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Comparison of magnetic parameters of *CFAV QUEST* from FLUX3D modeling and airborne measurements

J. Bradley Nelson
Troy C. Richards

Defence R&D Canada – Atlantic

Technical Memorandum
DRDC Atlantic TM 2007-267
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Canada

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Principle Author

Original signed by J. Bradley Nelson

J. Bradley Nelson

Approved by

Original signed by Dave Hopkin

Dave Hopkin

Head/Maritime Asset Protection

Approved for release by

Original signed by Ron Kuwahara for

Calvin Hyatt

DRP Chair

Abstract

Under DRDC Atlantic contracts, Martec Ltd. developed a static magnetic model of *CFAV QUEST* for FLUX3D simulations using an existing finite-element model of the ship. The model accounts for both structural and some non-structural components of the ship. Martec performed a number of simulations with two magnetic configurations: induced magnetization only, and vertical permanent magnetization only. These simulated data have been used to estimate the permanent magnetization and magnetic susceptibility of a single prolate spheroid that best fits the overall ship's signature.

The National Research Council of Canada's Convair 580 aircraft was used to measure the magnetic signature of *CFAV QUEST* in August 2006. These data were also fitted to a single prolate spheroid model. The two sets of parameter estimates (from FLUX3D simulated data and from measured airborne data) were compared to determine how the FLUX3D magnetic parameters should be modified to more closely match the simulated and the measured *CFAV QUEST* signatures.

Résumé

Dans le cadre de contrats avec RDDC Atlantique, Martec ltée a produit, à partir d'un modèle structural d'éléments finis déjà existant, un modèle magnétique statique du NAFC Quest, aux fins de simulation avec le logiciel FLUX3D. Le modèle intègre des composants structuraux du navire et certains autres non structuraux. Martec a réalisé de nombreuses simulations avec deux configurations magnétiques : magnétisation induite uniquement et magnétisation verticale permanente seulement. Ces données de simulation ont servi à estimer la magnétisation permanente et la susceptibilité magnétique du sphéroïde allongé unique qui reproduit le mieux la signature globale du navire.

En août 2006, on a mesuré la signature magnétique du NAFC Quest, depuis le Convair 580 du Conseil national de recherches du Canada. Un modèle composé d'un unique sphéroïde allongé a été ajusté aux données obtenues. Les deux séries de paramètres estimés du sphéroïde (à partir des résultats de la simulation de FLUX3D et des mesures aéromagnétiques) ont été comparées pour déterminer de quelle manière on devrait modifier les paramètres magnétiques du modèle FLUX3D afin d'obtenir un meilleur accord entre les signatures simulées et mesurées du NAFC Quest.

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Executive summary

Introduction:

Under DRDC Atlantic contracts, Martec Ltd. developed a static magnetic model of *CFAV QUEST* for FLUX3D simulations using an existing structural finite-element model. The model accounts for both the structural and some of the non-structural components of the ship. Martec performed a number of simulations with two magnetic configurations: induced magnetization only, and vertical permanent magnetization only. These simulated data have been used to estimate the permanent magnetization and magnetic susceptibility of a single prolate spheroid that best fits the overall ship's signature.

The National Research Council of Canada's Convair 580 aircraft was used to measure the magnetic signature of *CFAV QUEST*. These data were also fitted to a single prolate spheroid model. The two sets of parameter estimates (from FLUX3D simulated data and from measured airborne data) were compared to determine how the FLUX3D magnetic parameters should be modified to more closely match the simulated and the measured *CFAV QUEST* signatures.

Results:

The position along the ship of the best-fit prolate spheroid for both the FLUX3D and airborne data agree to within a few meters. Even though the susceptibility estimate from FLUX3D data is a factor of 3 larger than from the airborne data, we recommend analysing other data from underwater range data, near-field surface measurements, and other airborne experiments before finalizing the FLUX3D magnetic susceptibility value.

The permanent vertical magnetization in the FLUX3D model should be changed to 0.0055 Tesla in the downward direction, and 0.0029 Tesla in the longitudinal direction to more closely match the measured magnetic signature of *CFAV QUEST*.

Analysis of the FLUX3D data by itself suggests that the centre of permanent magnetization is offset from the centre of induced magnetization by approximately 5-6 meters.

Significance:

If there is a shift between the centres of induced and permanent magnetization, then a more complex model may be needed to accurately reflect the magnetic characteristics of *CFAV QUEST*. A more complex model will also be required to model the near-field of the ship, especially if the degaussing coils are engaged.

Future Work:

Comparisons with underwater, surface, and airborne measurements are required to determine the best magnetic susceptibility and flux densities to use in the FLUX3D model to obtain the closest match between simulated and measured signatures. The FLUX3D model should be modified to include the degaussing system on *CFAV QUEST*.

Nelson, JB, Richards, TC, 2008. Comparison of magnetic parameters of *CFAV QUEST* from FLUX3D modeling and airborne measurements. DRDC Atlantic TM 2007-267, Defence R&D Canada - Atlantic

Sommaire

Introduction

Dans le cadre de contrats avec RDDC Atlantique, Martec ltée a produit, à partir d'un modèle structural d'éléments finis déjà existant, un modèle magnétique statique du NAFC Quest, aux fins de simulation avec le logiciel FLUX3D. Le modèle intègre les composants structuraux du navire et certains autres non structuraux. Martec a réalisé de nombreuses simulations avec deux configurations magnétiques : magnétisation induite uniquement et magnétisation verticale permanente seulement. Ces données de simulation ont servi à estimer la magnétisation permanente et la susceptibilité magnétique du sphéroïde allongé unique qui reproduit le mieux la signature globale du navire.

On a mesuré la signature magnétique du NAFC Quest, depuis le Convair 580 du Conseil national de recherches du Canada. Un modèle composé d'un unique sphéroïde allongé a été ajusté aux données obtenues. Les deux séries de paramètres estimés du sphéroïde (à partir des résultats de la simulation de FLUX3D et des mesures aéromagnétiques) ont été comparées pour déterminer de quelle manière on devrait modifier les paramètres magnétiques du modèle FLUX3D afin d'obtenir un meilleur accord entre les signatures simulées et mesurées du NAFC Quest.

Résultats

Nous avons obtenu un accord de quelques mètres entre les positions le long du navire, des sphéroïdes les mieux ajustés : celui calculé par FLUX3D et l'autre déterminé à partir des données aéromagnétiques. Bien que la susceptibilité calculée avec les résultats du FLUX3D soit trois fois plus élevée que celle estimée à partir des mesures aéromagnétiques, nous recommandons d'analyser d'autres données de reconnaissance sous-marine, des mesures du champ proche en surface et les résultats d'autres expériences aéroportées avant de fixer la valeur définitive de susceptibilité magnétique du modèle FLUX3D.

On obtiendrait un meilleur ajustement avec la signature magnétique mesurée du NAFC Quest, en modifiant, dans le modèle FLUX3D, la magnétisation verticale permanente à 0,0055 tesla vers le bas et à 0,0029 tesla le long du navire.

