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FLIGHT HANDLING QUALITIES
A Problem-Based-Learning Module for Final Year Aerospace Engineering Students

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ABSTRACT

This paper describes the methodology and key results from the first 3 years of operation of '*Flight Handling Qualities*' (FHQ), a Problem-Based-Learning core module for 4th year Master of Engineering (MEng) undergraduates in Aerospace Engineering and optional module for the Systems Engineering MSc Programme, at the University of Liverpool. The module aim is to equip students with the skills and knowledge required to tackle aircraft handling qualities (HQs) and related '*whole aircraft*' problems. Students are presented with the theory of handling qualities engineering in a series of interactive lectures. The students work in teams of 4 or 5 and undertake a number of team-building exercises throughout the first semester. Teams are presented with the idea that the aircraft with its handling qualities is the focus for knowledge acquisition and skills development. Each team is given the task of assessing and quantifying the HQs of a particular aircraft in a particular role, and then developing fixes to any handling deficiencies they identify; the current aircraft include the Wright Flyer, Grob 115, Blackhawk, Bo-105 and XV-15. Teams write an interim report at the end of the first term and a final report at the end of the second term, showing how they have assessed the aircraft, developed solutions to the problems and made recommendations concerning the aircraft's suitability in the defined role. The Reports also address the technical feasibility and economic viability of the proposed upgrades. The teams present their work to mock 'Customers' (group of staff, another student team, visiting Industrialists) with the objective of demonstrating that the aircraft is now fit for the role. Each individual student maintains a '*Personal Learning Journal'*, in which they document the development of their understanding of handling qualities and, more general, transferable skills. The module is designed to enable students to engage in all elements of the Conceive-Design-Implement-Operate (CDIO) cycle.

1. INTRODUCTION

In 1969, test pilots George Cooper and Raymond Harper defined HQs as "*Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role*" (Ref 1). Since then, various testing methodologies, analytic response criteria and design standards have been developed, and the subject has grown into a 'systems' discipline in its own right, aimed at ensuring that neither operational performance or safety are compromised by deficiencies in handling (Refs 2-5). The discipline has developed through a symbiosis between engineers and pilots, and requires designers and operators to come to mutual agreement on the priorities and necessary compromises in the whole design trade-off process. Handling Qualities engineers are often required to deal with serious problems during flight test development caused by inadequate concurrency in the early design process, combined with insufficient modelling and simulation. Engineers who work at this 'whole aircraft' level are exposed to the impact of decisions/judgements in the various technical sub-disciplines on the trade process, e.g. aerodynamics, structures, power systems, avionic systems. These are the components of a classical Aerospace Engineering degree programme, usually taught separately from an engineering science perspective. The Flight Handling Qualities module provides the framework for learning opportunities at the whole aircraft level, taking account of operational capability and flight safety and enabling students to experience the pressures of compromise, alongside satisfying pilot demands, within tight timescales and demanding targets. Critical to the success of this module has been the availability of a piloted simulation facility and experienced test pilots to enable realistic impressions and assessment of HQ issues to be gained. The facility at The University of Liverpool is described in Refs 6 and 7 and Appendix E.

The FHQ module allows students to engage in all 4 stages of the CDIO cycle; broad operational requirements are set, analysis and assessment against military and civil standards define the problem areas requiring design changes to be conceived and implemented, and the flight simulator allows the operational impact of the solutions to be quantified. At a fundamental level, the learning opportunities lie within the challenges of how to match capability with requirements, while meeting safety constraints, and how to exploit the creative energy of a team.

This paper presents the overall methodology of the FHQ module and includes sketches from the FHQ Team activities over the last 3 years. A set of Appendices is included to make this paper a self-contained, complete description of the module. Appendix A gives the Guidance Notes for students undertaking the module, including a section on 'the purposeful group'. Appendix B outlines the required structure of the Team Report. Appendix C gives the advice to Teams for their oral presentations and associated assessment. Appendix D summarises the various changes to the module content and structure over the last 3 years and also plans for the future. Finally Appendix E describes the primary modelling and simulation tools available to the FHQ Teams – FLIGHTLAB and HELIFLIGHT.

2. FLIGHT HANDLING QUALITIES – THE MODULE

2.1. Overall Methodology

The module was conceived as a 15 credit[1] problem-based-learning activity providing the opportunity for students to integrate and apply knowledge and skills gained during 4 years of a multi-disciplinary Aerospace Programme. The Module Specification states that, "*The aim of this module is to provide students with the opportunity to learn about handling qualities theory, and then to put this into practice by making an assessment of an aircraft with specific handling qualities deficiencies, and developing the technology to fix these, either through aerodynamic design or control system augmentation*." The theory of handling qualities engineering is presented during the first 6 weeks in semi-formal lectures, supplemented by a number of team building exercises (see Section 2.4 below) and half-day workshops on the use of the modelling and simulation software package, FLIGHTLAB (Refs 6, 7, also Appendix E). A comprehensive set of lectures notes is provided to each student, who also has access to standard text books and key papers and reports on the subject (e.g. Refs 8-21). The students are formed into Teams of 4 or 5, allocated a-priori by the module coordinator based on perceived ability, pre-requisite knowledge and gender. Each team is presented with the task of assessing and quantifying the HQs of their particular aircraft in a defined role. They are required to identify and develop fixes to handling deficiencies. Each team has to write an interim Report at the end of the first semester showing how they have assessed the basic aircraft, describing the HQs and indicate potential solutions to the problems. A Final Report is required at the end of the second semester, describing the ways in which the HQ problems have been fixed, making recommendations on the future use of the aircraft and its suitability in the role. Teams are required to present their work to a 'Customer' group with the objective of demonstrating that the aircraft is now fit for the role. Each individual student maintains a 'Personal Learning Journal', in which they document the development of their

[1] Students take 120 credits in undergraduate programmes, 180 credits in postgraduate taught programmes

understanding of handling qualities, how they impact operational capability in the form of self-reflection notes.

The initial 'lectures' cover the following topics

a. Resume of flight dynamics principles for fixed and rotary wing aircraft (building on year 3 material)
b. Introduction to handling qualities and HQ specifications and Levels
c. Concepts of operational flight envelope and safe flight envelope, missions, mission phases and mission task elements, usable cue environment, response types
d. Dynamic Response Criteria including stability, bandwidth, quickness, Control Anticipation Parameter (CAP), control power, cross coupling
e. Assembling the required handling qualities and defining the overall HQ level
f. Designing a HQ manoeuvre based on a mission task element, inc. performance standards

Students are encouraged to produce a road map of their expected progress covering such activities as,

a. Develop understanding of defined aircraft type and operational role, including breakdown of missions and mission phases
b. Task division discussed, agreed and allocated by Team with guidance from mentor
c. Familiarise with use of FLIGHTLAB and associated toolboxes
d. Quantify 'predicted' HQs using FLIGHTLAB offline, identifying HQ deficiencies and potential shortcomings in operational role; prepare and give presentation to coordinator and mentor
e. Design initial piloted tests, including critical mission task elements; solicit feedback from test pilot, conduct first trials
f. Workshop to discuss potential improvements including pilot comments and input
g. Strategy for improved design
h. Make design changes to aircraft configuration or control system
i. Evaluate impact of changes using toolbox and piloted tests
j. Present results to Customer group
k. Write Team report on HQ analysis and Assessment (see Appendix B)

Students maintain a personal learning journal, which fully documents the development of their understanding, through learning reflections. The Teams are encouraged to meet regularly, keep records of their decisions and action trail, and share understandings and skills through Technical Leaflets (T-Leaves). The module design is centred on a number of Learning Outcomes, the assessment of which now underpins the accreditation of Engineering degree Programmes by the UK Engineering Council and associated professional bodies, e.g. The Royal Aeronautical Society, The Institution of Mechanical Engineers. The Institution of Electrical Engineers.

The module features timetabled weekly 2-hour sessions, but the students are expected to meet in their teams weekly on, at least, one other occasion to review progress, share knowledge and allocate future tasks. During the Simulation trials, the Teams have access to their test pilot for about 2.5 hours, within which they conduct the briefing, run the simulation and conduct the de-briefing; the actual simulation slot is nominally 75 minutes. The students can communicate with the test pilots outside this period by email.

