplishment [6] within GTS-West; the work results in safety and reliability only because the people work to make the results safe and reliable. This will be critical in seeing how the boundary objects are used in the next case.

### Summary

To recap, the above was a relatively simple case. (Recall that all of GTS-West's service requests are in some way exceptional; completely routine repairs are handled internally by the airlines.) We presented this simple case to highlight the use of official processes with the flows of information across several boundaries and the use of informal working arrangements to actually accomplish the work. This is consistent with Mambrey and Robinson's as well as others' findings. As in the German ministry, we also observed the use of compound artifacts in the accumulation within the ROC and GlobalCOM as well as the inscription of workflow onto the document. (Note however that the electronic nature of the workflow inscriptions make them amenable to being inside and outside of the document simultaneously.)

In addition, we observed the creation of multiple boundary objects in coordination (and nearly simultaneously) and a tension between safety and timeliness which will get played out in the boundary object. We now move to a more complex case that more clearly elucidates the use of boundary objects within their context of use.

## CASE 2

The case began at SouthCentral Airline's regional maintenance facility. SouthCentral, like many large passenger operators, has large maintenance facilities at their hub airports where they perform routine fleet inspections and repairs on well-standardized schedules. Each facility has a sizeable maintenance crew and team of experienced repair engineers.

SouthCentral had one of their long haul aircraft in for scheduled maintenance. This time the aircraft was undergoing an extensive, month-long overhaul or "D-Check". (In a D-Check, they essentially disassemble and reassemble the plane.) As part of the check, the mechanics needed to verify compliance with a deadline for an FAA air-worthiness directive (AD). An AD is an FAA mandate to repair suspect or problematic parts; this is similar to an automobile recall. As part of the AD, the FAA tells operators how to inspect and repair the part. This AD was for the dorsal fin attach angles for the vertical stabilizer (i.e., where the leading edge of the tail assembly connects to the fuselage), a critical component.

Following a detailed inspection, SouthCentral realized that the current attach angle plate was not compliant with the AD and would need to be replaced. When the mechanics attempted to order the part, they discovered that the current plate was non-standard -- it had eleven fasteners (i.e., rivets) in the body of the plane instead of the blueprint thirteen. Having an incorrect number of fasteners was a critical problem, as it was likely to impact the strength and stability of the plate. Furthermore, that the plate had only eleven fasteners meant that the replacement plate would need to be specially created to match, at very considerable expense. First though, they needed to determine whether the current eleven-fastener configuration would actually be compliant with the AD.

SouthCentral placed an urgent ("next day") request with GTS-West for assistance. The job came in to Structures, as in the above case, in the form of a GlobalCOM message with scanned sketches attached to the digitized body of the written request. Upon reviewing the job, the long-haul supervisor assigned the job to Nadya, a senior service engineer. (The case was observed from the time it was received by Nadya.) In a brief aside from the work, she explained that SouthCentral faced two possible resolutions: design a special replacement part to match the existing hole configuration or retool the fuselage to blueprint in order to accept the standard replacement part. The former, the option preferred by SouthCentral, would require analysis and special FAA approval for a minor deviation from the AD.

Nadya's first activity, as was often true with service requests, was to ensure that she understood the problem and had enough information to be able to build a reasonable case for a solution. SouthCentral had submitted some competent sketches of the attach angle plate along with their request, but they did not clarify the hole spacing. She wondered aloud about the location of the two missing fasteners, "Are they shaved off the end? Missing in the middle? Where?" She called SouthCentral and discovered that the holes were evenly spaced. Given her long experience with this model of aircraft, this was a counterintuitive situation.

Nadya next thought through the fastener discrepancy. She explained: "You see, all aircraft are hand built, hand crafted. They are never exactly to blueprint. This was probably mis-drilled and they had to accommodate. Some supervisor inspected it and signed off. It was probably tagged… When engineering signs off on something they tag it." Aircraft manufacturing is at times more art than science, and minor design modifications are allowed on the shop floor to accommodate material variances, available expertise, and the like. Any such deviations from blueprint are "tagged" and signed off by a supervisor. A record is kept by the original operator. Checking the serial number for the SouthCentral craft, she commented, "It's 431, that's about thirty years old. It's pretty early in production. For something that old, it [the tag] is probably long gone. For a record like this, what's the chance of us still having it around? Nil. Even if it were still here, no one could ever find it."

### The ROC and Processes of Reuse

Nadya had worked an attach angle plate job just a few days earlier, so this assembly was fresh on her mind, but she still searched STAIRS for similar cases. She was looking for any special variances on repairs to this part, because she was looking for precedences to help guide the stress analyst's investigation. If she found any, she would place them in the ROC electronic record for later use by the Stress analyst. She commented, however, that "I found a lot [of helpful historic cases], some things that could work. One ref [reference] sounded identical; unfortunately it was old, 1982. Records that old are very incomplete. We'll probably have to do basic analysis unless Samir can find something better. And some times he does. That's the problem with old repairs, old records – rough, vague and sketchy."

