Abstract
This paper expands Langan-Fox, Sankey, and Canty’s (2008) examination of the phenomenal growth in air traffic by discussing the human factors (HF) issues confronting air traffic controllers (ATCOs). Growing worldwide air traffic demands call for a radical departure from current air traffic control (ATC) systems (see Langan-Fox, Canty, & Sankey, 2009). Future systems will conceivably have a fundamental impact on the roles and responsibilities of ATCOs. Valid and reliable methods of assessing HF issues associated with these changes are crucial for advancing theory and for designing systems, procedures and training. We outline major aviation changes and how these relate to five key HF issues in ATC: (a) situation awareness; (b) workload; (c) boredom, vigilance, and monotony; (d) motivation and stress; and (e) trust, complacency, and over-reliance. A review of the literature suggests that situational awareness and workload have been widely researched and assessed using a variety of measures, whereas issues of stress, trust and boredom are predicted to become more significant. Researchers should develop measures to assess these concerns and their impact on ATCO performance. The current paper provides an evaluation of research and measures used in HF research on ATC systems which will facilitate future research and ATC measurement.

Keywords
Air traffic controller, situation awareness, workload, stress
1. Introduction

Global air traffic demand is already reaching capacity and is predicted to double by 2020-2025 (Hollnagel, 2007). This rapid growth has placed a major strain on existing air traffic management (ATM) systems. One solution proposed to address the issue of increased air traffic and growing demands on air traffic controllers is ‘free flight’, defined by the Radio Technical Commission for Aeronautics (RTCA) as “a safe and efficient flight operating capability under instrument flight rules in which the operators have the freedom to select their path and speed in real time” (Anonymous, 1995). In the redesigned airspace, elements will include ASA management operations airspace (Joint Planning and Development Office [JPDO], 2007), ‘corridors in the sky,’ ‘gaggles,’ and ‘platoons,’ with more aircraft per ATCO (Kopardekar, Bilimoria, & Sridhar, 2007, 2008). However, as yet, “the role of the human in future systems has not yet been fully explored or identified” (Kopardekar et al., 2008, p. 330). It appears then, that the HF issues associated with the newly configured airspace are relatively unknown. Figure 1 illustrates these ‘unknowns.’ While the existing literature widely endorses free flight and increased automation as a means for meeting demands for enhancing capacity, efficiency, and safety in ATM systems, these solutions have a number of implications for controllers. In particular, researchers have expressed concerns over a number of human factors (HF) issues associated with the introduction of new ATM systems and the impact of these new systems on the performance and future role of ATCOs. These concerns include a loss of situation awareness (SA; Endsley & Kaber, 1999), changes in workload (Metzger & Parasuraman, 2001), complacency and mistrust of automated systems (Parasuraman & Riley, 1997), and increased stress levels (Straussberger, 2006) (see Figure 1).

Figure 1. Key human factors (HF) and human resource (HR) issues for future air traffic management (ATM) systems and air traffic controllers (ATCOs)
2. NextGen airspace hierarchical configuration and air traffic controller roles

2.1. Current and future airspace configurations

The management purpose of current, rigid and static airspace boundaries is to ensure that the controller is not overloaded. Currently, ATCOs are responsible for separation assurance duties within sectors (Kopardekar et al., 2008). In order to achieve the dynamic resectorization of airspace that is integral to NextGen ATM, future airspace configurations must be flexible, adaptable, and able to accommodate new elements such as highways-in-the-sky and generic sectors (Kopardekar et al., 2008). To do so, future airspace will be separated into four elements: (a) ASA operations airspace; (b) high altitude airspace; (c) structured, classic, or low altitude airspace, and; (d) super density metroplex operations airspace surrounding busy and multiple airport regions (see Figure 1). ASA operations airspace is expected to increase airspace capacity by reducing the dependence on ATCOs. In high altitude airspace, the ATCO will be responsible for separation assurance but will be supported by automation. The classification of high altitude sectors as “generic” will result in the ATCO not needing to rely on local knowledge, nor having to memorize airspace-specific details; decision support tools will promote the ATCO interchangeability (Kopardekar et al., 2008). Indeed, Stein, Della Rocco, and Sollenberger (2006) claim dynamic resectorization may potentially negate much of the ATCOs sector-specific expertise. Unlimited dynamic resectorization also requires that controllers be continually notified of changes affecting their airspace, posing challenges for ATCO decision making and placing greater demands on workload and on gaining and maintaining SA of acquired traffic. Indeed, in a simulation of lateral inter-facility dynamic resectorization, en route controllers recorded slightly lower workload ratings (but higher SA ratings) in dynamic resectorization scenarios (Hadley, Sollenberger, D’Arcy, & Bassett, 2000). Additional research is essential as this concept becomes more prevalent and expands to accommodate more constraints. In super-density low altitude airspace, the ATCO will manage flows, whilst classic low altitude airspace may contain mixed operations where the ATCO, assisted by decision support tools, may still be in charge (Kopardekar et al., 2008).