2.2 Learning Outcomes

Learning outcomes are defined for all modules offered as part of an accredited degree programme, with accreditation determined by demonstration of assessment. They can conveniently be divided into four categories, below, each with its own list of sub-outcomes.

Knowledge and Understanding: On successful completion of the module, students should be able to demonstrate:

a. knowledge and understanding of a range of different handling qualities requirements for different classes of aircraft and different missions (e.g. ADS-33E, MIL STD 1797, FAR 25/29)
b. the way in which different aircraft design

parameters affect handling qualities
c. an understanding of the uses of HQ rating scales
d. how to apply modelling and simulation methods to whole aircraft dynamics
e. how to design and conduct a handling qualities experiment
f. appropriate terminology for interacting with pilots in briefing, while flying and in de-briefing
g. how to improve handling qualities through control system or aerodynamic design.

Intellectual Abilities: On successful completion of the module, students should be able to demonstrate their ability to apply knowledge and understanding of the above topics to:

a. solve HQ problems and carry out the associated analyses, HQ parameter calculations and evaluations
b. describing and explaining qualitative aspects of handling qualities, including pilot opinion
c. using the methodologies to model, simulate and improve Flight Handling Qualities.

Practical Skills: On completion of the module, students should be able to show experience and enhancement of the following discipline-specific practical skills:

a. in the use of specialist software, e.g. FLIGHTLAB, MATLAB/SIMULINK
b. in the use of a Flight Simulator and the design of HQ experiments.

General Transferable Skills: On completion of the module, students should be able to show experience and enhancement of the following key skills:

a. written, presentation and inter-active communication skills
b. group-working skills
c. mathematical and IT skills
d. problem-solving skills
e. lifelong learning skills through the use of a learning journal, in which new knowledge gained is recorded properly through reflection, problems highlighted and solution options discussed.

2.3 Assessment

The assessment is based on three components as shown in Table 1.

Assessment	*Weighting %*	*Timing*	*Material*
Continuous Assessment	30%	Fortnightly returns	Individual's HQ Learning Journal
	50%	Week 10, semester 1	Interim Report on HQs
		Week 10, semester 2	Final report on HQs
	20%	Week 9, semester 2	Team's oral presentation

Table 1 Flight Handling Qualities Assessment

The personal learning journals are read by the module coordinator, who provides written and oral feedback and gives a score on a scale of excellent to unsatisfactory. The Interim Reports are given a provisional mark and the students are encouraged to make improvements based on the written and oral feedback from the module coordinator and mentors. These can be embodied within the Final Report, handed in at the completion of the module. The oral presentation is marked on the same scale as the PLJ, addressing such aspects as technical content, team-work, presentation quality (see Appendix C). Typically, each presentation, lasting 30 minutes, followed by a 30 minute Q&A session, will be assessed by 6 different people (module coordinator, moderator, visiting Engineers, Departmental staff members, mentors).

2.4 Team Building Exercises

Four exercises have been developed to expose students to some of the trials and tribulations of Team 'work and play'.

a. The Paper Tower and the Helicopter Landing Pad; teams are required to build, from newspaper, a tall free standing tower with a helipad on top (i.e. a space > 0.5 sq ft, for an identified model helicopter to be placed). Raw materials and basic tools are provided and the teams have 40 minutes to design and build the tower and a further 10 minutes to describe the design and construction process. This is an 'icebreaker' type of exercise which encourages the team to work towards a goal with time and technical constraints, while featuring both competitive and fun aspects.

b. The dilemma of the Rookie Test Pilot. The teams are asked to consider the scenario where an aircraft company is about to deliver a new model to a customer. The Chief Test Pilot and Chief Designer are agreed that they have created a product that meets the customer requirements very well. They ask a new 'rookie' test pilot, recently joined from the military, to make a quick evaluation of the aircraft against some specification aspect. The pilot returns to say that he feels that the aircraft does not adequately meet the requirements and there may be a problem in operational service; he discovered a HQ deficiency when pushing the aircraft to its performance limits. A meeting is called between the Chief TP, Designer and Managing Director to resolve the situation; the FHQ teams are asked to play the different roles in this role-play exercise. This exercise provides the team the opportunity to explore situations where there is strong vested interest by more than one member of a Team and another member who holds a different view, equally strongly, and may feel isolated and pressured into giving way.

c. A Paper Review – What's in it for me? Teams are required to conduct a critical review of Ref 13, (Lessons Learned Concerning the Interpretation of Subjective Handling Qualities Pilot Rating Data, Roger Hoh, 1990). In this paper a number of issues are dealt with that the students need to take into account during the module, e.g. vested interest, importance of good experimental design, data scatter, the 6-sigma pilot. The Teams report back during a Lecture slot on their findings. Conducting paper reviews to establish the critical knowledge to guide the student's own understanding and research progress is vitally important in engineering and conducting this as a collective exercise has proved very successful. For a class size of 20, about 90 minutes can easily be allocated to this review.

d. How Can I Help You? Students are asked at the beginning of a lecture (on Dynamic Response Criteria) to note one thing that they have difficulty with understanding. During the following week they should share this with the team, and the team members should work with each other to reach an improved state of knowledge and understanding. The results of the sharing are brought back to the whole FHQ group the following week. This exercise simply encourages the students to not hold back from asking for help and encourages sharing of knowledge, so important for team success.

3. FHQ MODULE SKETCHES

Each FHQ Team is provided with a short description of their aircraft and its operational role, defined to stretch its capability. The aircraft have no stability and control augmentation at the outset and it is known that pilots will experience various levels of difficulty in performing the defined mission. Handling qualities and pilot difficulty are measured in Levels, 1-4, where, broadly speaking, Level 1 means that the pilot is able to achieve the defined mission well with safety and performance standards. Level 2 means that the standards are only just achievable and pilot workload is, at worst, extensive. Level 3 means that the mission tasks are not achievable and in Level 4, there is a high risk of loss of control. By analysing the dynamic behaviour of the aircraft in response to control inputs, the teams should be able to identify where the deficiencies lie; these are the predicted HQs. If the teams design the tests correctly, the pilot simulation tests should confirm these results and also highlight other deficiencies; these are the assigned HQs, given on a scale of 1-10 (HQR 1-3 is Level 1, 4-6 is Level 2, 7-8 is Level 3 and 9-10 is Level 4). The design of the test manoeuvres to be flown by the pilot is critical to the whole HQ test and evaluation process. The teams need to de-construct the aircraft missions into phases and then into mission task elements (MTEs), which serve as the basis of the test manoeuvres. If the students identify the HQ-critical MTEs then the pilots will almost certainly discover the major deficiencies. A key task for the students is to link the predicted and assigned HQs. In the following sketches, the aircraft, mission and operational performance are summarised, and examples of the work of the FHQ Teams from 2005 are given.

Team 1 - The Bo105 in the Anti-Submarine Warfare (ASW) Role

The Bo105 helicopter is to be upgraded to fly ASW missions to and from a mother Frigate. The following outline performance should be used in the Handling Qualities assessment.
Ref 14 is available as a knowledge supplement.

Outline Performance Requirements

- Hover Power (torque) margin (% to 88% red line torque) 10%
- Cruise speed H > 250ft 140 kts
- Emergency transient manoeuvre capability in cruise 2.5g
- Low speed wind envelope (for deck, landing and take-off operations)
- 0 – 60 deg 50kts
- 60 – 90 deg 30kts
- 90 – 180 deg 20kts
- Control margins throughout the low speed wind envelope should be 10%
- Handling qualities may degrade from Level 1 to Level 2 (HQR 5 max) with high winds from side and rear quarters.
- Missions may be conducted in partially degraded environments when the low speed envelope may be reduced by 20%
- Deck touchdown velocity limit for undercarriage 12 ft/sec
- Landings should normally be achieved with 50% safety margin (adequate performance limit)
- To take advantage of quiescent periods (of ship motion) landings should be successfully completed within 10seconds from hover alongside ship
- Pilot should have full hover hold capability for ASW mission phase
- As an emergency situation the aircraft should be tested to evaluate its characteristics in autorotation and during an engines-off landing

Figure 1 shows a sketch of the critical approach and landing MTEs identified by the students; performance standards were used that conform to a typical manual landing within the narrow constraints of a deck grid. The team identified one of the critical deficiencies as a lack of yaw attitude response in the basic aircraft. Through the use of feedback/feedforward control they were able to improve the response and measured this in terms of the ADS-33 attitude quickness parameter. Figure 2 shows that the team were able to increase the quickness to reach the Level 1/2 handling qualities boundary. This improvement in agility was achieved without a penalty to stability. With a 20kts wind from the rear (a worst case for ship operations), the pilot-awarded HQRs improved from 6 (Level 2) in the original Bo105 to 3 (Level 1) in the upgraded aircraft. In all, the team designed 5 MTEs to exercise the HQs in various phases of the mission. The improvements resulted in Level 1 HQs in most areas. Their control system upgrade required relatively straightforward technology, although the Team recognised that new dual-port actuators would be required to accept the electronic inputs from the augmentation system.