L'analyse des données calculées par FLUX3D elles-mêmes suggère que le centroïde de la magnétisation permanente et celui de la magnétisation induite sont décalés de cinq ou six mètres

Importance des résultats

L'existence du décalage entre les centroïdes de la magnétisation induite et permanente suggère qu'un modèle plus complexe est nécessaire pour reproduire plus fidèlement les caractéristiques magnétiques du NAFC Quest. Un modèle plus complexe serait aussi nécessaire pour modéliser le champ proche du navire, en particulier lorsque l'on active les circuits démagnétisants.

Recherches futures

Des comparaisons entre les mesures sous-marines, en surface et aéroportées sont nécessaires pour déterminer quelles valeurs de susceptibilités magnétiques et de densités de flux adoptées dans le modèle FLUX3D permettraient d'obtenir le meilleur accord entre les signatures simulées et mesurées. On devrait modifier le modèle FLUX3D pour y ajouter le système démagnétisant du NAFC Quest.

Nelson JB et TC Richards, 2008. *Comparaison des paramètres magnétiques du NAFC Quest déterminés par un modèle FLUX3D et des mesures aériennes.* RDDC Atlantique TM 2007-267, R & D pour la défense Canada – Atlantique.

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Table of contents

List of figures

List of tables

1. Introduction

CFAV QUEST has been designated as the platform for a variety of electromagnetic, infra-red, radar, and acoustic signature management tasks. These tasks include developing the measurement techniques, modeling the equivalent sources that reproduce the signatures, and creating a time-history of those source parameters. The magnetic signature of *CFAV QUEST* has been measured with airborne sensors (Refs 1-3), towed sensors (Ref 4), and bottom-mounted sensors. The last airborne measurements, gathered in August 2006 with the National Research Council's Convair 580 aircraft, have been fit to a "uniformly magnetized prolate spheroid model" in order to estimate the magnetic susceptibility and permanent magnetization parameters of the ship.

A FLUX3D static magnetic model was developed under contract by Martec Ltd., based on an existing finite element model of the ship. Refs (5-7) describe the FLUX-3D model and the early simulation results. The model accounts for both the structural and some of the non-structural components of the ship. It assumes the magnetic susceptibility (see Section 2) of all ferrous components of the ship was 300, based on the magnetic properties of the hull steel. However, the permanent magnetization was not known, so the simulations used an arbitrary flux density that gave roughly the correct amplitude of the predicted magnetic fields at the depth of underwater ranges.

Martec conducted a total of sixteen simulations consisting of four ship headings (0° true, 90° true, 180° true and 270° true), two ship configurations (induced magnetization only, vertical permanent magnetization only), and two aircraft altitudes (80 metres and 150 metres).

These simulated data have been fit with the same uniformly magnetized prolate spheroid model in order to compare the magnetic susceptibility and permanent magnetization estimates with those from the airborne measurements. The object of this comparison is to determine:

1) whether the centre of the prolate spheroid is coincident in both models,

2) whether the susceptibility and permanent magnetization estimates are sensitive to including data from very close to the source, or whether only "far-field" data should be used,

3) whether the assumed magnetic susceptibility of 300 is approximately correct or needs to be modified,

4) what permanent magnetization should be used in the FLUX3D model to better match the simulated and observed magnetic signatures.

Section 2 gives a brief introduction to the prolate spheroid model and Section 3 compares the derived parameters from fitting the measured airborne and FLUX3D simulated data. Section 4 gives the conclusions.

2. Prolate spheroid model

Figure 1 shows a prolate spheroid with semi-major axis “a” and semi-minor axis “b”.

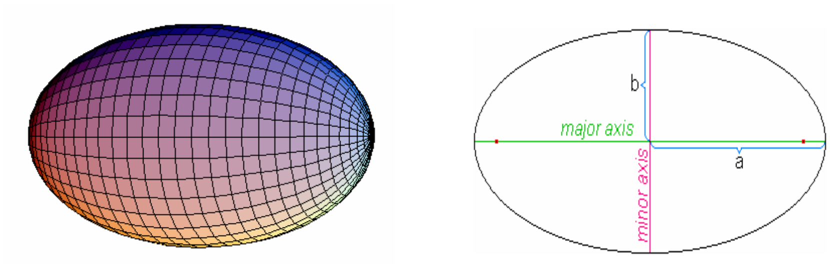

Figure 1. Prolate spheroid with semi-major axis “a” and semi-minor axis “b”.

In this work, we assume that *CFAV QUEST* can be modeled as a single prolate spheroid with permanent magnetization $\mathbf{M_P}$ and induced magnetization $\mathbf{M_I}$, both in Ampere/meter. The permanent magnetization has the components (M_{Px}, M_{Py}, M_{Pz}), and the induced magnetization is a function of the geometry of the prolate spheroid and the magnetic susceptibility χ_m, a dimensionless parameter. Refs (4,8) gives a full description of the prolate spheroid model and equations for the magnetic field due to both permanent and induced magnetization.

The parameters “a” and “b” were chosen to be the half-length and half-beam of *CFAV QUEST* respectively:

$$a = 36.0 \text{ m}$$
$$b = 6.3 \text{ m} .$$

The model used in Ref 8 assumed that the centre of the spheroid was known. In this work, however, a non-linear least-squares method was used to solve for both the longitudinal and vertical position (Δx, Δz) of the best-fit prolate spheroid relative to the midpoint/midline of the ship. Δy was assumed to be zero because of the high degree of port/starboard symmetry of the ship’s design. Thus the unknown parameters in the prolate spheroid model were:

$$M_{Px}, M_{Py}, M_{Pz}$$
$$\chi_m$$
$$(\Delta x, \Delta z) .$$

3. Results

3.1 FLUX3D simulated data

Figure 2, reproduced from Ref 7, shows the FLUX3D model of *CFAV QUEST* that Martec used in their simulations. The origin of their coordinate system was (0,0,0) = (midpoint between bow and stern, centreline of the ship, and waterline=5.05 m above the keel) and we have used the same origin in this report.