2.1. Future air traffic controller roles

Four types of ATCO roles are envisioned for NextGen: (a) capacity managers; (b) flow contingency providers; (c) trajectory managers and; (d) separation managers (JPDO, 2007; see Figure 1). In NextGen, capacity managers will design and strategically allocate airspace and dynamically adjust the assignment of airspace to tactical separation providers. The role of flow contingency providers will be to identify potential flow problems and to collaborate to develop flow strategies. Trajectory managers will predict individual flight contention within a flow for resources, identify complex future conflicts, and coordinate individual trajectory resolutions. Finally, separation managers’ role will be to eliminate residual conflicts left by the strategic functions of TB operations (for further details, see JPDO, 2007). While much has been written on ATC HF issues (particularly SA and workload), the evolving ATM system and changing nature of the ATCO role means that these issues will acquire a new significance because future technologies and procedures will affect ATCOs in new and different ways. For example, Willems and Koros (2007) claim that it is currently unclear how using data link to provide ATC clearances, real-time weather and other data affect shared SA between the flightdeck and ATCOs. Furthermore, relatively neglected issues of ATC, such as complacency and mistrust of
automated systems, stress, and boredom, vigilance and monotony will become increasingly relevant as future ATM systems become increasingly automated and the ATCO role undergoes fundamental change.

3. Human Factors Constructs and Measures in Air Traffic Control

3.1 Situation awareness

A major concern associated with free flight and advanced automation in ATC is the impact on SA, defined as “the perception of elements in an environment, within a volume of space and time, comprehension of their meaning and projection of their status in the near future” (Endsley, 1995, p.36). The effects of free flight and automation on the ATCO SA and performance have been well documented (see, e.g., Sharples et al., 2007), with the research generally supporting the notion that the higher the level of automation, the more difficult it is for ATCOs to maintain their SA of system and environmental dynamics. Existing SA measures must be evaluated to determine suitability in future systems that are based on dynamically adjusting airspace sector boundaries and digital communication. Despite the availability of a wide variety of SA measures (Jeannot, Kelly, & Thompson, 2003), researchers in the ATC field have made some rather narrow choices (see Table 1).

Table 1. Summary of key existing measures for ATCO HF issues

<table>
<thead>
<tr>
<th>Situation Awareness</th>
<th>Workload</th>
<th>Boredom, monotony, &amp; vigilance</th>
<th>Motivation &amp; stress</th>
<th>Trust, complacency, &amp; over-reliance</th>
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<tr>
<td>SAGAT</td>
<td>NASA-TLX</td>
<td>Physiological measures</td>
<td>DSSQ</td>
<td>SATI</td>
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<td>HCT</td>
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<td>SASHA_Q</td>
<td>ISA</td>
<td>Deviations noticed</td>
<td>CPQ</td>
<td>Other subjective rating scale</td>
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<td>SALSA</td>
<td>AIM</td>
<td>Error detection</td>
<td>SDS</td>
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<td>SPAM</td>
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<td>Observable</td>
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<td>SAVANT</td>
<td>Primary task performance</td>
<td>DSSQ</td>
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<td>Physiological measures</td>
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<td>PUMA</td>
<td>Physiological measures</td>
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Note: AIM = Impact on Mental Workload; ATCO = air traffic controller; ATWIT = Air Traffic Workload Input Technique; CAST = Consequences of future ATM [Air Traffic Management] systems for ATCO Selection and Training; CPQ = Copenhagen Psychosocial Questionnaire; DSSQ = Dundee Stress State Questionnaire; HCT = Human Computer Trust; ISA = Instantaneous Self-Assessment; NASA-TLX = National Aeronautics and Space Administration Task Load Index; PUMA = Performance and Usability Modelling; RSME = Rating Scale of Mental Effort; SAGAT = Situation Awareness Global Assessment Technique; SALSA = ‘Measuring Situation Awareness of Area Controllers within the Context of Automation’ in its
3.2 Workload

Workload is a key ATCO HF issue (Rantanen & Nunes, 2005) and it is becoming increasingly pertinent with growing air traffic demands and the subsequent introduction of future ATC systems. Hilburn and Jorna (2001) explored both the subjective and objective workload of ATCOs. In their analyses, they found the best predictor of ATCO workload was traffic load, that is, the number of aircraft (NA) managed by the controller. Other factors contributing to workload included the number of flight altitude transitions, mean airspeed of the aircraft, the mix of aircraft, direction variations, the proximity of aircraft, and weather conditions.

Notwithstanding these findings, Hilburn and Jorna (2001) claimed that most workload measures in the ATC domain rely upon subjective report. A number of other studies have also underscored the importance of traffic complexity and NA as significant drivers of perceived (Metzger & Parasuraman, 2001) and psychophysiological workload (Vogt, Hagemann & Kastner, 2006). The majority of ATC workload measures rely upon subjective report (see Hilburn & Jorna, 2001). Salmon et al. (2006) considered the NASA-TLX to be the most commonly used and also the most widely validated of the various techniques available, and the current research supports this view. With the introduction of TB operations the ATCO position is envisaged to involve less direct control of aircraft. Therefore, observable activities (i.e., radio communication, data entries) may become less frequent and workload fluctuations may not necessarily be reflected in observable performance changes (Averty et al., 2004). Using a single approach to measuring operator workload has traditionally proved. Thus, researchers have advocated a combination of measures when assessing workload (Kaber et al., 2007). Indeed, a well designed multi-method approach will ensure comprehensiveness when assessing ATCO workload.