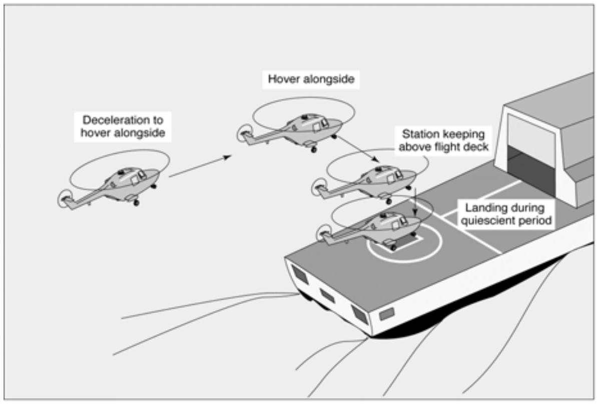


Fig 1:The Deck Landing Mission Task Element

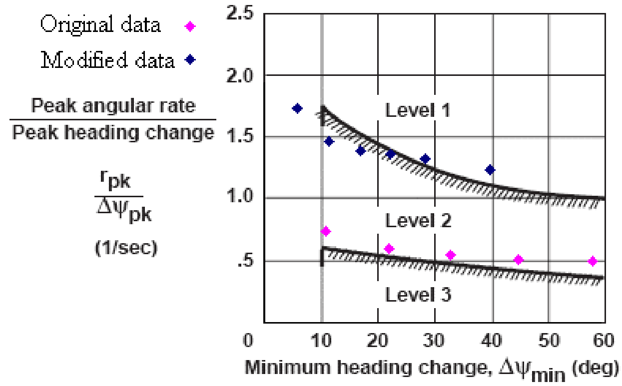


Fig 2 Bo-105 Yaw Attitude Quickness
(◊ original Bo105 ◊ with yaw quickening)

Team 2 – Bell XV-15 in Search and Rescue Role

The XV-15 aircraft is to be used in the search and rescue (SAR) role operated by the coast guard. It will normally take-off and land vertically in helicopter mode (nacelle = 90 deg), convert to airplane mode (nacelle = 0 deg), re-convert to helicopter mode on arrival at the rescue location and reverse the process to fly back to base. A special 'loiter' phase is envisaged where the aircraft is operated with the nacelles tilted to 60deg; when the edges of the conversion corridor are at 60kts and 150kts.
Refs 15 and 16 are available as knowledge supplements.

Outline Performance Requirements

- A conversion mode speed envelope of 80-130kts
- Manoeuvre capability of +2.5, 0g within this envelope
- Ability to increase and decrease speed within the corridor rapidly maintaining constant height
- Ability to change flight path angle (climb and descend) within corridor while maintaining constant speed
- Typical manoeuvres to be flown in SAR mode will include terrain following, valley tracking and rapid speed and height changes.
- Manoeuvres may be performed in partially degraded visual environments.
- This aircraft will occasionally be operated from busy airports and it is required to assess its vulnerability to an encounter with the vortex wake of a large civil transport aircraft.
- Landings should normally be achieved with 50% safety margin (adequate performance limit)
- To take advantage of quiescent periods (of ship motion) landings should be successfully completed within 10 seconds from hover alongside ship
- Pilot should have full hover hold capability for ASW mission phase
- As an emergency situation the aircraft should be tested to evaluate its characteristics in autorotation and during an engines-off landing

Research ongoing at the University allowed this team to access published material on the mission phases of a future civil tilt rotor operating in the search and rescue role (Fig 3). The so-called loiter mode was emphasised in the outline requirements, with nacelles rotated to the 60 deg position. The team were able to develop an MTE to exercise the roll-yaw handling qualities and the height-speed control coordination during turns. The HQs in this roll-step manoeuvre (Fig 4) flown at 100kts were rated as 6 before improvement and 4 after the upgrade. The newly developed control system suppressed unwanted couplings and gave the pilot more precise control of roll angle during the tracking phase along the runway edge. The HQs at higher speeds were not improved as the increased stability provided by the control system reduced the agility. This result highlighted the trade off between these two HQ attributes to the team, and the importance of the need for compromise in design.

Tilt Rotor Aircraft
Search & Rescue Mission Phases

- *take off*
- *climb out/conversion*
- *climb-cruise in airplane mode*
- *loiter in search zone*
- *recover to search point/rescue*
- *climb out/conversion*
- *climb-cruise-descend in airplane mode*
- *approach and re-conversion*
- *landing*

Fig 3 The Nine SAR Mission Phases

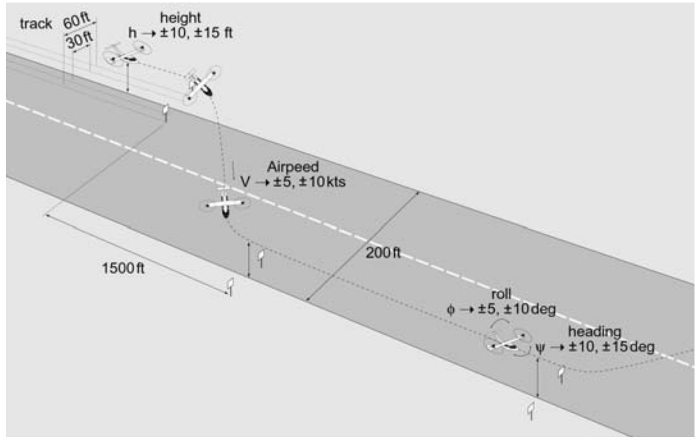
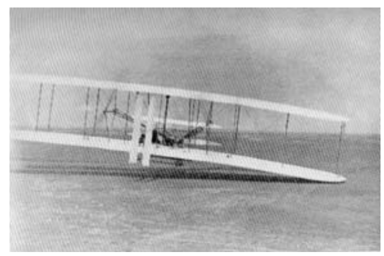


Fig 4 The Roll Step Mission Task Element with performance standards

Team 3 – The Wright Flyer development into a Practical Aeroplane

The Wright Flyer was first flown on Dec 17th 1903, marking the first successful powered flight. However, the aircraft displayed a number of HQ deficiencies that took the Wright Brothers about 2 years to fix. The aircraft is to be developed as a vehicle which can be used as a basic observation platform, flying circular flight paths over the ground in winds up to 10kts. The following outline performance should be used in the Handling Qualities assessment.
Refs 17 - 19 are available as knowledge supplements.



Outline Performance Requirements

- Take-off run < 300 ft
- Climb to 250ft altitude < 1 minute
- Cruise speed 35kts
- Maximum speed 45kts
- Time to turn through 360 deg < 30 secs
- Typical manoeuvres to be performed include:
    - roll to 20 deg bank, perform coordinated turn through 90 deg and roll out on new heading
    - recover from upset caused by vertical or side gust
    - land following engine failure at altitude of 250ft
    - change speed by +/- 5kts
- As an emergency situation, HQs following engine failure from a height of 250feet, gliding and landing should be assessed.