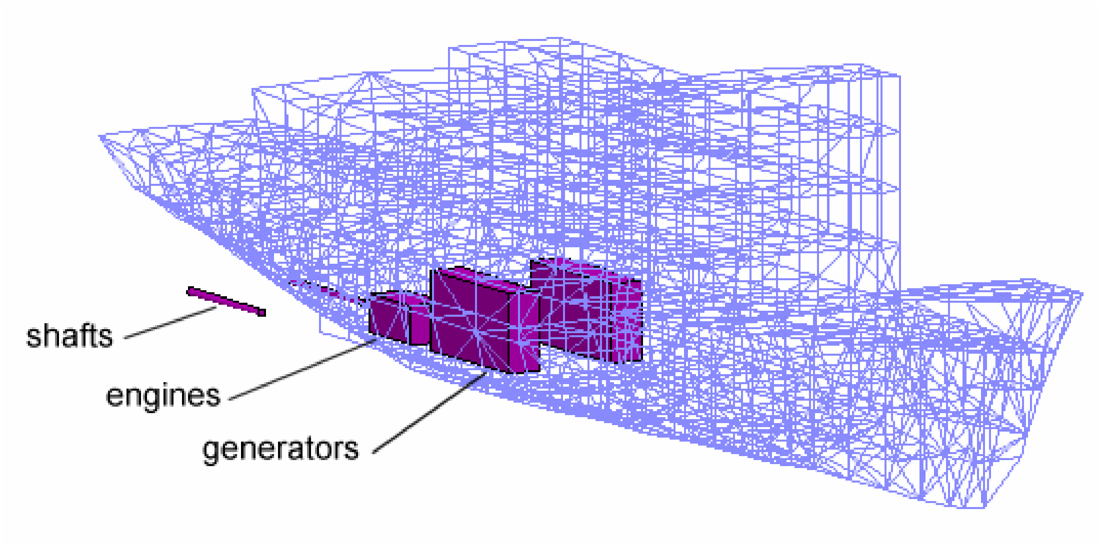

Figure 2. FLUX3D model including non-structural components.

Figures 3a-d show mesh plots of the total-field from the FLUX3D model with only the induced magnetization, at an altitude of 80 m above the mid-line of the ship, for ship headings of 0° true, 90° true, 180° true and 270° true respectively. Figures 4a-d are mesh plots of the total-field when only vertical permanent magnetization was present.

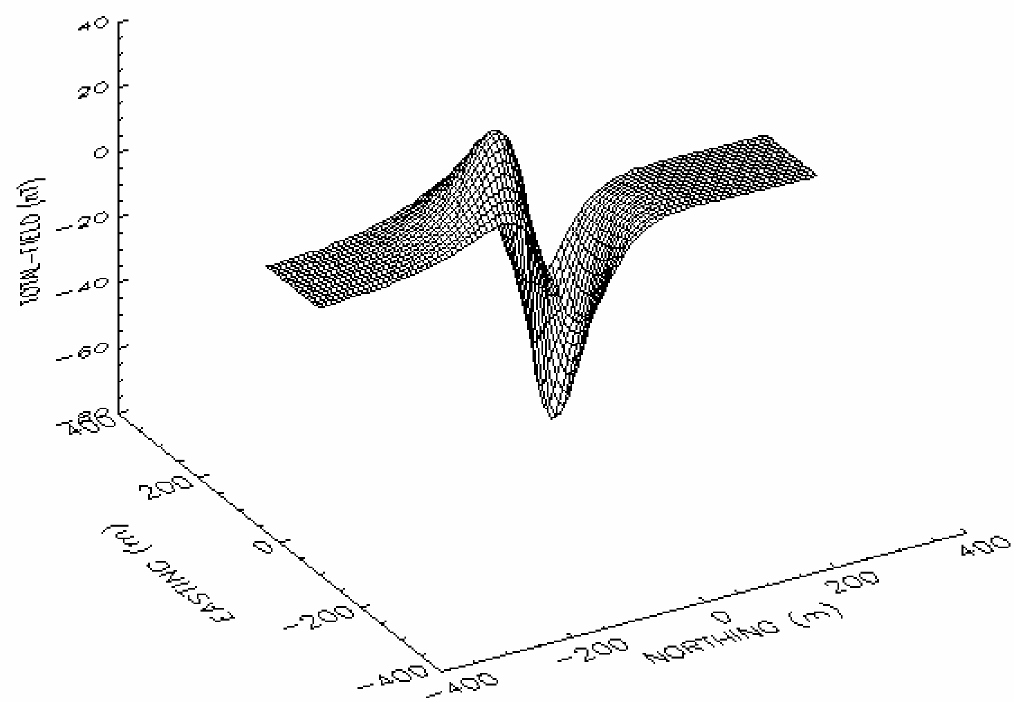

Figure 3a. Total-field anomaly due to induced magnetization only, ship heading = 0° (True), aircraft altitude=80 m.

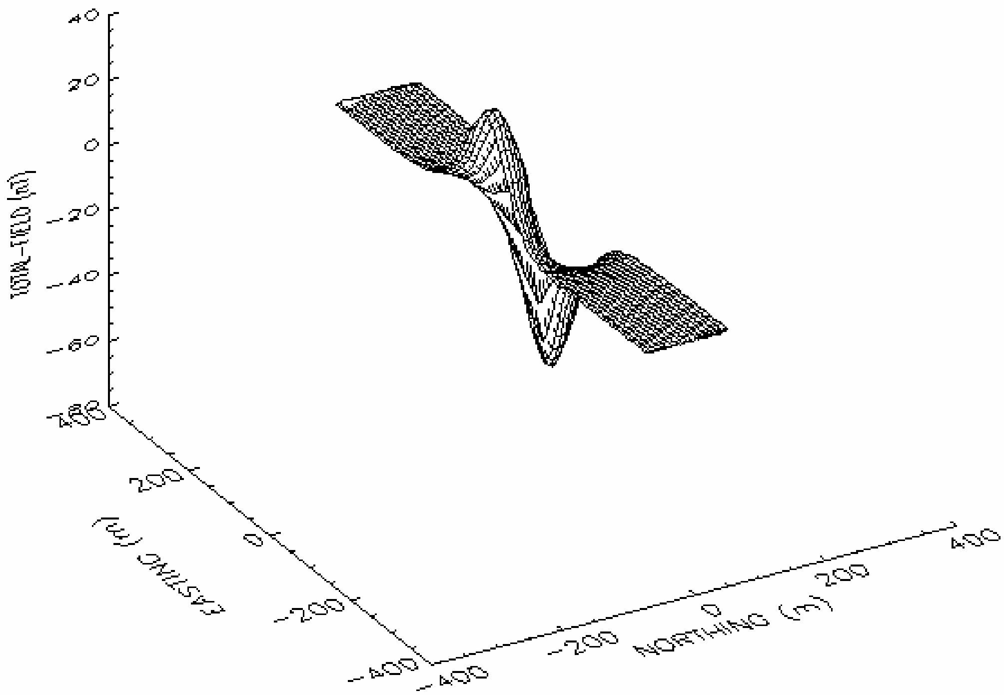

Figure 3b. Total-field anomaly due to induced magnetization only, ship heading = 90° (True), aircraft altitude=80 m.