It is common practice for both Structures and Stress engineers to scour the archival ROCs for ones that might match their current job. They look for ROCs that can be reused directly, parts that can be used as building blocks to jump-start a new analysis, or cases which set precedence (i.e., helped understand what allowances had been made in the past and under what conditions). Frequently, the engineers are more successful than Nadya was in this case. For her, only one was a close match, and that required too much effort to re-interpret. In our observations, "too old" and "not a good fit" were markers for ROCs that had problematic recontextualization. These would contain information that was either outdated (e.g., because of procedural changes) or inappropriate (e.g., because of shift in conditions, such an operators financial state). In this case, the 1982 ROC was too challenging to re-use as it predated the AD, but in general, analysts would attempt to recontextualize prior ROCs and re-use those they found appropriate.

### Finding a Solution

As Nadya prepared the ROC, she explained how the service request would proceed. "[Samir will] check if strength is sufficient with the eleven, compared with the blueprint thirteen. Reed McGovern [the DER] will decide in the end. He'll use Stress' [response] and make a decision. If it is not sufficient, it will be a real mess. They'll [SouthCentral] have to fill and re-drill all the holes. Normally this is not the case though, he approves." She predicted that it would be approved with the eleven. "This [part] is designed so far above one hundred percent [tolerance], you can take out a couple of fasteners, no problem."

As with the first case, the record was then handed off to Stress for analysis. Samir was the Stress analyst assigned to the job. As he started his diagnosis, he first wondered whether this was a preventative or a corrective repair. SouthCentral and Nadya had both omitted this information. Samir, on further reflection, concluded that it was not critical, because the plate was going to be replaced regardless.

In this situation, Samir eschewed the usual stress calculations, reasoning that this configuration had performed without failure for thirty years. In completing his review, Samir was convinced that the eleven fastener configuration was suitable for strength. If there had been problems with the reduced fastener configuration, they would have been discovered before thirty years. We believe that he felt confident that SouthCentral had sufficiently capable maintenance engineers and facilities to have uncovered and reported any problems throughout the aircraft's history. We will return to this in the analysis below.

Samir wrote up his argument in support of a "minor deviation" to the AD, allowing a replacement plate with eleven fasteners. The response was then checked by his supervisor and approved by the DER. From the approved ROC Nadya composed a response to SouthCentral giving the approval.

Again, this was a relatively straightforward case. Although it was a non-standard repair, the participants treated it as relatively routine. That is, the particular situation with mis-drilled holes on the dorsal fin attach angle plate was rarely seen, but dealing with manufacturing exceptions was not unknown.

## PRIVILEGED AND PROBLEM OPERATORS

This non-problematic case highlights a specific kind of contextualization in using the GlobalCOM messages: how relationships between GTS-West and operators are used to interpret, use, and create these boundary objects. The airplanes that GTS-West supports are owned and operated by a very diverse set of organizations: some domestic, some international, some private, some corporate, some large and some operating a single aircraft. In providing customer support, a service engineer at GTS-West gets to know these operators well over the years -- their constraints, preferences, helpful and problematic contact people, and so on. Engineers have developed similar understandings of third-party repair facilities, where repairs are outsourced.

Case 2 unfolds with Samir trusting SouthCentral's handling of their aircraft. SouthCentral is one of the largest and most trusted operators of this model family. Nadya and Samir were very familiar with the practices of both the airline and this maintenance facility. This can be observed in Nadya's ability to identify the right person to contact to quickly resolve her fastener spacing question. It was also foundational to Samir's final evaluation – if problems with the eleven-fastener configuration had not surfaced in thirty years (implicitly any problems would have been detected by SouthCentral's maintenance crew) then the configuration was clearly suitable for strength.

Not all operators earned the privileged status of SouthCentral. In explaining the above case, Samir described another case he had worked recently with the same AD but a different airline. In a routine inspection, Marita Air, a foreign operator, had found a major crack in the attach angle plate. While this was clearly unacceptable, Samir had no authority to insist on a repair: "Even if we judge it is not safe, we cannot ground the plane. That is not our authority [because it's foreign]." Samir goes on to explain that it was very hard to find a suitable replacement part abroad. The anticipated time for delivery and installation was 240 days. Marita was asking for 1000 flight hours "as-is" to wait for the part, but "at a hundred and fifty flight hours a month, that's six months! That is not acceptable [leaving it unrepaired], not at all."

For this foreign operator, Samir came up with and submitted a temporary repair, which could be approved for six months, just long enough for Marita to get the part. However, he went on to say that he is convinced that they will not order the part now, but instead would procrastinate. They will wait until the six-month temporary expired to order the part. "Then they'll be back in the exact same situation as they are in now, with another 240 day wait from there." He was clearly frustrated: "…It's like a surgeon, you know. He does his job, but you don't do yours. He'll get angry, 'why'd you let your cancer grow?!?' but that's it, he can't do anything. It is just an objective judgment."