From their offline analysis, the Team discovered that the original Wright Flyer was unstable in pitch, roll and yaw. The large negative pitching moment, C_{m0}, caused by the camber on the main wing, meant that the centre of gravity (cg) of the aircraft needed to be aft of the aerodynamic centre, giving a large negative 'static margin' (h) and hence pitch instability (Fig 5). The team designed five MTEs to test the aircraft in take-off, climb, cruise, turning flight and landing; in its original form the HQs of the aircraft were rated Level 3. Part of the re-design involved increasing the size of the canard control surface and its distance from the cg. The cg was moved forward and the instability reduced. Figure 6 shows a comparison of the pitch attitude during take off and climb out before and after modification. Although the take-off itself was still Level 3 with the upgrade, the climb manoeuvre was rated Level 2, as were all the other in-flight manoeuvres.

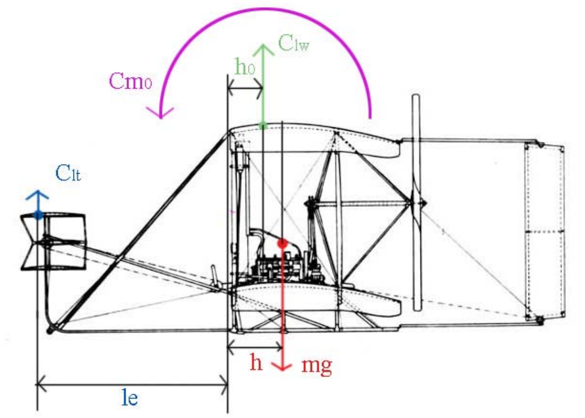


Fig 5 Free-body Side-view of Wright Flyer showing applied forces

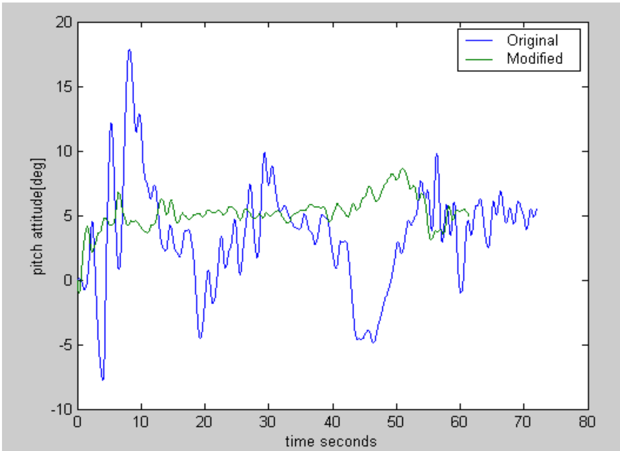


Fig 6 Comparison of pitch attitude variation during take-off and climb before and after modification

Team 4 - Grob Tutor Conversion to Combat Trainer

The Grob Tutor is designed as a basic flying trainer. The aircraft is to be upgraded to provide initial training for combat and to provide rough/small field performance.

Refs 20-21 are available as a knowledge supplements

Outline Performance Requirements

The following outline sea level performance should be used in the Handling Qualities assessment.

- Maximum cruise speed — 200kts
- Sustained ‘g’ capability at 200kts — 3
- Transient g capability at 200kts — 4
- Time to roll to 70deg (and hold) from level flight — < 2 secs
- Landing speed (with flaps extended) — < 70kts

Typical manoeuvres should include;

- Aircraft should be able to track a moving or fixed target at combat speed (200kts) maintaining target within azimuth and range constraints of typical forward firing weapon.
- The aircraft should have roll HQs sufficient to fly a slalom type manoeuvre with reasonably high levels of aggressiveness (e.g. runway roll-step with Aspect Ratio of 0.1).

As an emergency situation the aircraft’s vulnerability to encountering the vortex wake of a large aircraft (Hercules-class) should be assessed.

The Grob Team was faced with a broader range of challenges as a new powerplant was required and significant redesign of the control surfaces as well as control augmentation. The Team also had to quantify the risk in the emergency situation of a close encounter with the vortex wake of a Hercules-size aircraft. The Team modified an existing simulation of a vortex wake and designed an experiment whereby the pilot flew through the vortex at different approach angles and different flight conditions. Figures 7-9 show the aircraft roll rate, pilot’s aileron control movement and aircraft height change during the encounter. The pilot holds full opposite aileron for about 5 seconds during the encounter as the roll rate built up to about 60deg/sec and the aircraft lost nearly 200 feet in height. The severity was classed as catastrophic, requiring that operational constraints be introduced (e.g. separation distances, even during intense military activity) to reduce the encounter risk.

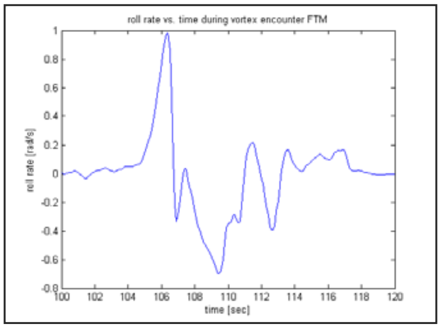


Fig 7 Roll rate during vortex wake encounter

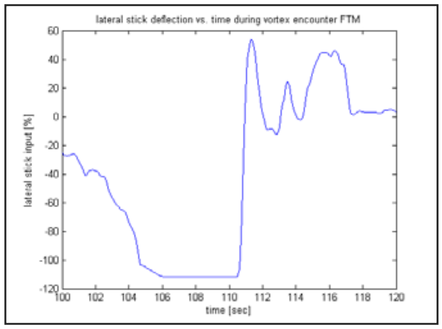


Fig 8 Pilot's roll command during vortex wake encounter

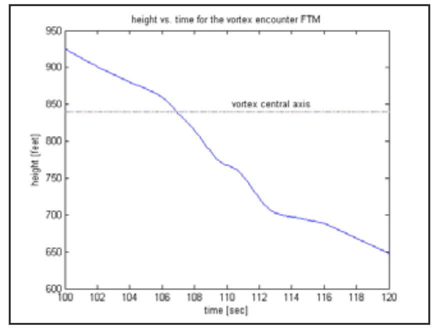


Fig 9 Height changes during vortex wake encounter

Team 5 – The UH-60 Blackhawk in the Tactical Transport Role

The Blackhawk helicopter is designed to fly tactical transport missions, delivering troops and equipment to different points in medium intensity battle areas. The aircraft is to be fitted with stability and control augmentation system to improve the handling qualities and allow flight in degraded visual environments.

Outline Performance Requirements

The following outline performance should be used in the Handling Qualities assessment.

- Hover Power (torque) margin (% to 88% red line torque) 15%
- Cruise speed H > 250ft 150 kts
- Tactical operating speed 100< H<250ft 100 kts
- Tactical operating speed 50 => 100ft (NoE) 45 -100 kts
- Tactical operating speed < 50ft 45 kts
- Transient g capability 2.5g at 100kts

Typical nap-of-Earth manoeuvres

- Terrain following, valley-following/jinking to avoid enemy, acceleration-deceleration across clearing, rapid bob-up manoeuvre for observation

Missions may be conducted in partially degraded environments when low speed 're-positioning manoeuvres such as a side-step or bob-up may be required.
An assessment should be made of this aircraft's ability to survive a loss of tail rotor drive through damage caused by hostile fire.

The UH-60 Team needed to understand and come to terms with many of the basic destabilising and cross coupling effects in an unstabilised helicopter in their off-line analysis and piloted tests. One of the HQ parameters they homed in on was the large yaw coupling when the pilot applied collective; an effect that led to Level 3 handling qualities when the pilot tried to use the maximum agility of the aircraft. The HQ criteria took the form shown in Fig 7 and, as part of their repair work, the Team designed a de-coupler that gave Level 1 handling qualities. The pilot awarded Level 2 HQRs when applying maximum torque in the Bob-Up MTE but qualified this with the statement that this was likely to be acceptable in the rare emergency situations when this level of agility would be required.