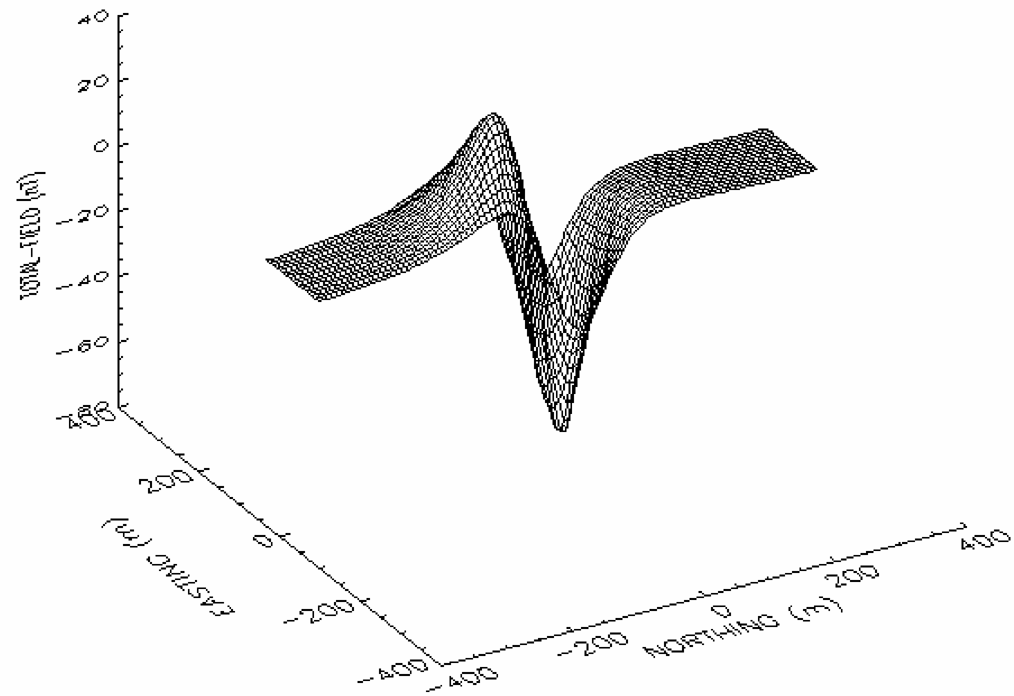

Figure 3c. Total-field anomaly due to induced magnetization only, ship heading = 180° (True), aircraft altitude=80 m.

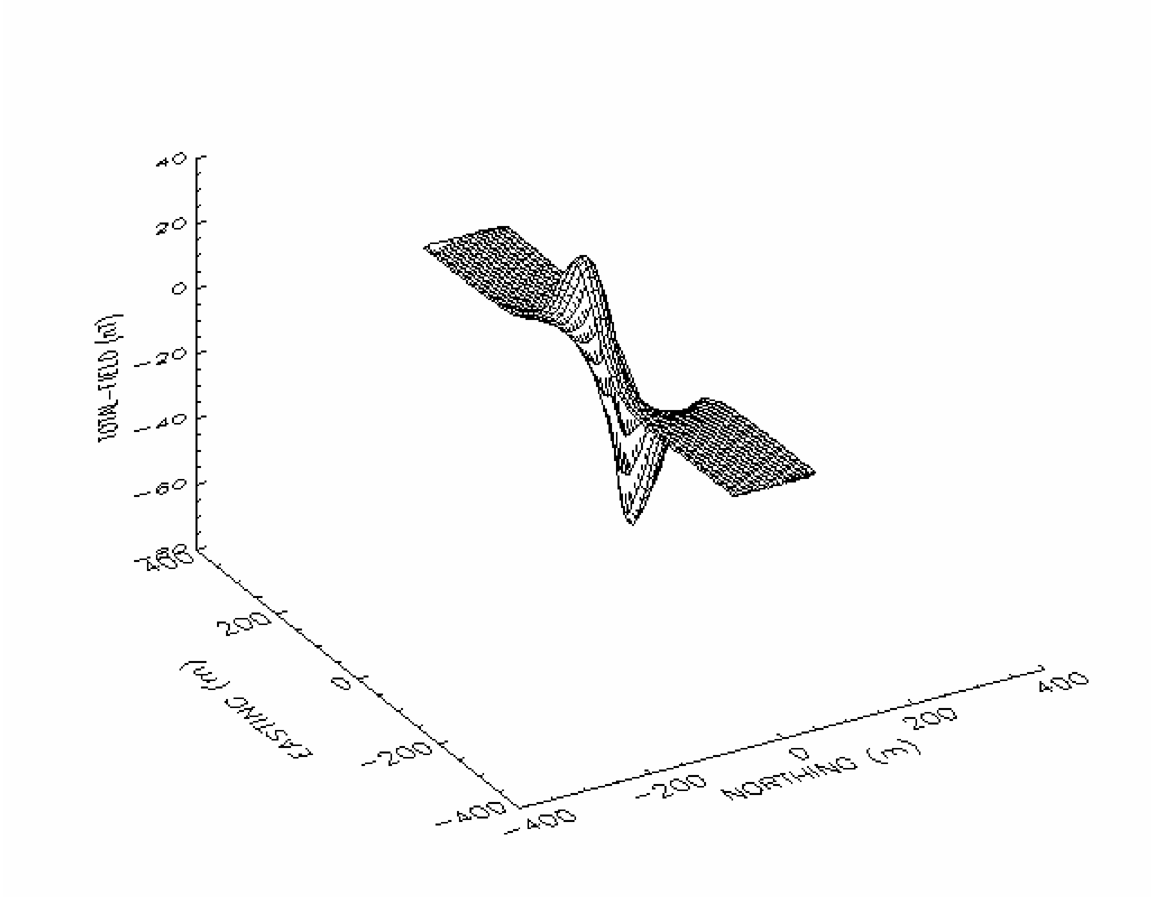

Figure 3d. Total-field anomaly due to induced magnetization only, ship heading = 270° (True), aircraft altitude=80 m.