These fine-grained distinctions about operators were not restricted to Nadya or Samir. They were rampant. For example, one airline might request an AOG without describing their context, and they would be believed. Another might be seen as "crying wolf again." The following comment occurred during a heated debate between two Structures and Stress engineers over timeliness and reliability tradeoffs in a particular job. A specific operator, KrysAir, was constantly submitting AOGs. The comment was intended humorously, but only in part:

> Stress: "If we understand their schedule, they may understand ours. We have other things going on! All theirs will be R&R with all AOGs. [All of this operator's AOG requests would be treated as 'remove and replace', the most rapid but severe repair strategy.]"

Of course, engineers do not interpret interactions just at the operator level; they do so as well about individuals and maintenance facilities. Indeed, this occurred in Case 1, when Kai requested that Todd talk Beechwood's repair crew through the dimensions for the APU door installation. Kai made this a verbal request rather than mandated in the ROC. He did this because he trusted a Global employee who happened to be on-site to ensure the installation was done correctly. (This was politically less sensitive with the maintenance crew than placing the details of installation in the written record, which would have implied that he believed the repair crew might not be up to the task.)

## BOUNDARY OBJECT META-NEGOTIATIONS

By definition, boundary objects lie within an information flow, since they translate meaning from one group to another. Each is a unique object and a unique event. However, since they are constantly under interpretation and contextualization in GTS-West, they also lie within an event sequence, one composed of all boundary objects from one group to the other. This second event space, then, creates an implicit negotiation (or rather, meta-negotiation) about how to interpret and contextualize each individual boundary object. In reality, this meta-negotiation constantly unfolds in the enactment of each request.

Thus, understanding the meta-negotiation is key to potential re-use. Yet, how individual boundary objects are being interpreted is often excluded from the individual objects themselves. Indeed, this is part of the decontextualization process for the organization's bureaucratic procedures.

At GTS-West, we saw that at least the operator's prior history with GTS-West influenced all interactions with and interpretations of the boundary objects in a repair request resolution. That is, a single boundary object is seldom interpreted only within itself; boundary objects exist within a history greater than themselves.

This history consisted of the perpetual negotiations and renegotiations surrounding the boundary objects. As has been seen, the approach to a solution, as represented in the ROC and GlobalCOM records, would shift according to the perception of the operator's expertise, cooperation, and competence. As such, a response to SouthCentral, with their large Global fleet and proven reliability of their regional repair centers, would receive a different response than would Marita. In the KrysAir example, the Stress engineer threatened to unilaterally change activity around KrysAir requests, based on his interpretation of their bothersome manner.

Conversely an individual repair request, and its related boundary objects, could alter the stream. An egregious misinterpretation of a repair, intractable maintenance crews, or problematic elicitation of repair information could all sour the internal assumptions about a given airline. This process could also happen in reverse. During the duration of the study the reputation of a South American carrier developed though a series of exceptionally professional jobs to be viewed as more competent than some domestic operators.

The contextualization based on opinions of operators also affected the creation of contemporary ROCs (e.g. Kai not assigning the job to Bud), but more importantly, it likely affected their later interpretation for reliable reuse. As previously mentioned the ROC, as an organizational memory component, is frequently leveraged for reuse. It is in the resultant processes of recontextualizing these historical cases that the ROC as boundary object begins to break down. In the routine process of decontextualizing the ROC for archive, the details surrounding the ROC creation are absent, most importantly the information about the historical stream and its negotiations is often lost.

A clear design implication of this study is to find better ways to preserve a specific kind of state -- the ability to recreate the meta-negotiations and relationships at the temporal point where the boundary object was crystallized. We cannot hope to capture all context. Setting aside the impossibility, no one will do it organizationally: The ROC is an audit trail, ripe for legal problems in a safety-critical environment. Nonetheless, simple augmentations may be sufficient.

Necessarily, opinions of operators and others are only part of what GTS-West engineers use to contextualize the GlobalCOM messages and ROCs as boundary objects. We do not mean to imply this is the only issue for engineers in interpreting their work. They also note Global management strictures and FAA regulations, time pressures, and staffing issues. They may differ in their opinions from their colleagues. Nonetheless, within GTS-West, engineers' views of incoming messages and outgoing phrasings were critical and common enough to their work.

We believe it is possible to augment engineers' memory of the context – by simply signaling operators' or repair stations' conditions at various dates. The inferences are still up to the engineers and analysts; the augmentation merely helps them handle additional complexity.

To summarize, then, the two cases showed GTS-West personnel balancing safety, reliability, and timeliness in order to routinely satisfy operators' and GTS's requirements. The service engineers do so by interpreting and contextualizing the critical boundary objects (ROCs and GlobalCOM messages) with regard to larger considerations, including the history of interactions with the operators and others. We note that results from field studies cannot be easily generalized, and indeed GTS has a rather unique culture. However, this study provided hope that one can uncover meta-negotiation information in the event stream to supplement boundary objects for later use. At GTS-West, this would allow service engineers to more easily reuse parts of its organizational memory. In other companies, perhaps with safety imperatives or with simplified information flows, we believe it likely that we can find other, similar meta-negotiations occurring.

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