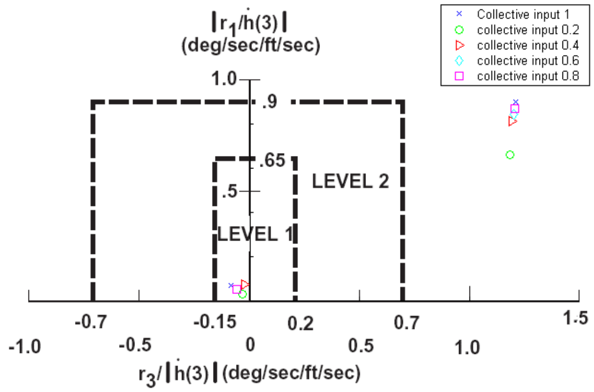


Fig 7 ADS-33 HQ criterion for cross coupling between collective and yaw rate (r) following a height rate command ($\dot{h}$)

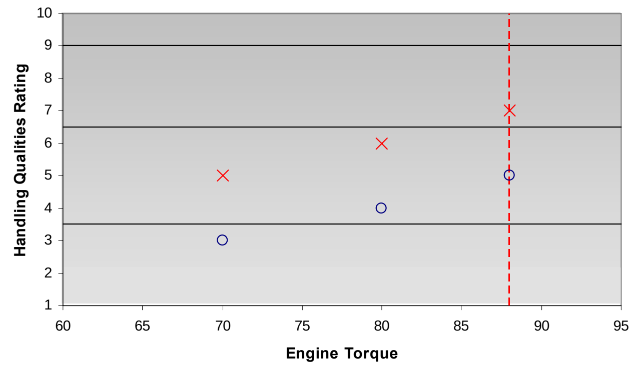


Fig 8 UH-60 Bob-up HQRs as function of applied torque; × - original aircraft ○ – after decoupling and stabilisation (------ maximum continuous torque)

4. TECHNICAL FEASIBILITY AND ECONOMIC VIABILITY

Students are required to address these topics in the context of the upgrades they have conceived, designed and implemented. Most teams often approached these by comparing the original aircraft with the upgraded aircraft and also an existing aircraft that featured a similar performance to their upgraded aircraft. For example, the Grob Team compared their new aircraft with the Raytheon T-6A Texan II, an option that matched the performance of the upgraded Grob, except for the rough field, short landing performance. The Bo105 Team achieved their improvements entirely within a new automatic flight control system, as did the UH-60 Team. The latter had costed the fitting of a duplex redundant system, to achieve the appropriate level of hardware redundancy, but had not taken account of the likely software costs and were unable to quantify the certification costs. The Wright Flyer team were restricted to use 'technology of the day' but were guided by the Wright Brothers experience in 1904 and 1905 and some information on their expenditure is available in the literature. Within these comparisons, the added performance must be weighed against the likely extra weight (hence reduced payload) and cost of the upgrade. The question then boils down to whether it is cheaper to upgrade or buy new, in which case operating costs also enter the picture. The confidence in the weight and cost data that the students have access to, or were able to 'guestimate' in this phase of the module is actually rather low. Also, experience to date suggests that, while the technical feasibility can be a relatively straightforward question to tackle, the financial viability is much more challenging and often given short thrift in the final stages of the Teams' work. Clearly, economics play a major part in the engineering process but the limited exposure the students have to the subject within their degree programme, and the limited access to manufacturers' technical and pricing data, in turn limits the students ability to address this issue within FHQ. In practice, learning about Handling Qualities, conducting the assessments and making the necessary design changes, already engage the students in active learning to major extent. The whole subject of economic viability within the FHQ module is under review, a process informed by the many lessons learned during the first four years of operation.

5. SOME LESSONS LEARNED

Lessons learned during the early years of this PBL module have led to developments summarised in Appendix D. Some of the key areas are listed below;

a. Setting of 'deliverable' dates; the module assessment is based on a number of key deliverables, e.g. the final report and Team presentation. It is important to take account of other course-work commitments when setting the dates for these. In particular, clashes with hand-in dates for the individual and group project reports can lead to high workload and deterioration of quality.

b. What are Personal Learning Journals? Some students have difficulty with self reflection on their learning and distinguishing between knowledge and intellectual abilities. Engagement of staff from the University's Centre for Lifelong Learning has helped to reinforce the value of this aspect of the module.

c. FLIGHTLAB Workshops. When these sessions occur is critical to their value – too early and the students cannot associate; too late can inhibit progress.

d. The Importance of Pilot briefings. Teams need to understand the purpose of the pilot briefing and how a common understanding of what is required can save considerable time.

e. Preparation for trials. Teams that are well prepared for the piloted tests and have sought the opinions of the test pilot beforehand are likely to have a successful trial; the opposite is also true.

f. Dealing with Team Problems. Teams who face their technical and personal problems together and promptly usually achieve a equitable work-share. In particular, Teams experiencing problems with members not 'pulling their weight' need to deal with this in a deliberate fashion; if this does not succeed, they need to raise the problem with the module coordinator.

6. CONCLUDING REMARKS

This paper has presented a description of the approach taken in the development and delivery of a problem-based-learning module for students in their 4th and final year of the Aerospace Engineering Degree Programme at the University of Liverpool. The students engage in active learning in all four phases of the CDIO cycle. They analyse aircraft deficiencies that inhibit pilots from achieving desired mission performance, they conceive options for repairing the aircraft and correcting the deficiencies, they design and implement the successful options and they evaluate the improvements against operational standards using a piloted flight simulator. The students work in Teams of 4, giving about 600 man hours of effort available for the tasks to be undertaken. Students are encouraged to adopt professional project conduct processes in this module, and are given milestones and deliverables related to their HQ predictions, initial piloted trials, interim reports, second pilot assessments, team presentations and final reporting. Each student maintains a personal learning journal for recording their experiences. Generally, students regard the FHQ module as an integrating experience, requiring hard, co-operative, work in Teams to achieve the goals. The module is reviewed annually and subject to continuous improvement.

ACKNOWLEDGEMENTS

The Flight Handling Qualities module engages the students in active learning and the success of the module in achieving its learning outcomes has been largely due to the positive spirit in which all 3 years' cohorts have been able to engage in this process. A number of staff at the University have been important in the development and delivery of the module, particularly Tom Shenton, the module moderator, the team mentors (Ben Lawrence, Mark Voskuijl, Robert Armstrong, Neil Cameron and Michael Jump) and the simulation laboratory manager Mark White. The visiting QinetiQ assessors (Andrew Tailby, David White, Paul Taylor) have provided valuable feedback on the module both to the staff and students. On one occasion Roger Hoh (Hoh Aeronautics and main author of ADS-33) joined the FHQ class to give feedback on their review of his paper on Lessons Learned in Handling Qualities Investigations. Critical to the success has been the contribution from the visiting test pilots, Andrew Berryman and Martin Mayer. Both ex test pilots and tutors at the UK's Empire Test Pilot School, Andy and Martin have provided exceptional learning opportunities for the students – reviewing experimental design, mission task elements, performance standards etc. – and aiding their understanding of the importance of handling qualities to operational effectiveness and flight safety. The author acknowledges the substantial contributions of all these people to the module.

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APPENDIX A

GUIDANCE NOTES FOR AERO 401 - FLIGHT HANDLING QUALITIES

1. INTRODUCTION

Flight Handling Qualities is a 15-credit, Problem-Based-Learning (PBL), module. The aim is to equip students with the skills and knowledge required to tackle handling qualities and related 'whole aircraft' problems in Industry. The theory of handling qualities engineering will be presented in the first 6 weeks of the first semester and a set of notes will be provided to each student to supplement the lectures. The students form into 5 Teams of 4. Each team will be presented with a task of assessing and quantifying the HQs of a particular aircraft in a particular role and developing fixes to any handling deficiencies. Each team will have to write a Report (Interim, 1st Semester) showing how they have assessed the basic aircraft, describing the HQs and indicate potential solutions to the problems. A Final Report (2nd Semester) will be written describing the ways in which the HQ problems have been fixed, and making recommendations concerning the future use of the aircraft and its suitability in the role. They will present their work to a 'Customer' (group of staff) with the objective of demonstrating that the aircraft is now fit for the role. Each individual student will maintain a 'Learning Journal', in which they will document the development of their understanding of handling qualities from the beginning of the module.

Students need to spend about 150 hours on a 15-credit module, or about 7.5 hours per week (on average) over 20 weeks.

Assessment will be 100% coursework.

These guidance notes are intended to help students understand the process of active, problem-based, learning and to describe the structure and content of the module.

2. THE ESSENCE OF PROMBLEM BASED LEARNING

Four themes underlie PBL.

- Explore problems using background knowledge and experience,
- Analyse problems and formulate hypotheses that might explain them,
- Design and conduct experiments or perform theoretical analysis to test hypotheses,
- Develop new understandings and formulate problem solutions.