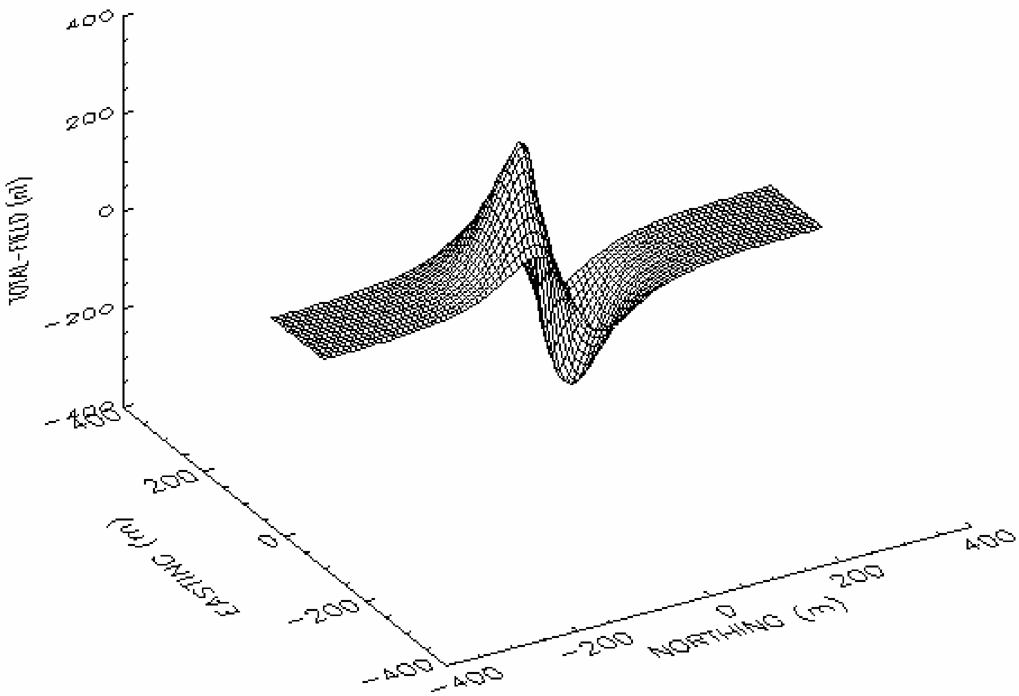

Figure 4a. Total-field anomaly due to vertical permanent magnetization only, ship heading = 0° (True), aircraft altitude=80 m.

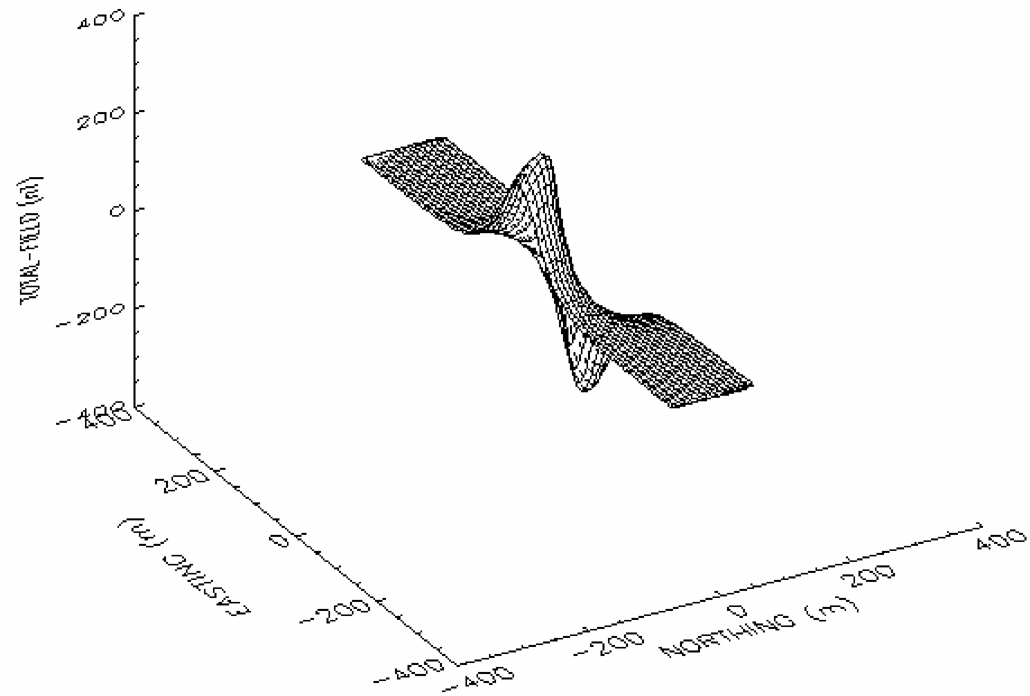

Figure 4b. Total-field anomaly due to vertical permanent magnetization only, ship heading = 90° (True), aircraft altitude=80 m.

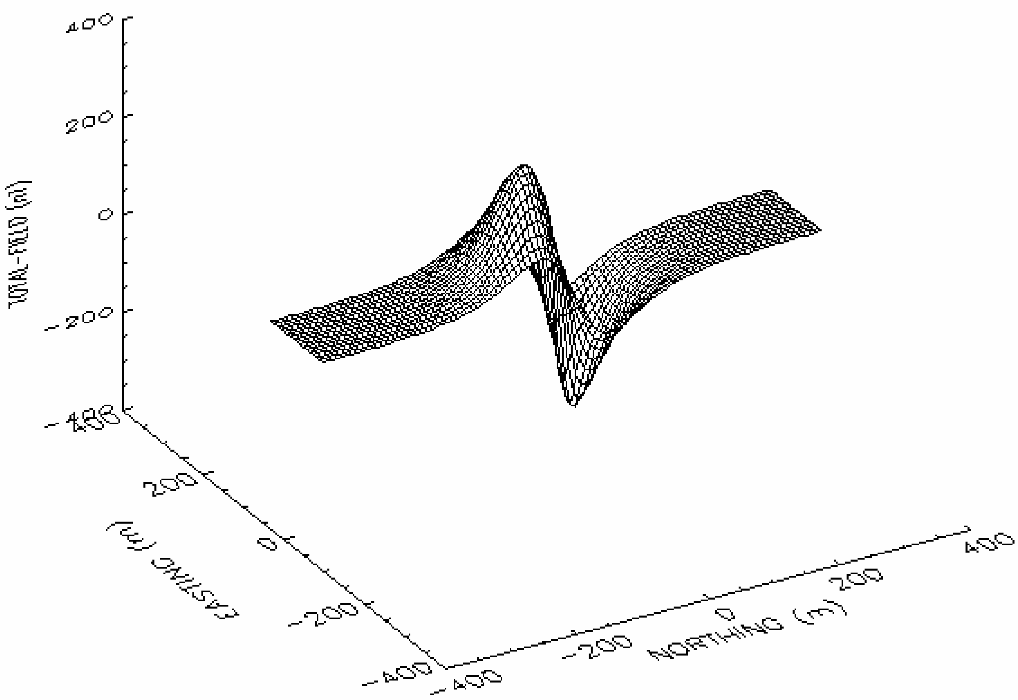

Figure 4c. Total-field anomaly due to vertical permanent magnetization only, ship heading = 180° (True), aircraft altitude=80 m.