3.3 Boredom, vigilance, and monotony

ATC boredom, vigilance, and monotony have not been well researched (Straussberger, 2006). The aim of increased automation in ATC systems is to lower the information-processing demands of the task environment and promote better vigilance. However, if the nature of the ATCO role becomes too monotonous, controller motivation and/or vigilance may decline, with concomitant effects on performance and error detection/correction (Wickens, Mavor, & McGee, 1997). Measures of vigilance may include both physiological and subjective instruments. For example, eye movement technology – an indicator that the visual channel is overburdened (Veltman & Gaillard, 1996) – is a particularly useful measure when assessing the effects of technology such as datalink of the boredom, vigilance and monotony of ATCOs in future ATC systems. However, there are issues of cost, intrusiveness, and inherently large individual differences that should be considered before adopting this measure (Hilburn & Jorna, 2001).
3.4 Motivation and stress
A reduction in workload may lead to a decrease in ATCO motivation and an increase in stress. According to Ruitenberg (1999), as the job becomes less complex, the intrinsic task motivation of controllers may be lost. Other areas of research have demonstrated that human operators of complex, high-criticality systems like to remain in control (Miller & Parasuraman, 1999). Although ATCOs will still be responsible for the safety of traffic in future ATC systems, they will have less control of it (Kirwin, 2001). This may well lead to increased stress or burden (Dougherty, 1993). Many subjective measures of ATCO stress have been employed – e.g., the Dundee Stress State Questionnaire (Helton et al, 2005) the Stress Diagnostic Survey (Lesiuk, 2008), the repertory grid methodology (Crump et al, 1981), the Recovery-Stress Questionnaire and the Scale of Feelings (Straussberger, 2006). Behavioral manifestations of ATCO arousal – e.g., distress, physical movements and voice quality (Ming et al, 2004) – have been used to measure stress in ATC. ATCO stress levels have also been documented in terms of physiological adaptations such as changes in hormonal secretion (Wetherell et al, 2004), heart rate (Collet, Averty & Dittmar, 2009), and blood pressure (Ming et al, 2004). Consensus has not been reached as to which is the most appropriate way of measuring stress in ATC. Indeed, research should compare and contrast across different measures of stress in order to determine which is most appropriate to assess the stress levels of ATCOs.

3.5 Trust, complacency and over-reliance
According to Lee and Moray (1992), trust is an essential mechanism for automated ATM systems to deliver the proposed capacity and safety benefits. However, research on trust in ATM systems is scarce. Muir (1988; cited in Wickens, 1992) argued that individuals are often too trusting (‘over-trusting’) or not trusting enough (‘under-trusting’) of automated systems. Indeed, these situations have been observed in ATC (Parasuraman & Riley, 1997). The measurement of ATCO trust in ATC systems has relied almost exclusively on subjective metrics. Most studies have developed their own, or have modified previous measures (e.g., Stedman et al., 2007). After noting the shortage of studies examining ATCOs’ trust of ATC systems, Goillau , Kelly, Boardman and Jeannot (2003) specifically developed the SHAPE Automation Trust Index (SATI) for use during real time simulations. SATI is based on a set of rating scales that measure both the controllers’ overall level of trust, and the constituent elements (e.g., reliability, predictability, understandability, etc.). Since SATI was created based on feedback from ATCOs themselves (see Adams et al, 2003), a clear advantage of this measure is that it is pragmatic and consistent with how trust is understood by operators within the ATC domain.

4. Discussion and Conclusion
The introduction of free flight and future ATC systems with increased automation may have the intended impact of increasing airspace capacity and reducing the workload of ATCOs. However, these changes may be accompanied by unintended reductions in SA, unbalanced workload, increased stress, and issues of mistrust, boredom and monotony. With these issues becoming increasingly pertinent to the ATCO role, it is necessary to consider valid and reliable ways of measuring them as we attempt to advance theory and also ATC system, procedure and training program design efforts. The current research has highlighted a number of issues: (1) that human factors measurement instruments in the aforementioned areas should be
evaluated as to their utility for research in future ATC studies. Only a small amount of available ATC measures were used in research. This is consistent with the view of Rantanen (2004); (2) issues of vigilance, monotony, boredom, stress and trust have been largely neglected in recent years, with additional research required to better understand these issues and how they are measured in the context of future ATC systems; (3) the existing literature appears to be disparate, with researchers choosing to focus on examining one issue, ignoring complementary or corresponding areas. For example, whereas workload measures provide insight into how hard an operator must work to perform tasks with a new design, SA measurement provides insight into the level of understanding gained from that work (Endsley, 2006). Implications for measurement are that it may be possible to combine, or embed, certain measures within another measure; (4) existing research has used small sample sizes, and has been conducted in strictly controlled laboratory environments. Additional research in operational settings is needed to enhance external validity and generalisability to real-world ATC settings.

References