In PBL, the tutor acts as a facilitator rather than a teacher, encouraging useful lines of questioning rather than providing explicit answers, and, when appropriate, provides problem solving structures or methodologies.

In PBL, the students take responsibility for their own learning, engaging in active learning through critical self reflection, self assessment and collegial learning.

In the Flight Handling Qualities module, the aircraft with its handling deficiency becomes the focus for knowledge acquisition. This method of learning helps the student to garner transferable, technical and interpersonal skills that will serve them for the rest of their lives.

3. THE LECTURES

The Lectures provide the theoretical basis for aircraft handling qualities. They are supplemented by a handout containing copies of the Powerpoint presentation slides. Attendance at the lectures is a required part of the module. The Lectures will be structured on a rational basis and will present a holistic approach to Handling Qualities Engineering based on a mission analysis. The Lectures will prepare students for the PBL component of the module.

4. HQ TEAM ACTIVITY

The objectives of the HQ team PBL activity are to;

(i) quantify the HQs of the aircraft as given against appropriate criteria and measures thus defining areas requiring improvement,
(ii) understand the sources of the deficiencies,
(iii) design improvements using both aerodynamic and control system technologies, implement in the simulations and test the upgraded aircraft,
(iv) demonstrate that the upgraded aircraft has Level 1 HQs in its operational flight envelope for the defined mission. Any areas where the HQs are likely to degrade to Level 2 or 3 should be discussed and appropriate methods for dealing with these deficiencies should be defined,
(v) define and rationalise the level of redundancy in any flight control system functions.

The final report should cover all these topics and will be graded on how well the students address these issues.
Critical to the success of any team activity is achieving a mutual understanding of what has to be done, agreeing an equitable share of the tasks, supporting each other when required, each individual pulling their weight and agreeing a plan. The plan needs to be realistic and achievable in the timescales but it also needs to be challenging because many of the skills and knowledge will not exist in the team at the outset and the nature of the handling qualities problems are such that developing solutions requires thinking 'out-of-the-box', i.e. outside the constraints of current knowledge and understanding. The significance of this will hopefully become clearer as the module progresses.

Developing a mutually agreed plan is also critical to a successful outcome. A good plan will have defined 'Waypoints' which indicate the successful completion of a task or group of tasks. A Waypoint will be reached when one or more goals have been met. The teams will need to define these goals – sometimes referred to as Exit criteria – if the exit criteria are met then it is possible to move on toward the next Waypoint. The Teams are strongly encouraged to take this concept very seriously. The Waypoint concept is drawn from aerial navigation whereby a pilot will define on the map a series of points (joined by straight lines) that he/she has to pass over on route to their destination. Possible Waypoints in the FHQ Team Activity include;

a) complete mission analysis with defined mission task elements, flight test manoeuvres and associated performance standards
b) agree appropriate HQ criteria (relevant to mission) and define (compute) aircraft HQs according to criteria (usually involves applying test inputs to FLIGHTLAB model in offline mode)
c) conduct piloted evaluations of aircraft HQs in 'baseline' configuration and establish pilot perceived HQs
d) define the areas where HQs are suitable for mission and where there are deficiencies (based on results from b) and c))
e) hypothesise/develop alternate concepts for fixing HQ deficiencies
f) complete testing of candidate solutions and quantify levels of improvement achieved.

The HQ Team Report should be structured as shown in the HQ Team Report template. The length of the Report is not prescribed but it reflects the efforts of the team over a 20-week period and is worth 50% of the module assessment so is effectively worth the same as a conventional 7.5 credit module and therefore needs to be a substantial document. The HQ team should share the production of this report. It is stressed that the Team Report is a major product of the Team work that is assessed – it should properly reflect the work of the Team over the period of their knowledge skill and development.
One of the potential negative aspects of team work is the concept of a 'passenger' – a member who does not contribute an equitable

share towards the work of the team. Normally a Team will develop working practices and ethics that discourage any member from becoming a passenger. This will come partly from mutual encouragement and support and partly from taking a disciplined approach to responsibility. The assessor has to deal with the rare situation of a Team not achieving its full potential because of a passenger. This will be achieved by having flexibility to award different ‘marks’ for each member for their contribution to the Team Report. To facilitate this it is required that the contributions to each section of the Team Report be indicated, e.g. member 1 – 25%, member 3 – 75%.

A Team will know if a member is not pulling his or her weight, simply because progress in the allotted tasks will not be satisfactory. The first solution is to try to solve this ‘problem’ within the Team. If this does not work then the issue needs to be brought to the attention of the module coordinator who will help the Team resolve the problem. Identifying potential passenger problems at an early stage, and reaching a satisfactory solution to such problems, is crucial and forms part of the team skill development which can be carried forward into one’s career.

Section 7 of these notes for guidance discusses some of the attributes of a successful and purposeful group and other potential problems. It is strongly recommended that students study these carefully and initiate team discussion on what these issues mean to them and their work.

5. THE PERSONAL LEARNING JOURNAL

The focus of the Personal Learning Journal (PLJ) is to record the conduct and completion of required tasks. The Journal also aims to encourage self-reflection on what has been learned and how things could be done differently. The Journal should provide a rich source of information about a student’s self-assessed knowledge and competence in the exercise of skills. The Journal also provides the basis of an external assessment of the student’s competence in terms of their technical knowledge and understanding, intellectual skills and abilities, ability to apply these skills in practical situations and generally transferable skills, particularly relating to team-work.

A good understanding of what is required in terms of content in the PLJ is important. An PLJ is not a list of facts but is a reflection by the person on how their understanding and thinking has changed over a period and why. The Journal counts for 30% of the module assessment and is a very important document. It should be handed in to the module coordinator, in hard copy, every 2 weeks commencing on the date of the 3rd Lecture period; the coordinator will return it signed and marked with a grade in the following week with appropriate comments (according to scale; A – excellent, B - very good, C - good, D – fair, E – unsatisfactory).

6. THE ORAL PRESENTATIONS

Each HQ team will present their findings to the module coordinator, at least one other HQ Team and others as required, including practicing engineers from Industry. The presentation will last for 30 minutes and will involve all members of the team. The overall aim of the presentation is to convince the audience that the Team has been able to develop solutions to the HQ deficiencies that provide an operator with an aircraft that is safely usable within a defined operational flight envelope. The presentation should cover the same ground as the HQ Team Report and make recommendations for further improvements that the Team consider appropriate.

There will be an interim presentation in the first semester, prior to the first simulation trials, where teams will present the results of their offline HQ analysis and the design of the simulation experiments. Duration will be 20 minutes (15 presentation and 5 questions). Satisfactory progress at this stage is required before Teams qualify to conduct the first simulation trial.

7. THE ASSESSMENT

At each stage the assessor asks the question – what aspect of the students learning do we wish to assess? We actually wish to assess your technical knowledge and understanding, your intellectual skills and abilities, your ability to apply these skills in practical situations and your generally transferable skills, particularly relating to team-work. The assessor will make ongoing judgements based on what you record in your Learning Journal, which will be handed in for assessment every 2 weeks from the beginning of the module.

Assessment is made according to the following scheme.