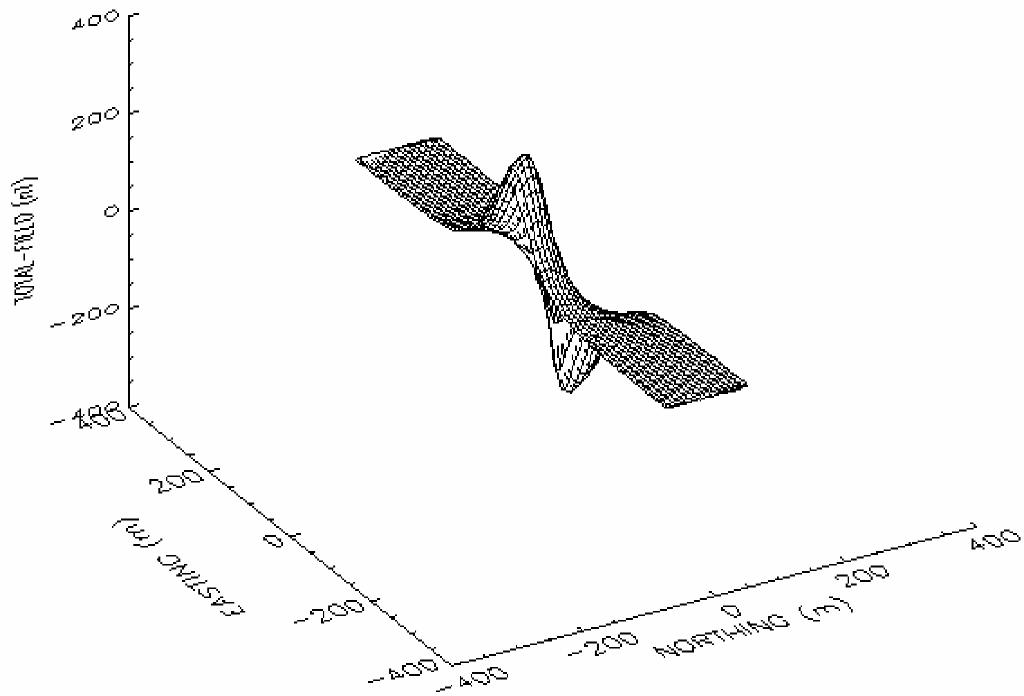

Figure 4d. Total-field anomaly due to vertical permanent magnetization only, ship heading = 270° (True), aircraft altitude=80 m.

It is unfortunate that the nodes for the simulations, i.e. the (North, East) points where the field values were calculated, were not the same grid for all the simulations as this makes direct comparison of the mesh plots difficult. However, Figure 5 is plot of the simulated total-field at the same points in space for the 0° and 180° "induced magnetization only" simulations. Although the longitudinal induced magnetization stays almost the same for opposite headings (neglecting the effect of different structures on the bow and stern of the ship), the vertical magnetization stays constant no matter what heading. Since the total-field reflects both the longitudinal and vertical magnetic state of the ship, one would expect there to be some differences in the simulated field on opposite headings for the "induced magnetization only" data.

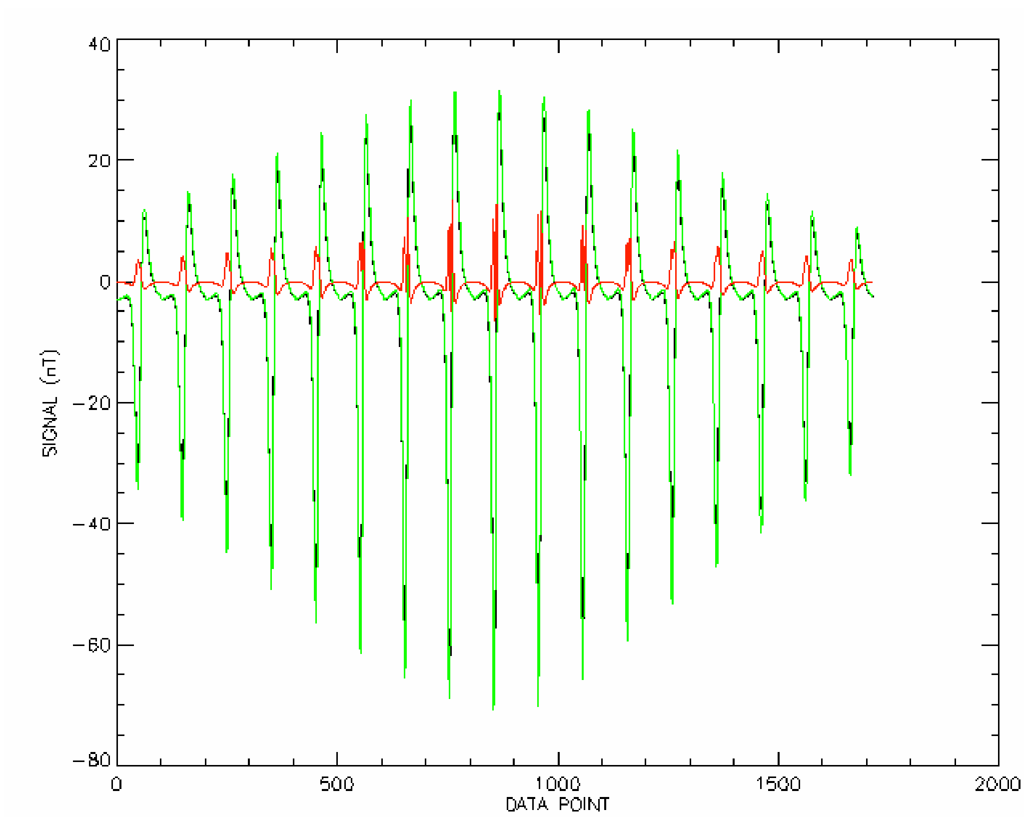

Figure 5. Total-field anomaly due to induced magnetization only. Black = Ship heading 0° (True); Green = ship heading 180° (True); Red = Difference between Black and Green traces. Aircraft altitude=80 m.

Figure 6 compares the "vertical permanent magnetization only" simulated total-field data for ship headings of 0° and 180°. If the magnetization stays the same for all headings, and the source of that magnetization is centred on the ship, then the total-field should be the same for both 0° and 180°. The red trace in Figure 5 clearly indicates that this is not the case, suggesting that the centre of magnetization is probably not aligned with the centre of the ship.