Assessment	*Weighting %*	*Timing*	*Material*
Continuous Assessment	30%	Fortnightly returns	Individual's HQ Learning Journal
	50%	Week 10, semester 1	interim Report on HQs Final report on HQs
		Week 10,	
	20%	semester 2	Team's oral presentation
		Week 9, semester 2	

8. TEAM WORK – REFLECTIONS ON THE 'PURPOSEFUL GROUP'

a) The HQ teams are groups of 3, 4 or 5, that need to develop confidence and trust in each other to derive the most out of the module. Without trust and confidence, there is a high risk that many aspects of the work will not be completed well or fully. With trust and confidence, the team result will far exceed the capabilities of each individual or the 'sum of the parts'.

b) The HQ team is a group with a purpose. That purpose will involve sharing responsibility for the outcomes of the group work. That purpose also reflects the need for a structure to the activities that will evolve over time.

c) Purposeful groups – teams – will have common goals, share a common vision - negotiating, establishing and agreeing on this vision and these goals - is a critical task of the group.

d) At some stage early in the life of the group, there will be a realisation that the goals are best achieved by treating the work as a 'project' with milestones, tasks and task allocations, deliverables etc, i.e. drawing up a plan. This project organisation will require every member to play their part but it may be that one member is 'voted' as having the overall responsibility for ensuring that the plan is adhered to. Such a person is described as the project manager and they will take on the task of keeping the whole picture in their minds as well as detailed technical work.

e) A group provides a rich learning experience in itself – members can observe what others do and say, and then observe what happens next.

f) A group provides an environment in which new (improved) behaviours can be tried out, new and richer skills can be developed and personal confidence strengthened, old, tired ideas replaced with new, better rooted ones.

g) Receiving feedback from others within the group is one of the advantages of the group as a context for support.

h) Group members can gain information about the impact of their behaviour on others, which is not ordinarily available to them.

i) Leadership can move around the group; a healthy group allows space for this to happen – an unhealthy group does not.

j) All groups experience communication problems. The challenge is being able to address these positively in a blameless manner – this is critical to the success of the group.

k) With a group of 3, members need to be particularly sensitive about sub-agendas. It can be destructive if 2 members of the group decide to do things in a particular way because they are having difficulty with the third member. It might seem a short term imperative but it will not work in the long term. Find a way of involving all members in all discussions and, particularly, all decisions. Ignore this advice at your peril!

l) Groups need to establish a way in which decisions get made and which can then be taken as a given or datum for subsequent discussions.

m) Listen to what your colleagues have to say, and never dismiss a colleague's contribution; always respond positively and only interrupt politely. Give people time to express their ideas even though you may feel you know the answer or strongly disagree; I will repeat this – give your colleagues time to articulate their ideas.

n) A group needs to discuss and agree on some basic 'rules of operation', e.g. attendance, punctuality, structure of meetings, how to review progress, formats of material, how you record your progress.

o) Beware of and be sensitive to collisions and collusions – they are inevitable and on the positive side they provide opportunity for personal change and growth.

p) A successful group acknowledges, respects and works with the different strengths of members of the group. Let your group grow strong and work towards a group solution!

APPENDIX B

TEAM REPORT STRUCTURE

Executive Summary

1. Introduction
2. Background to Handling Qualities – theory and practice
3. The Test Aircraft
   3.1 Description of Aircraft and Role (inc. day in the life of system description)
   3.2 The Operational Flight Envelope, Missions and Mission Phases
   3.3 Mission Task Elements and Flight Test Manoeuvres
4. Handling Qualities of the Test Aircraft
   4.1 Overall Methodology
   4.2 Off-line assessments
   4.3 Piloted assessments
   4.4 Overall assessment (impact on role)
   4.5 Conclusions and Recommendations
5. Handling Qualities Improvements

   5.1 Improvement Options
   5.2 Design synthesis and analysis
   5.3 Piloted assessments
6. Discussion
   6.1 Technical Feasibility Issues
   6.2 Economic Viability Issues
7. Conclusions
8. Recommendations

Appendices

- Details of design, analysis techniques and results
- Powerpoint presentation

APPENDIX C

GUIDANCE ON TEAM PRESENTATIONS

1. use powerpoint presentation; laptop and video project will be available but teams can bring their own laptop – allow a few minutes at the beginning for setting up
2. structure of presentation should **broadly** follow along the lines:
   a. introduce team
   b. introduce aircraft, role and critical HQs
   c. basic aircraft – good and bad HQs from offline tests and piloted simulations; use HQ theory to support conclusions
   d. HQ repair work – rational, design goals, methods
   e. Accomplishments
   f. Repaired aircraft - good and bad HQs from offline tests and piloted simulations; use HQ theory to support conclusions
   g. Technical feasibility and economic viability
   h. Outstanding issues
   i. Conclusions and recommendations
3. Teams have 30 minutes to present – keep to time!
4. This will immediately be followed by a 20-minute session of Q&A. Issues to be addressed will include:
   a. How well have the conclusions been supported by the analysis and the results presented,
   b. How well were the HQ problems of the test aircraft understood by the presenting team,
   c. To what extent has the design work repaired the identified HQ problems,
   d. Was the presentation clear and coherent, well supported by visual aids, a team effort
5. Everyone should have an equitable share of the presentation and indicate their contribution to the work
6. Speak clearly and professionally, look at audience, engage with eye contact, emphasise important points
7. Use clear and simple slides; Show results in a concise way, point to information on

the slides to draw audience attention to things

8. Results and analysis will carry the most weight
9. Back up conclusions and hypotheses with evidence
10. Don't be afraid to admit mistakes (but don't make the presentation a comedy of errors!) and highlight what you have learned
11. I recommend that you present yourselves smartly as a team
12. Have a procedure for answering questions especially if they are not directed at a particular individual – work as a team
13. Rehearse your presentation until it is really good and ask colleagues to sit in a give critical comments – don't be afraid of these
14. Teams will be scored on the basis of how well they have addressed items 4a-4d above on a scale of Excellent, Very Good, Good, Fair, Poor and Unsatisfactory.

APPENDIX D

AERO 401 FLIGHT HANDLING QUALITIES – DEVELOPMENTS 2002-2006

Academic Year	Developments
2002-3	• 15 students (5 groups of 3) • single semester (2nd)
2003-4	• 17 students (4 groups of 3 and 1 group of 4) • extended over 2 semesters • interim report at end of semester 1
2004-5	• 21 students (4 groups of 4 and 1 group of 5) • interim presentation prior to first simulation trial (introduced to ensure that teams have conducted sufficient offline HQ analysis to be prepared for piloted trial • team mentors introduced (post-grad students available as facilitators) • changed specification for Grob Tutor (200kts rather than 250kts which required unrealistic design changes) • special lecture on the personal learning journal by staff form the University's Centre for Lifelong Learning • special lecture on Sustainability in Engineering
2005-6 (under review)	• increase credit value of module (22.5) • introduce more FLIGHTLAB workshops in semester 1 • complete initial HQ assessments earlier in semester 1 to allow upgrade work to begin earlier • Special Lectures on Technical Feasibility and Economic Viability introduced • Introduce dedicated FHQ periods during the second semester (e.g. whole week prior to second simulation trials)

APPENDIX E

The FHQ Tools – FLIGHTLAB and HELIFLIGHT

HELIFLIGHT (Ref 6, 7) is a PC-based re-configurable flight simulator, with five key components that are combined to produce a relatively high-fidelity system, including:

- selective fidelity, aircraft-specific, inter-changeable flight dynamics modeling software (**FLIGHTLAB, Ref 22**) with a real time interface,
- 6 degree of freedom motion platform,
- four axis dynamic control loading,
- a three channel collimated visual display for forward view, plus two flat panel chin windows, providing a wide field of view visual system,
- re-configurable, computer-generated instrument panel and head up displays.

A view of the cockpit pod is shown in Figure E1.

The software at the center of operation of the facility is FLIGHTLAB, providing a modular approach to developing flight dynamics models, and enabling the user to develop a complete vehicle system from a library of predefined components. FLIGHTLAB also provides a range of tools to assist in the generation of highly complex, non-linear, multi-body models. To aid the generation and analysis of flight models, three Graphical User Interfaces (**GUIs**) are available: **GSCOPE**, FLIGHTLAB Model Editor (**FLME**) and Xanalysis.

Figure E1 HELIFLIGHT at the University of Liverpool

A schematic representation of the desired model can be generated using a component-level editor called GSCOPE. Components are selected from a menu of icons, which are then interconnected to produce the desired architecture and data is assigned to the component fields. Figure E2 shows the collective and lateral stick control system for the FXV-15.