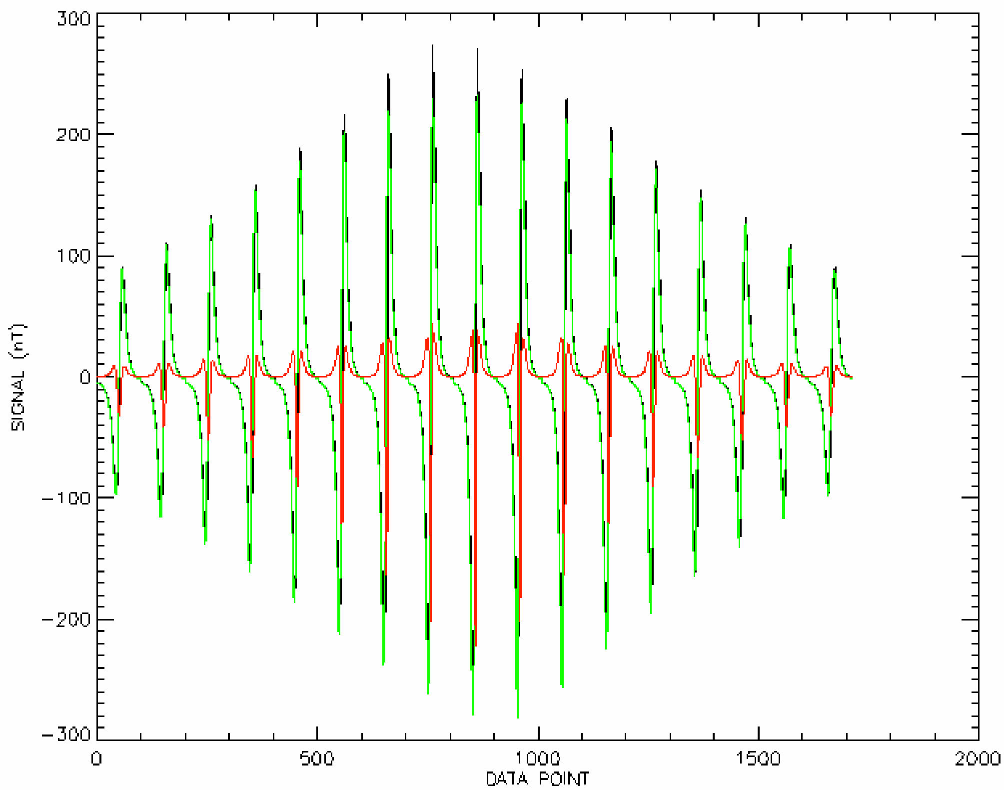

Figure 6. Total-field anomaly due to vertical permanent magnetization only. Black = Ship heading 0° (True); Green = ship heading 180° (True); Red = Difference between Black and Green traces. Aircraft altitude=80 m.

In general, the FLUX3D simulated anomalies have the shape and characteristics that are expected and thus the more detailed analysis in the following sections is warranted.

3.2 Magnetic parameters from FLUX3D simulated data vs. range cut-off

Table 1 compares the prolate spheroid parameters as a function of range cut-off, i.e. not including data closer than a given range from the centre of the ship for generating the best-fit model, for all 80 meter altitude data and only induced magnetization. Table 2 shows the same thing for all 150 meter altitude data and only induced magnetization. Tables 3 (80 m altitude) and Table 4 (150 m altitude) show the same thing for data simulated with only vertical permanent magnetization.

The parameters are remarkably consistent, varying by only a few percent even if some of the data close to the ship are excluded in the fitting procedure. Even the best-fit position of the spheroid varies by only a few meters. For the permanent magnetization case, there does appear to be a small longitudinal offset of the center of the best-fit spheroid from the midpoint of the ship ($\Delta x \sim -4$ m). This is consistent with the conclusion of Section 3.1 where the difference between the 0° and 180° total-field anomalies for the permanent magnetization case were attributed to an offset of the source from the centre of the ship.

For the induced case, however, there is no such obvious displacement. The most variation for both the permanent and induced magnetization cases is in the parameter Δz.

Note that the estimated susceptibility χ_m in Tables 1-2 are near 3.4, whereas Martec used a value of 300 in the FLUX3D ship model. This apparent discrepancy is not as bad as it first appears because our prolate spheroid model assumes a uniformly magnetized spheroid, not a uniformly magnetized spheroidal shell. The spheroidal shell would be a better approximation to the physical structure of a ship, but because it is not clear that it would actually lead to better fitting of the measured (or FLUX3D simulated) data, we have not used it. A more useful comparison would be the estimated susceptibility from fitting FLUX3D data to that derived from fitting measured data. Section 3.3 addresses this question.

Table 1. Prolate spheroid model parameters as a function of range cut-off. Altitude = 80 m, induced magnetization only.						
RANGE CUT-OFF (m)	M_{Px} (A/m)	M_{Py} (A/m)	M_{Pz} (A/m)	χ_m	Δx (m)	Δz (m)
0	-3.5	0.0	-13.4	3.2	-0.6	-2.2
20	-3.7	0.1	-13.7	3.3	-0.6	-1.7
40	-3.7	0.2	-14.4	3.4	0.1	-1.0
60	-3.3	0.1	-14.5	3.4	0.4	-0.6
80	-2.9	0.0	-14.4	3.4	0.3	-0.2
100	-2.5	0.0	-15.2	3.4	0.1	0.1
120	-2.2	0.0	-16.4	3.5	0.0	0.2
140	-1.9	-0.1	-13.6	3.4	0.0	5.3
160	-1.6	0.0	-16.7	3.4	0.0	0.5
180	-1.4	0.0	-16.5	3.4	-0.1	0.9
200	-1.3	0.1	-16.3	3.4	-0.1	1.2
220	-1.1	0.2	-15.9	3.3	-0.1	1.5
240	-1.0	0.2	-15.3	3.3	-0.1	1.9
260	-0.9	0.3	-14.7	3.3	-0.1	2.2
280	-0.8	0.3	-14.2	3.2	0.2	3.2

Table 2. Prolate spheroid model parameters as a function of range cut-off. Altitude = 150 m, induced magnetization only.						
RANGE CUT-OFF (m)	M_{Px} (A/m)	M_{Py} (A/m)	M_{Pz} (A/m)	χ_m	Δx (m)	Δz (m)
0	-3.4	0.1	-13.0	3.3	-1.0	-1.0
20	-3.4	0.1	-13.0	3.3	-1.0	-0.9
40	-3.2	0.1	-13.1	3.3	-0.5	-0.8
60	-2.8	0.1	-13.2	3.3	0.2	-0.7
80	-2.4	0.2	-13.2	3.3	0.9	-0.7
100	-2.3	-0.1	-13.0	3.3	0.8	-0.4
120	-2.2	0.1	-13.4	3.4	0.5	0.5
140	-2.2	0.0	-12.1	3.3	0.4	0.0
160	-2.1	-0.2	-11.0	3.3	0.4	0.1
180	-2.0	-0.2	-9.3	3.2	0.1	0.6
200	-1.9	-0.1	-11.6	3.3	-0.2	1.7
220	-1.8	0.0	-12.9	3.3	-0.2	2.9
240	-1.7	-0.2	-13.7	3.4	-0.1	2.3
260	-1.7	-0.4	-14.8	3.4	-0.1	3.0
280	-1.5	-0.5	-15.0	3.3	-0.2	3.1

Table 3. Prolate spheroid model parameters as a function of range cut-off. Altitude = 80 m, vertical permanent magnetization only.						
RANGE CUT-OFF (m)	M_{Px} (A/m)	M_{Py} (A/m)	M_{Pz} (A/m)	χ_m	Δx (m)	Δz (m)
0	-14.5	-0.4	221.5	-0.1	-7.8	-6.0
20	-12.7	0.0	224.0	0.0	-7.3	-4.2
40	-4.1	0.8	225.6	0.2	-5.2	-1.1
60	-1.7	0.3	221.9	0.2	-4.5	-0.7
80	-1.7	0.1	211.6	0.3	-4.4	-0.9
100	-1.5	-0.2	211.7	0.3	-4.3	-1.0
120	-1.3	-0.5	217.1	0.3	-4.1	-0.7
140	-1.2	-1.1	225.1	0.2	-4.0	0.1
160	-0.9	-1.7	232.8	0.1	-3.9	1.1
180	-0.5	-2.3	238.5	0.1	-3.8	2.2
200	-0.1	-2.6	242.1	0.0	-3.7	3.0
220	0.4	-2.8	243.7	0.0	-3.7	3.5
240	0.8	-3.1	244.0	0.0	-3.6	3.5
260	1.1	-3.3	243.5	0.0	-3.5	3.2
280	1.5	-3.4	242.8	0.0	-3.4	2.6

Table 4. Prolate spheroid model parameters as a function of range cut-off. Altitude = 150 m, vertical permanent magnetization only.						
RANGE CUT-OFF (m)	M_{Px} (A/m)	M_{Py} (A/m)	M_{Pz} (A/m)	χ_m	Δx (m)	Δz (m)
0	-0.1	0.2	242.4	-0.1	-4.9	-2.4
20	-0.1	0.2	242.5	-0.1	-4.9	-2.3
40	0.7	0.3	242.7	-0.1	-4.6	-2.1
60	1.3	0.2	242.1	0.0	-4.4	-1.4
80	0.8	0.4	240.0	0.0	-4.6	-0.4
100	0.8	-1.5	238.1	0.1	-4.6	0.6
120	0.3	-0.9	228.3	0.3	-5.0	3.3
140	0.2	-1.4	233.7	0.2	-5.1	3.0
160	0.9	-3.3	236.0	0.2	-4.2	3.4
180	1.0	-3.6	248.6	0.0	-3.9	3.3
200	1.1	-3.4	239.4	0.1	-4.5	3.2
220	1.1	-2.7	243.7	0.1	-4.4	3.6
240	1.2	-5.0	243.5	0.1	-4.3	3.7
260	0.9	-5.9	248.2	0.0	-3.8	4.6
280	1.3	-6.0	247.7	0.0	-4.0	4.7

3.3 Magnetic parameters from FLUX3D simulated data vs. airborne measurements

Table 3 suggested that there was a small effect on M_{Px}, Δx, and Δz when the very closest data were included for the 80 m results with permanent magnetization only. For this reason, the FLUX3D spheroid parameters with Range cut-off = 40 were used for comparison with the airborne results.

Table 5 compares the permanent and induced magnetic parameters from the FLUX3D simulations to those derived by fitting the airborne total-field measurements from August 2006 (unpublished) to the same prolate spheroid model.

Table 5. Prolate spheroid model parameters calculated from FLUX3D data vs. airborne data.

DATA SET	M_{Px} (A/m)	M_{Py} (A/m)	M_{Pz} (A/m)	χ_m	Δx (m)	Δz (m)
FLUX3D 80 m, induced only, cut-off=40 m	-3.7	0.2	-14.4	3.4	0.1	-1.0
FLUX3D 80 m, perm only, cut-off=40 m	-4.1	0.8	225.6	0.2	-5.2	-1.1
August 2006 airborne data	43.9	-6.3	82.1	1.13	0.8	-2.5

When the input FLUX3D data came from induced magnetization only, the best-fit prolate spheroid had only small amounts of permanent magnetization along any axis. The signature was created mainly from the magnetic susceptibility, which is what one would expect. When the input FLUX3D data came from permanent magnetization only, the best-fit prolate spheroid had a very small magnetic susceptibility, and a very large permanent magnetization. Again, this is what one would expect.

The estimated vertical positions of the best-fit prolate spheroid for both the FLUX3D and airborne data agree to within 1.5 meters. This is excellent agreement. The estimated horizontal positions from the "induced magnetization only" FLUX3D data and the airborne data agree very well, but the "permanent magnetization only" FLUX3D result is displaced by 5-6 m. Figure 2 shows that the ship's engine is significantly aft of the mid-point of the ship and it is possible that the permanent magnetization assigned to the engine in the FLUX3D model is causing this shift in position. If this is the case, a more complex model than a single prolate spheroid may be required to accurately model both permanent and induced magnetization in *CFAV QUEST*.

The susceptibility estimate from FLUX3D data is larger by a factor of 3 than from the airborne data.

The permanent vertical magnetization (M_{Pz}) calculated from fitting the FLUX3D data is a factor of (225.6/82.1) = 2.75 larger than from fitting the airborne results.

4. Conclusions

The fact that the positions of the best-fit prolate spheroid for both the FLUX3D and airborne data agree to within a few meters is very encouraging. However, if the permanent magnetization in the engine is creating a shift between the centres of induced and permanent magnetization, then we may require a more complex model to accurately reflect the magnetic characteristics of *CFAV QUEST*.

Even though the susceptibility estimate from FLUX3D data is a factor of 3 larger than from the airborne data, we recommend comparing it to that derived from underwater range data, near-field surface measurements, and other airborne experiments before modifying the FLUX3D magnetic susceptibility value.

The permanent vertical magnetization (M_{Pz}) obtained from fitting the FLUX3D data is 2.75 times larger than from fitting the airborne measurements. According to Ref 7, Martec assigned a permanent magnetic flux density of 0.01502 Tesla downwards along the Z axis which resulted in the permanent vertical magnetization shown in Table 5. If that flux density were dropped by a factor of 2.75, then the FLUX3D and airborne results would agree. Thus we recommend changing the FLUX3D vertical permanent magnetic flux density from 0.01502 Tesla to 0.0055 Tesla in the downward direction.

To match the FLUX3D model and the airborne results, longitudinal permanent magnetization (M_{Px}) must be added. Since a permanent flux density of 0.01502 Tesla downward produced a vertical permanent magnetization of 225.6 A/m in the downward direction, and we wish to generate a longitudinal permanent magnetization of 43.9 A/m, this implies that a permanent flux density of 0.0029 Tesla should be added along the longitudinal axis in the FLUX3D model.

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Comparison of magnetic parameters of *CFAV QUEST* from FLUX3D modeling and airborne measurements

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

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5. DATE OF PUBLICATION (month and year of publication of document) February 2009	6a. NO. OF PAGES (total containing information Include Annexes, Appendices, etc). 32	6b. NO. OF REFS (total cited in document) 8

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered).

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Under DRDC Atlantic contracts, Martec Ltd. developed a static magnetic model of *CFAV QUEST* for FLUX3D simulations using an existing finite-element model of the ship. The model accounts for both structural and some non-structural components of the ship. Martec performed a number of simulations with two magnetic configurations: induced magnetization only, and vertical permanent magnetization only. These simulated data have been used to estimate the permanent magnetization and magnetic susceptibility of a single prolate spheroid that best fits the overall ship's signature.

The National Research Council of Canada's Convair 580 aircraft was used to measure the magnetic signature of *CFAV QUEST* in August 2006. These data were also fit with the prolate spheroid model. The two sets of parameter estimates (from FLUX3D simulated data and from measured airborne data) were compared to determine how the FLUX3D magnetic parameters should be modified to more closely match the simulated to the measured *CFAV QUEST* signatures.

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