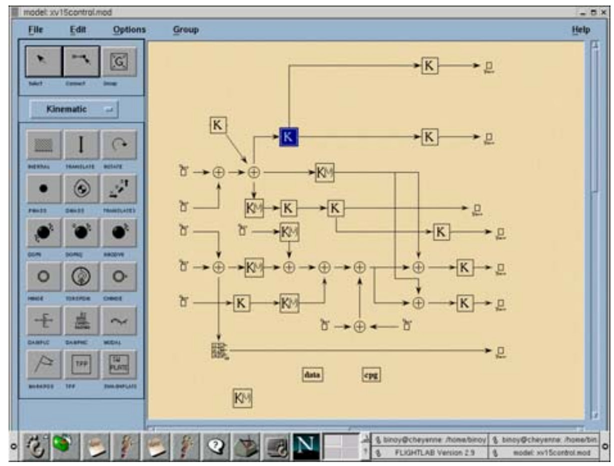

Figure E2 GSCOPE representation of the FXV-15 collective lever and lateral stick channel

FLME is a subsystem model editor allowing a user to develop models from higher level primitives such as rotors and airframes. Models are created hierarchically, with a complete vehicle model consisting of lower level subsystem models, which in turn are collections of primitive components. This is the Model Editor Tree, which puts all the predefined helicopter subsystems into a logical "tree" structure. A model tree for the XV-15 tilt rotor aircraft is shown in Figure E3.

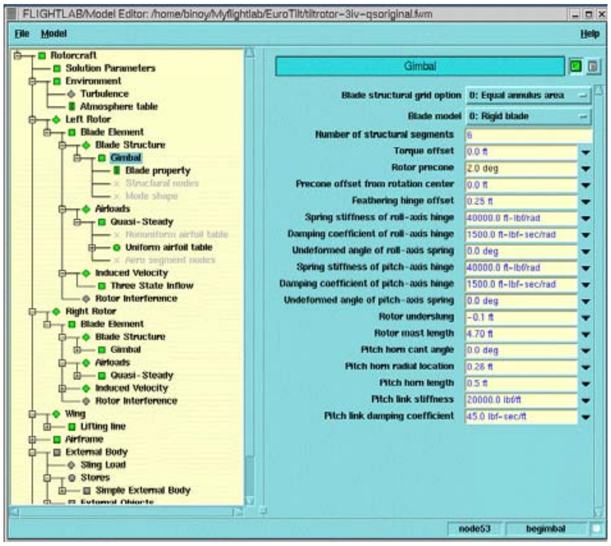

Figure E3 FLME expanded tree view and data input for the FXV-15 aircraft

Prior to running a real-time simulation, the model generated using the above tools can be analyzed using Xanalysis. This GUI has a number of tools allowing a user to change model parameters and examine the dynamic response, stability, performance and Handling Qualities of design alternatives (see Figure E4).

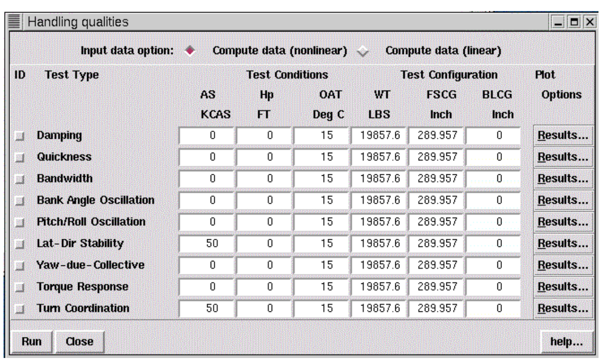

Figure E4 FLIGHTLAB Handling Qualities toolbox

The flight dynamics models form a vital part of a flight simulator, the detail of which will ultimately define the fidelity level of the simulation. Of equal importance is the environment into which a pilot is immersed. HELIFLIGHT uses a Maxcue 600 series motion platform together with Optivision collimated displays and Loadcue electronic control loading systems to create the virtual flying experience.

Three collimated visual displays are used to provide infinity optics for enhanced depth perception, which is particularly important for hovering and low speed flying tasks. The displays provide 135° horizontal by 40° vertical field of view which is extended to 60° vertical field of view using two flat screen displays in the footwell chin windows (see Figure E5). The displays have a 1024 x 768 pixel resolution, refreshing at 60Hz giving excellent visual cues when displaying a texture-rich visual database.

Figure E5 Typical pilot's eye view in HELIFLIGHT capsule

The sensation of motion is generated using the Maxcue platform, which has a significant movement envelope (see Table E1). The motion system is a six-axis, electrically actuated platform with a position resolution of 0.6μm. To ensure that the pilot does not receive "false" cues, the motion cueing algorithms can be tuned to correspond with the desired vehicle performance. To maximize the usable motion envelope, the drive algorithms feature conventional washout filters that return the simulator to its neutral position at acceleration rates below the perception thresholds, after a period of simulator motion.

Table E1: HELIFLIGHT motion envelope

Motion Parameter	Range [a]
Heave Range	500 mm
Peak Heave Velocity	± 0.6 m/sec
Peak Heave Acceleration	± 0.6 g [b]
Surge Range	930 mm
Peak Surge Velocity	± 0.7 m/sec
Peak Surge Acceleration	± 0.6 g
Sway Range	860 mm
Peak Sway Velocity	± 0.7 m/sec
Peak Sway Acceleration	± 0.6 g
Roll Range	± 28°
Peak Roll Rate	40°/sec
Pitch Range	+34°/-32°
Peak Pitch Rate	40°/sec
Yaw Range	± 44°
Peak Yaw Rate	60°/sec

[a] All motions are stated from mid heave with all other axes neutral. By coupling one or more motions, a larger range may be obtained.
[b] Measured over whole motion envelope. Heave accelerations of +1g/-2g may be produced near the centre of the motion envelope.

An important aspect of the overall fidelity of the system is the amount of delay or latency present. In HELIFLIGHT the flight dynamics model is running typically at 200Hz producing a 5msec delay. A delay of less than 16msec occurs as the output from the flight model is converted to produce a corresponding change in the simulator motion system. Latency in the visuals occurs due to the terrain texture density being displayed and varies with the specification of the graphics card. Currently this causes delays of between 16 - 30msec in the re-drawing of the terrain. In addition to this, the monitors are refreshing at 60Hz. Overall transport delay between pilot stick and motion base and visual response is estimated to be below 50msec.

HELIFLIGHT was commissioned for research and teaching use at the University of Liverpool in September 2000. During its first 4 years of operation the facility has been used extensively in a variety of research projects, undergraduate projects and laboratory classes as well as allowing students to experience a range of different handling characteristics. FHQ is the first PBL module to use the flight simulator.

As an illustration of the modeling standard used in a typical FLIGHTLAB model the Bell XV-15 aircraft (see Figure E6) is described.

Figure E6 XV-15 aircraft in conversion mode

The main aeromechanics features in the FXV-15 are listed below;

- Rigid prop-rotor blades with non-linear, quasi-steady aerodynamics in table look-up form as functions of angle of attack and Mach number computed on 5 equi-annulus segments,
- Two 3-bladed counter-rotating gimbal rotors; the gimbal is modeled with torsional spring-damper components in pitch and roll. No individual blade flapping is allowed in the FXV-15 implementation,
- 3 degree-of-freedom, finite-state rotor inflow model (Peters-He),
- The unique engine-governor system of the XV-15 was modeled as a simple first order relationship between output and commanded torque, the latter is a function of throttle setting and atmospheric conditions, with throttle and collective geared together as a function of nacelle tilt,
- The rigid drive train system was modeled as a collection of gear, drive, clutch and bearing components with the interconnect shaft as the single degree of freedom driven by the resultant torque,
- The wing/flap lift, drag and pitching moment coefficients are defined as functions of angle of attack, nacelle angle and flap setting. 4 segments are used with the outer left and right segments immersed in the rotor slipstream and 2 inner sections assumed to be unaffected by the rotor wake,

- Rotor-wing-empennage interaction modeled by superimposing the uniform component of the rotor induced velocity onto the wing-empennage velocities; wing-empennage downwash angle included,
- Nonlinear fuselage aerodynamics are functions of angle of attack and sideslip,
- Empennage aerodynamics modeled in a similar manner to the main wing,
- The FXV-15 control system features the mechanical interlinks between the pilot's controls and the rotor and fixed-wing control surfaces, with gearings set as functions of nacelle angle; the system also includes the 3-axis stability and control augmentation system, featuring rate damping and feed-forward response quickening,
- For the tricycle undercarriage, the FLIGHTLAB generic rotorcraft component was selected and modified to the appropriate location and size,
- Ground effect rotor image system.

Within the FHQ module students are given tutorials and half-day workshops on the use of FLIGHTLAB and HELIFLIGHT.